The NBS Real-time Control System
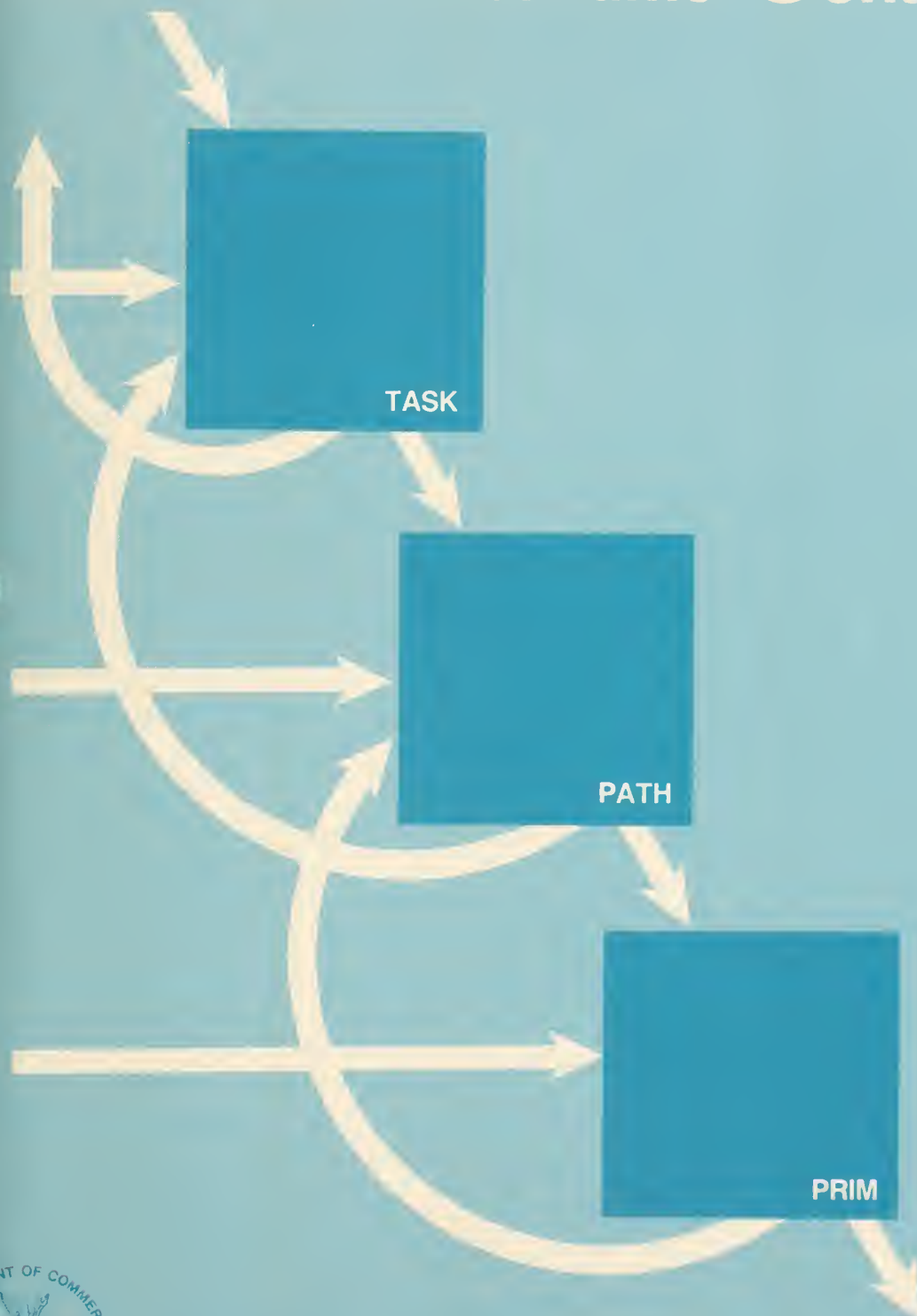
User's Reference Manual

Version 2.2c

OCTOBER 1988

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and
Roger D. Kilmer

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NIST Technical Note 1250

The NBS Real-time Control System User's Reference Manual

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National Engineering Laboratory
National Institute of Standards and Technology
(formerly National Bureau of Standards)
Gaithersburg, MD 20899

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(2) Four (4) Intel Model D2732A EPROMs (or equivalent) for each single-board computer in the system. For a complete RCS system (four single-board computers), a total of sixteen (16) EPROMs are required.

(3) One (1) DataTech Model QuadPlus 1/2" tape (or equivalent), 2400-foot length and 6250 bpi rating.

(4) Completed Order Form from the bottom of this page.

Send these items to the following address:

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>
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Mailing Address: _____

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Telephone No.: _____

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This chapter gives a brief description of the Real-time Control System (RCS) developed by the National Bureau of Standards (NBS) and describes how this manual is organized. The chapter also describes the documentation conventions used throughout the manual to indicate different types of information. The conventions include how the manual presents syntax descriptions of the languages within RCS. Finally, the chapter describes who should read this manual and points out which chapters will be most useful to you, depending on your purpose in using RCS.

1.1 THE PURPOSE OF RCS

RCS is a microprocessor-based system for the real-time control of automated systems. The applications described in this manual are for robotic systems; however, RCS can be used to control other types of automated devices.

RCS has two unique features that generally are not found in other control systems. First, because of the hierarchical control architecture of RCS, you can adapt RCS to control different systems. The hierarchical architecture makes RCS modular, with well-defined interfaces. NBS has been developing these interfaces using RCS for over 10 years. Second, RCS provides for real-time control based on sensor measurements. This feature enables you to modify RCS control commands, in real time, based on this sensor data.

1.2 ABOUT THIS MANUAL

This section introduces the organization of the manual, the documentation conventions used in the manual, and the conventions used for RCS words.

How This Manual is Organized

This manual is organized into 13 chapters, six appendices, a glossary, a bibliography, and an index. This chapter, "Introduction", introduces RCS and explains how to use this manual.

Chapter 2, "RCS Overview", provides a brief description of RCS, including its purpose and the basic processing structures implemented.

Chapter 3, "RCS Architecture", is a detailed description of RCS processing structures. This chapter provides the theoretical background necessary for understanding the design of RCS and how it operates.

Chapter 4, "RCS Components", describes the required and optional hardware and software for RCS.

Chapter 5, "RCS Installation Procedures", explains how to configure and install the hardware required to run RCS. It also explains how to install the RCS software supplied on magnetic tape by NBS, and how to get the system running for the first time.

Chapter 6, "Basic RCS Operations", provides step-by-step procedures for several RCS operations and utilities. It explains how to start up and shut down the system, edit and execute code, and use printer and tape utilities.

Chapter 7, "SMACRO", is a complete description of the SMACRO language created by NBS for use with RCS. SMACRO consists of word extensions to the FORTH programming language and operating system.

Chapter 8, "Communications", is a detailed description of the RCS communications process that enables communication of real-time data between the various parts of the system.

Chapter 9, "Robot Sensor Language (RSL)", describes RSL, a task-description language developed by NBS as an application for RCS.

Chapter 10, "RSL Control Levels", describes the structure of the four levels of the RSL application. Using this information, you can modify the RSL code for your own application.

Chapter 11, "RSL Extensions", explains how to create your own extensions to RSL.

Chapter 12, "RCS Application Examples", provides two example robot applications that use RCS. Each example is a step-by-step description of an application, including a partial listing of the SMACRO or RSL code with explanations. Each example traces the execution of a robot task.

Chapter 13, "Debugging Techniques", describes the interactive debugging procedures you can use with RCS.

Appendix A contains information on error messages. Appendices B through F include a user word summary, system maps, a disk directory, information on the 8087 operation codes relevant to RCS, and joystick schematics and interfacing information.

Finally, the manual includes a glossary of RCS and RSL terms, a bibliography listing additional reference material, and an index.

Documentation Conventions

This manual uses the following documentation conventions:

● The name of each keyboard key mentioned in the text appears in uppercase letters. For example, the carriage-return key appears as RETURN.

● In a control-key sequence, a caret (^) represents the CONTROL key. For example, control-C appears as ^C.

- Information that appears on the terminal screen appears in bold print. For example, the **:R rsl>** prompt appears on the terminal when the system is awaiting input from the terminal keyboard.

- Information that you must enter exactly as it appears in the manual is underlined. For example, "Enter <u>3 LOAD</u>" means to type 3 LOAD and press RETURN.

- Variable data that you are to enter is represented within square brackets ([ ]). The instruction "Enter <u>[block #] LOAD</u>" indicates that you are to replace [block #] with a specific block number when you enter the LOAD command. For example, you might type <u>3 LOAD</u> and press RETURN.

- The default string delimiter is a carriage return. The characters ^, \, and a space may also delimit strings. You need to use the correct character delimiter to include strings in source code blocks. String delimiters are listed in syntax descriptions.

Note: Memory address locations, board numbers, and port addresses are hexa-decimal numbers.

System Word Conventions

RCS defines many words to perform real-time task decomposition but you do not need all of these words to create application programs. This manual describes only the RCS, RSL, and FORTH words used to create application programs.

For the syntax descriptions of RCS, RSL, and FORTH words, this manual shows each command and its operands in the order in which you enter them.

1.3   WHO SHOULD USE THIS MANUAL

This manual is for NBS personnel and for robotics researchers in government, industry, and universities. The manual assumes that you are conducting research and developing applications for the real-time control of robots using sensors, hierarchical task decomposition, and multiple CPUs. This manual is intended for system developers and not for factory-floor operators of robotic systems. Although the manual includes the basic RCS operating procedures, it does not include the information these operators would need for the daily operation of a turnkey system.

This manual assumes that you are familiar with the concepts and terminology of robotics and with the FORTH programming language used extensively in RCS. The <u>polyFORTH 1 Reference Manual</u> and the <u>polyFORTH 8086 Operations Manual</u> from FORTH, Inc., of Hermosa Beach, California, provide in-depth information on the FORTH language and operating system used for RCS.

Also, if you intend to create or modify any RCS 8086 or 8087 assembler code for research or applications, the manual assumes you are already familiar with assembly language programming. Appendix E, "8087 Operation Codes for RCS", lists the 8087 operation codes that affect RCS operation.

Researchers using RCS can be divided into three classes: those who want to enter data for an existing application, those who want to modify an existing application while retaining the basic configuration, and those who want to create new applications.

Entering Data for an Existing Application

To use the sample application written in RSL, you need to edit the blocks of RSL code to enter the specific application data for your system. This robot-control data is specific for each application at a specific installation, and includes defined or recorded robot poses, defined locations and objects, and defined trajectories.

If you want to use RCS to enter specific data for the supplied sample application, be sure to read Chapter 6, "Basic RCS Operations", which describes how to edit blocks of code, and Chapter 9, "Robot Sensor Language (RSL)", which describes the data types used with RSL and how to edit RSL code.

Modifying an Existing Application

A typical modification to an existing application is to add a simple sensor, such as a ranging sensor or switch. When you add a simple sensor, the basic structure and configuration of RSL do not change. You need to edit approximately 100 lines of SMACRO or RSL code.

If you want to use RCS to add a sensor to an existing application, be sure to read Chapter 6, "Basic RCS Operations"; Chapter 7, "SMACRO", which describes SMACRO code; Chapter 9, "Robot Sensor Language (RSL)"; Chapter 10, "RSL Control Levels", which includes information on sensor preprocessing; and Chapter 11, "RSL Extensions", which describes how you can add RSL extensions.

Creating New Applications

To create new applications, you need to modify the basic structures (such as adding a new control level). Be sure to read Chapters 1 through 11 for a complete understanding of RCS and RSL.

Chapter 2 briefly describes the purpose and theory of RCS, and outlines the basic processing structure of RCS architecture. This overview is presented without technical detail; Chapter 3, "RCS Architecture", describes the architecture in greater detail.

2.1 WHAT IS RCS?

RCS is a research tool for investigating the use of real-time sensory-interactive control. The current implementation of RCS uses a multi-processor, hierarchically structured architecture for control of robotic systems. RCS is a stand-alone system that enables you to develop, compile, and test all necessary programs without a host. RCS provides an interactive programming environment, while retaining the run-time speed of a compiled system.

Multiprocessor System

RCS is designed around a multiprocessor computer system to provide the high-speed processing required to control a multi-axis robot in real time. The multiprocessor architecture also provides a natural modularity, which helps divide the control function of the system into easily understood control levels.

Hierarchical Control Levels

Each hierarchical control level receives a task from the level above and decomposes this task into a set of more primitive tasks, which it sends to the level below. The lowest control level (the robot controller) supplies the machine instructions to the robot. Each control level communicates with the adjacent levels through a common memory that all control levels share.

Modular Architecture

The modularity of RCS also simplifies the task of integrating different kinds of hardware into the system. For example, you can design a module to accept and process input from sensors and then modify existing modules to use this sensory information.

Control Function Techniques

RCS uses the following techniques to simplify the programming of control functions:

- Software modularization into well-bounded functions with clearly defined interfaces to enhance extensibility of the system by clarifying the information that passes between two "black box" modules.

- Use of generic software module structures to simplify module creation, debugging, and maintenance.

- Specification of well-defined data interfaces.

- Use of a common memory structure to simplify integration of independently developed modules, provide access to additional processes, and provide extensive diagnostic and status reporting capabilities.

- Replacement of separate internal looping structures with cyclic execution that repeats at globally specified periodic intervals to ensure that state changes within the system are synchronized with each other.

- Use of state table programming structures that provide an explicit representation of branch conditions. A state table provides an advantage over a nested IF-THEN-ELSE structure because a state table for a complex branch condition is easier to understand and modify.

2.2 THE ATTRIBUTES OF RCS

RCS provides a modular, flexible, and easily understandable computer hardware and software architecture for experimenting with sensory systems and robotic devices operating in real time.

Modularity

Just as a structured program consists of a series of well-defined modular components, the RCS hardware and software is modular. This modularity makes the system more manageable, enabling developers to concentrate their efforts on one module at a time.

The modular nature of the system software lets you reconfigure all or part of the system software simply by loading different software modules. This modularity ensures that if you make changes to one module you do not necessarily have to reconfigure other modules.

- Initialization procedures
- Real-time control function execution
- Communications
- Preprocessors and postprocessors
- Device drivers
- Diagnostics
- Monitor systems
- Error reporting

Flexibility

To provide hardware flexibility and extensibility, RCS uses the Intel
MULTIBUS. The MULTIBUS can support multiple processors, and compatible board
products are widely available.

The RCS software is flexible and extensible by its modular nature. Developers
can create sample input data for each module and examine the resulting output
data to analyze the operation of the module.

Understandability

NBS designed a generic software module structure as the basis for the various
modules operating within the system. After you understand the generic module
structure, you can more easily understand the specific modules within the sys-
tem, which are derived from this generic structure.

The modular design of RCS reduces the considerable complexity of a real-time
control system to a set of simple, well-defined, and easily understood seg-
ments. You can comprehend the operation of the entire system by analyzing the
operation of each module separately.

RCS simplifies the analysis of system operation by providing you with inter-
active diagnostic software tools to monitor system operation continuously,
display the system status, and capture data in real time.

2.3 RCS AS AN INPUT-PROCESS-OUTPUT STRUCTURE

The fundamental building block of the RCS architecture is the input-process-
output structure, which specifies functional modules that communicate through
well-defined data interfaces. The input-process-output structure is shown in
Figure 2-1.
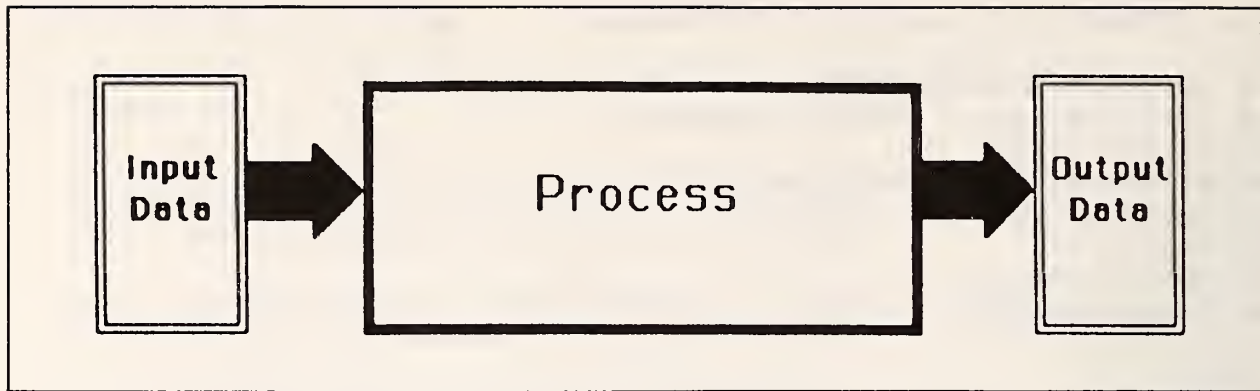
Figure 2-1. The input-process-output structure.

In this model structure, a functional module processes its input data set to
generate a set of output data. The function that each module performs is
independent of other processing that might occur within the system. Informa-
tion required by more than one module passes through the interface data sets
stored in common memory. You can understand the function of a module by
examining its input data, its output data, and a description of the processing
that occurs within the module.

You can define new modules to provide new capabilities, such as new sensors,
end effectors, or robot trajectory algorithms, and integrate these modules
with existing components of the system through the appropriate data
interfaces.

In addition to providing a clear understanding of the system, well-bounded
modules facilitate module testing and debugging. Simply by supplying input
data to a module, you can test that module in isolation before adding it to
the system or when diagnosing a problem.

2.4 PROCESSING WITHIN A GENERIC CONTROL LEVEL

Although using the basic input-process-output structure is an efficient method
of organizing a complex system, the large number of such structures is a prob-
lem in itself.

An effective solution to this problem is the use of generic software module
structures. This method helps you understand the system by standardizing the
basic operation of a module because you can view each module function as a
variation of the generic processing structure.

Within a module, you can view processing as a sequence of three processing
operations--preprocessing, decision processing, and postprocessing. (See
Figure 2-2.)
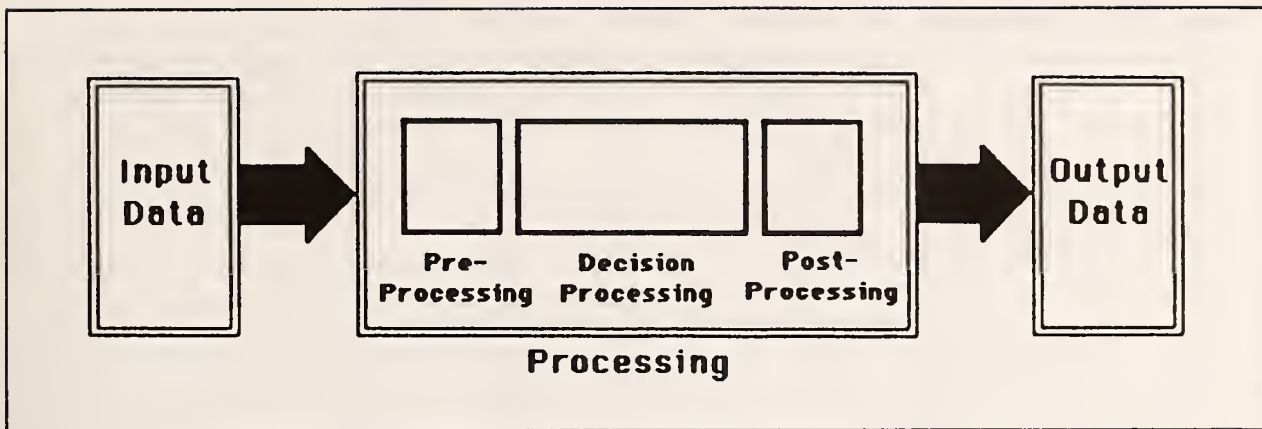
Figure 2-2. The processing structure within a module.

Preprocessing

In the preprocessing stage, the system evaluates, scales, and reduces the
input data, and transforms it into the appropriate set of variable values
required for decision processing.

Decision Processing

Decision processing is the primary mechanism that directs program execution
within a module. Decision processing selects the appropriate procedures for
execution based on the values of several high-level variables.

Decision processing defines the various test conditions and the corresponding
output procedures for the system to execute if the input from preprocessing
satisfies the test conditions. In RCS, state tables usually control this
decision-making process.

For a real-time control system, state table programs are preferable to
control-path diagrams and IF-THEN-ELSE structures because state tables provide
explicit representation of the branch conditions occurring during decision
processing. This representation makes branching easier to follow. The state
table is an enclosed version of the case statement used in programming lan-
guages such as Pascal and C.

Figure 2-3 illustrates the general form of a state table:

Inputs				Outputs
A	B	C	D	
T	X	T	T	5
T	X	T	F	4
T	X	F	X	3
F	T	X	X	2
F	F	X	X	1

T = TRUE   F = FALSE   X = DON'T CARE

Figure 2-3. The general form of a state table.

The state table in Figure 2-3 contains four input variables: A, B, C, and D, each of which can be either true or false. The system executes the first output where the values of the input variables match all the listed inputs on that line. For example, assume inputs A, B, and C are true and input D is false. When you look through the table, you see that this set up condition generates output 4. In this case, since input B does not affect the outcome, it could be either true or false.

Figure 2-4 shows an implementation of a state table that determines an output command for controlling a robot gripping an object based on the status of touch and force sensors and the position of the gripper.

In this example, there are five input variables: INPUT COMMAND, TOUCH SENSOR #1, TOUCH SENSOR #2, GRIPPER OPENING, and GRIPPER FORCE. The output consists of the command to be executed, OUTPUT COMMAND, and the status of the task currently being executed, OUTPUT STATUS. Each line in the state table corresponds to a set of conditions that can occur when the robot tries to grasp an object with its gripper.

For example, the third row of state table conditions corresponds to a situation where the object is touching one of the gripper fingers (TOUCH SENSOR #1 has contact) but not the other. In this case, the output commands the robot to move 0.05 mm to try to center the object between the gripper fingers and also commands the gripper to close 0.1 mm to grasp the object. The OUTPUT STATUS indicates that RCS is executing the GRASP command and that contact with the object has been made. Other lines in the state table correspond to other situations, including errors which might occur, and the corresponding output response that the robot and gripper should make.

INPUT COMMAND	TOUCH SENSOR #1	TOUCH SENSOR #2	GRIPPER OPENING	GRIPPER FORCE	OUTPUT COMMAND	OUTPUT STATUS
GRASP	NO CONTACT	NO CONTACT	X	X	CLOSE .1 MM	GRASP-EXECUTING
GRASP	NO CONTACT	CONTACT	X	X	CLOSE .1 MM MOVE +.05 MM	GRASP-EXECUTING CONTACT
GRASP	CONTACT	NO CONTACT	X	X	CLOSE .1 MM MOVE -.05 MM	GRASP-EXECUTING CONTACT
GRASP	CONTACT	CONTACT	$\geq$ object size	< grip force	CLOSE .1 MM	GRASP-EXECUTING FORCE
GRASP	CONTACT	CONTACT	$\geq$ object size	$\geq$ grip force	PAUSE	GRASP-FINISHED OBJ-IN-HAND
GRASP	CONTACT	CONTACT	< obj. size $\neq$ closed	X	PAUSE	GRASP-FINISHED NOT-OBJ, SIZE-VALUE
GRASP	CONTACT	CONTACT	CLOSED	X	PAUSE	GRASP-FINISHED NO-OBJ-IN-HAND

Figure 2-4. Example of a state table.

Postprocessing

The postprocessing stage performs any additional processing required after decision processing is complete. Saving internal variables and reformatting algorithm results for output or transfer to other modules are examples of postprocessing tasks.

This chapter describes the ways the control-level software running on the single-board computers can communicate and cooperate to perform control functions. It includes descriptions of the independence of data, program structures, hierarchical control architecture, interlevel communications, decision processing, and the contents of common memory.

3.1 HIERARCHICAL CONTROL ARCHITECTURE

Hierarchical control levels enable you to break a complex control task into manageable procedures. Each control level represents a well-defined, clearly bounded control function with a small number of inputs and outputs.

In this control scheme, you enter a high-level command such as "transfer the part" to the top level of a hierarchical system of control levels. The top level decomposes the task into sequences of more primitive commands (subtasks) to the next lower control level in the hierarchy. The bottom level in the control-level hierarchy generates the outputs to the actuator that performs the action.

Structure of a Control Level

The atomic unit within a control level is a functionally bounded module. This module consists of inputs, a process, and outputs (see Figure 3-1).
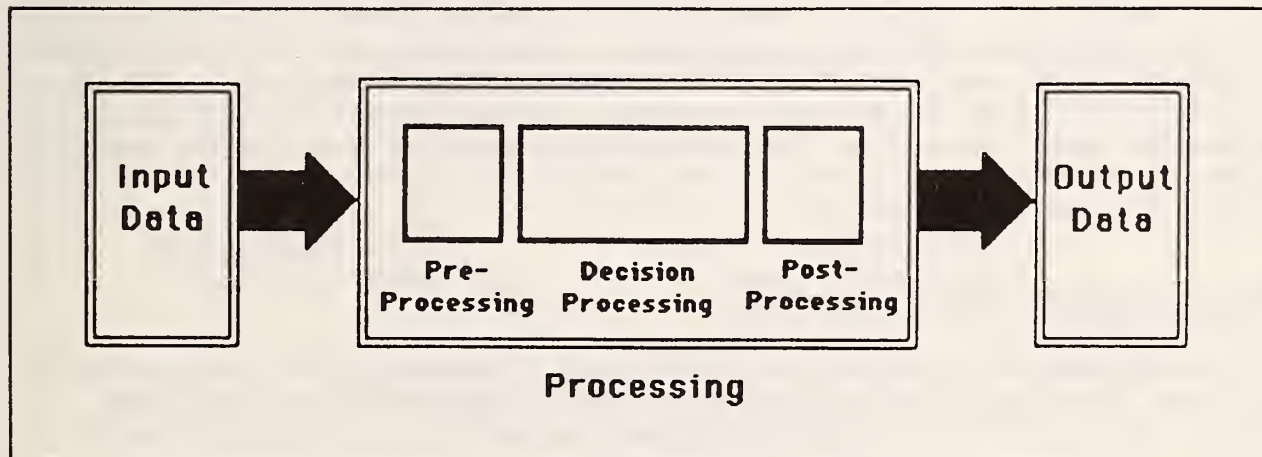
Figure 3-1. Components of a functionally bounded module.

The process shown in this figure includes the preprocessing, decision-processing, and postprocessing stages described in Chapter 2, "RCS Overview". The preprocessing stage accepts and conditions the inputs for the decision-processing stage of the module, and the postprocessing stage prepares the output and performs the handshaking required for data transmission.

You can group functionally bounded modules under a named high-level routine (a routine containing a series of statements that execute other routines). You can then execute this group of modules by entering the name of the high-level routine. RCS uses this method to maintain hierarchical relationships between routines.

A control level consists of groups of routines. The routines perform the functions of preprocessing the input, decision processing based on the input, and postprocessing the output.

Cyclical Control-Level Processing

RCS does not require the use of interrupts to respond to external events. Instead, RCS performs its processing in a cycle based on the periodic communications it conducts between different control levels. This cycle is called the communications cycle.

Real-time control depends on producing a response to changes in input data quickly enough for that response to be stable and effective. The system can provide continuous real-time control without interrupts only if the communications cycle repetition rate is fast enough (that is, the period of the communications process is short enough) to give the processing modules time to respond to the new input data.

RCS uses multiple processors to achieve the high-speed parallel processing needed to support a fast repetition rate. Each control level executes once during every communications cycle.

Cyclic execution has a major impact on the way control-level decision processing is implemented. Because a typical task takes many cycles to complete, the level must enable you to enter the algorithm description each cycle without losing track of what has already been done. RCS uses state variables to accomplish cyclic execution. State variables record the state of the algorithm at the end of each cycle and are used at the beginning of the next cycle to pick up algorithm execution.

Control-Level Decision Processing

You can program the decision-processing stage of a control level using a state table and state variables or using a series of IF-THEN-ELSE control structures. Each of these options provides certain benefits.

A state table has the advantage of separating the definition of a function from the timing of its execution. However, this separation can be a disadvantage when you are trying to trace the sequence of program execution. A series of IF-THEN-ELSE statements is easy to follow when you are tracing the sequence of program execution, but hard to understand and follow if it becomes long and complex.

The SMACRO language developed by NBS supports the following format for state tables:

```
state-table [state-var1] [state-var2] . . . [state-var7]
state:      [test-var1] [test-var2] . . . [test-var7] [routine A]
state:      [test-var8] [test-var9] . . . [test-var14] [routine B]
  .
  .
  .
default-state: [default-routine]
end-state-table
```

During execution, the system searches through the state table until it finds a line in which the values of all test variables match the values of the corresponding state variables. After the state table finds a line with matching variable values, it executes the routine at the end of that line. All lines after the first matching line are ignored. The state table executes the default routine if no line matches.

The following list contains examples of questions that a state table can answer for the decision-processing stage by examining test-variable status information:

● Has the level received a new command from the next higher level?
● Has the lower level returned its status to the current level?
● Has the lower level confirmed that it has received the last command?
● How far has the procedure progressed through its execution sequence?
● Have the sensors specified values for all symbolic variables?
● Has a specified event occurred?

Figure 3-2 illustrates the sources of information that a control-level procedure uses to determine the command to send to the next lower level and the status to send to the next higher level.
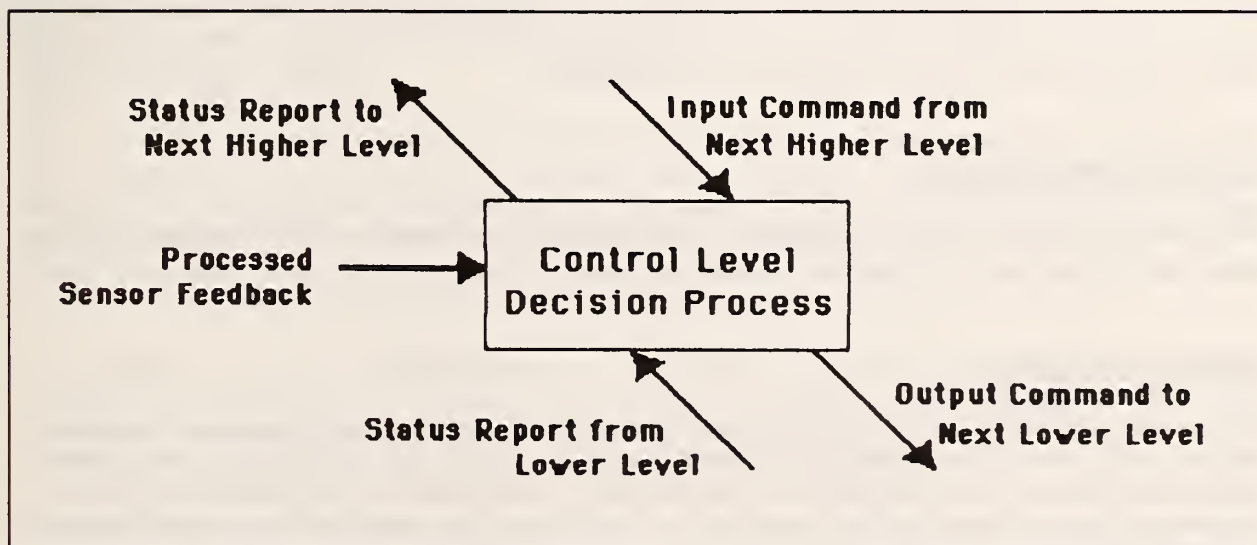
Figure 3-2. Inputs and outputs from control-level
decision processing.

Each control level may require multiple cycles to complete a command. After a control level completes its command, it sends a done status message to the next higher level, commands the lower levels to pause, and waits for a new command.

Interlevel Communications

The information that the communications process transfers to any control level consists of commands issued from the level above and status information returned from the level below.

The commands passed to a control level from the level above vary greatly from level to level and from application to application. However, the status information passed to a control level from the level below (or from other components such as sensor systems) usually reflects one of three possible results: executing, done, or error. The error status message can also indicate the reason for the failure.

The communications process is described in more detail in Chapter 8, "Communications".

3.2 RCS PROGRAMS

A complete control system based on RCS includes multiple programs running in parallel on the various boards within the system. These programs access the data they require from variables stored in common memory. To make the programs data-independent, you must use symbolic variables to represent the physical system and the objects manipulated by the system.

Programs also use common memory to pass command and status information to programs running on other boards. To enable communications between levels to be asynchronous, common memory provides double buffering for the input and output of the different control levels in the system.

3.3 RCS COMMON MEMORY

The common memory of RCS contains three major components: the system dictionary, the communication buffers, and the data files.

System Dictionary

The system dictionary contains records for every variable, procedure, state table, and list of variables in the system while it is operating. The system dictionary makes the interactive features of RCS possible by enabling you to locate, modify, and test any section of code quickly without having to modify the entire system.

After loading the application software, the contents of the system dictionary
enable you to perform the following functions:

- Execute procedures (functionally bounded modules)
- Create and initialize new variables
- Define lists of variables
- Show the value of a variable or a list of variables

The system dictionary maintains pointers to procedures and RCS updates these
pointers automatically when you reload a procedure. This automatic updating
enables you to modify a procedure, reload the procedure, and then run the sys-
tem without having to modify other procedures to integrate the altered
procedure.

Communication Buffers

The communication buffers provide communication paths between control levels,
sensor systems, robots, grippers, and other subsystems. RCS simplifies the
transfer of information between control levels by providing high-level com-
mands that make the details of the communications process transparent to the
control-level procedure.

To program a level to receive input commands or status, you identify the name
of the sending level and the name of the list of variables to be transferred.
Similarly, to program a level to send output commands or status, you identify
the name of the receiving level and the name of the list of variables to be
transferred.

The communications cycle reads output buffers every cycle and fills input
buffers on the same cycle only if those buffers are ready to accept input.
The communications protocol is described in more detail in Chapter 8,
"Communications".

Data in Common Memory

The factory of the future will maintain a database that describes every system
and object within its domain, and this data will be supplied to the control
algorithms during the manufacturing process. However, for RCS you must enter
manually the data required to specify the geometry of each object, the loca-
tion of each critical point, the approach path, the departure path, and inter-
mediate trajectories for each application of the system.

To maintain the data independence of a control algorithm, you should always
separate data from the algorithm that uses the data. Separating the data and
task definitions ensures that only the data, and not the algorithm, will
require alteration if the physical aspects of the system or the object change.

The common memory stores the data for all control levels and serves as the
interface between communicating control levels and between the control levels
and input/output systems. When a procedure requires data, its control level
assigns data from common memory to the appropriate symbolic variables within
the procedures.

Chapter 9, "Robot Sensor Language (RSL)", describes the NBS-developed language for robot-control applications. Therefore, this chapter presents only a brief overview of the kinds of information RCS needs in common memory to control a robot. Consider the example of a robot wrist and gripper. The kind of data you place in common memory to define the physical characteristics of a system with a robot wrist and gripper would include poses, objects, locations, and trajectories.

Pose data

Poses comprise the most fundamental data required to control a robot. You use the name of each pose to identify a specific position and orientation in the workspace of the robot.

To create a pose, you enter numerical information from the keyboard or use a joystick to describe a specific position and orientation. Alternatively, you can program the robot system to "learn" poses by using sensor systems to capture a pose you select manually.

A pose in the example robot gripper system consists of a specific position and orientation for the wrist and gripper. Figure 3-3 illustrates some different poses for this system.
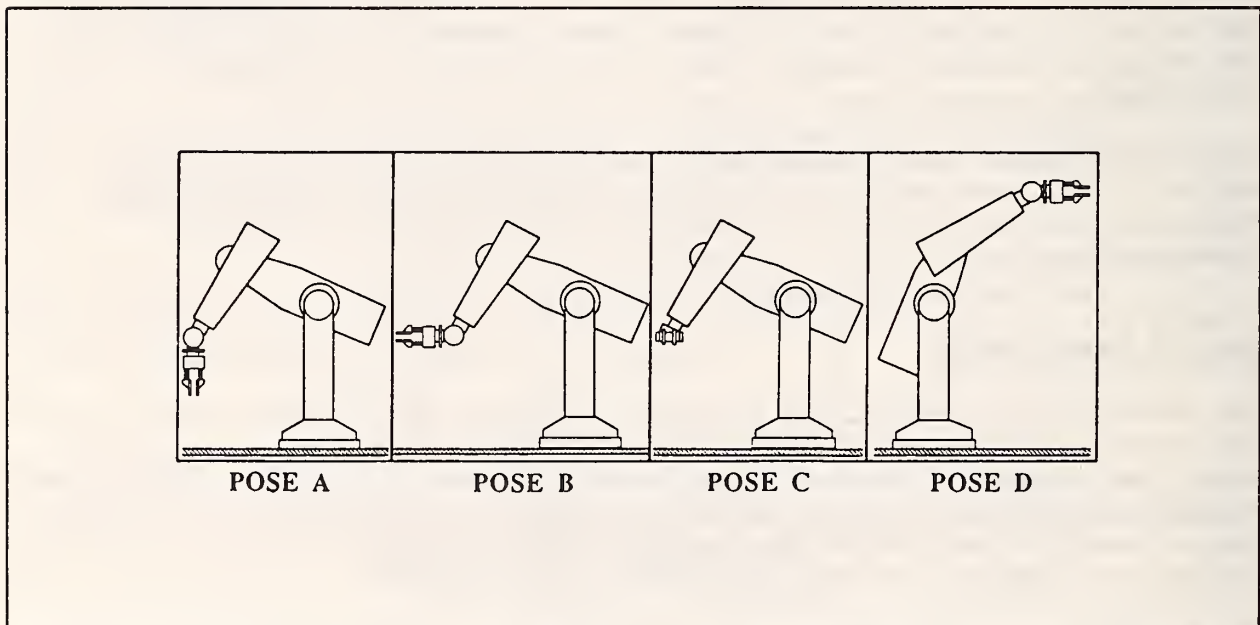
Figure 3-3. Examples of poses.

Object data

Object data specifies such things as the grip size and grip location on an object that the robot is manipulating. The grip size specifies the width that the gripper needs to accommodate and the grip location specifies the location at which to grip the object. Figure 3-4 illustrates the grip size and grip location on an object.
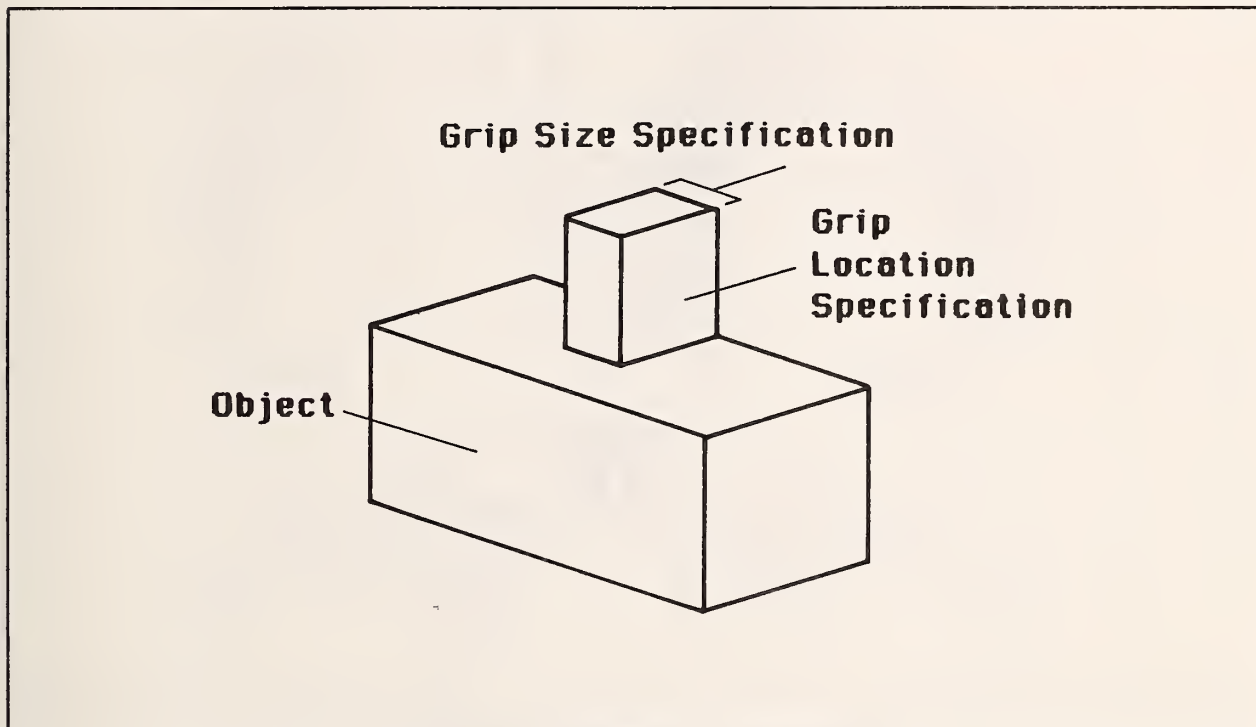
Figure 3-4. Example object data specifications.

Location data

Location specifications refer to coordinates within the workspace of the robot. These specifications describe points such as the goal point of a move-to command.

Figure 3-5 illustrates an example of a location where the robot is to place an object.
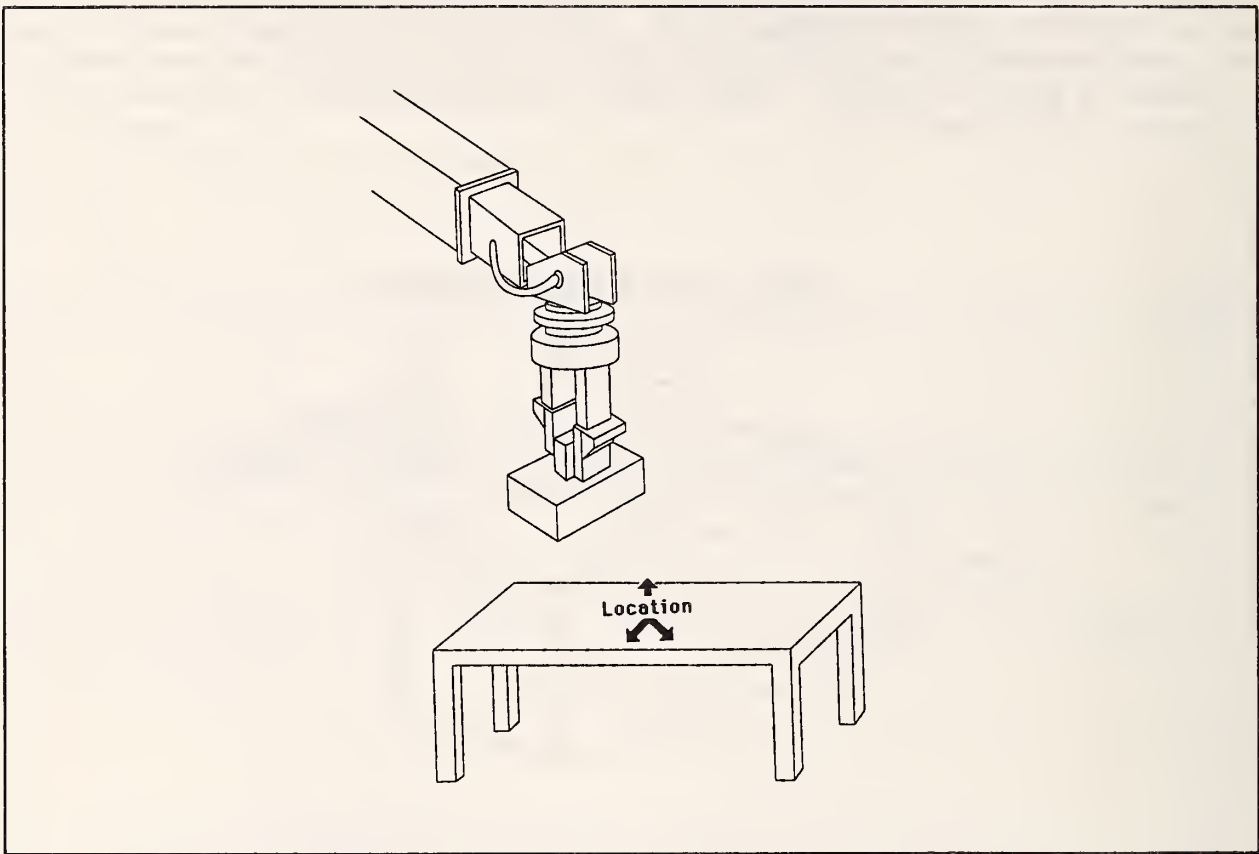
Figure 3-5.   Example location.

Trajectory data

Trajectories define how the robot is to move from one location to another. Each object and location has specific requirements as to how the gripper should approach and depart. You also need to provide intermediate trajectory data to guide the gripper from one departure to the next approach.

Trajectory data can refer to objects, location points, or arrays of location points. The specifications for a trajectory can include specific beginning or end location points (as well as objects or arrays), maximum acceleration, maximum velocity, and braking distance.

Figure 3-6 illustrates some of the possible components of trajectory data.
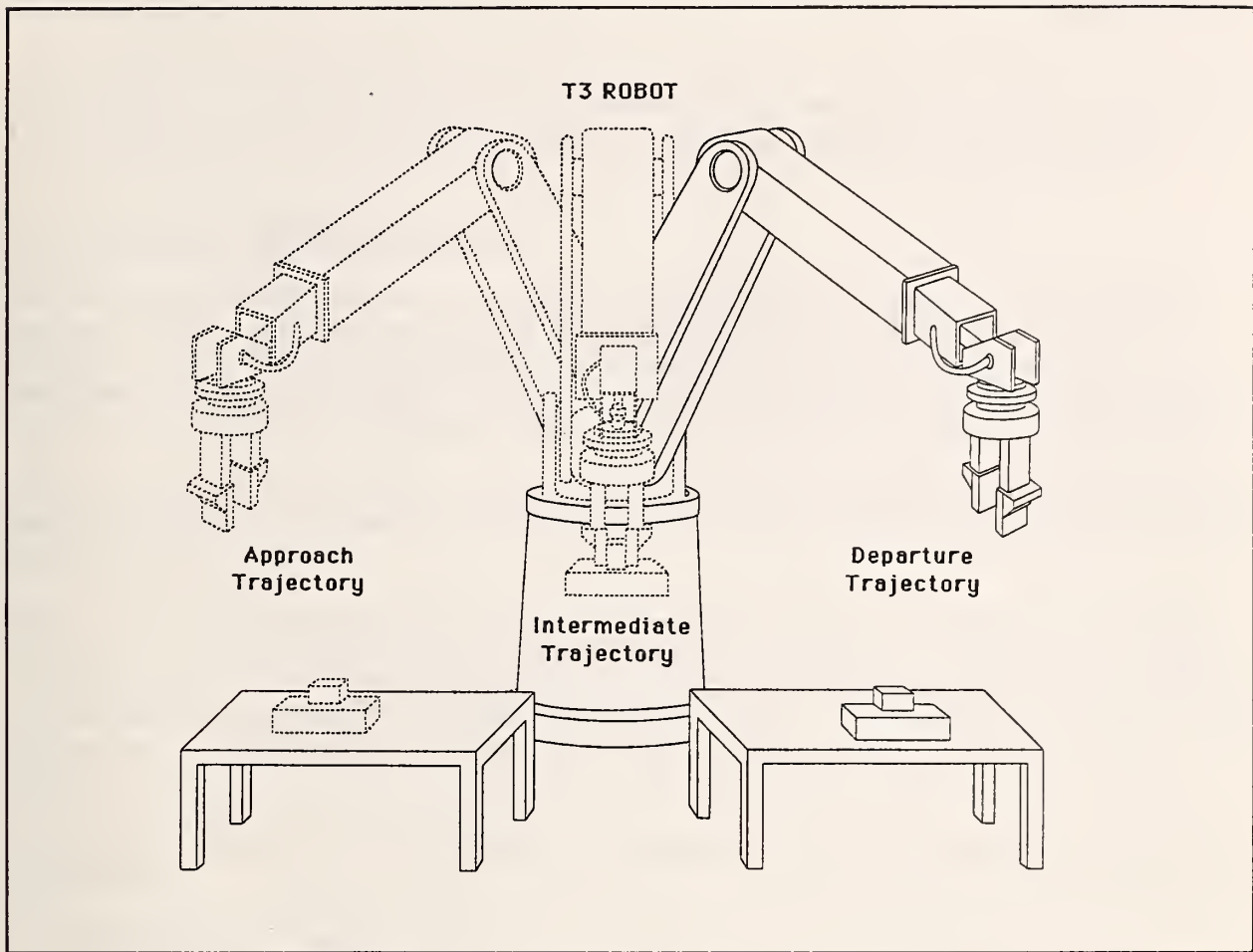
Figure 3-6. Examples of trajectories.

This chapter describes the hardware and software components of RCS, including the organization of the memory address space, I/O space, and disk blocks.

4.1 HARDWARE COMPONENTS OF RCS

RCS is a MULTIBUS-based multiprocessor microcomputer system. The MULTIBUS defines a bus structure supported by many vendors with compatible board products. RCS currently supports up to seven Intel 86/30 single-board computers, each with an 8087 floating point coprocessor. Each 86/30 computer can run one or more RCS control levels, depending on timing considerations.

Each single-board computer includes local RAM and contains the FORTH operating system in PROM. All computers in the system share access to a common memory and Winchester disk.

One of the single-board computers is the master board; the others are slave boards. The user terminal attaches to the master board. Except for unusual circumstances (such as a system crash), all user communication with the slave boards occurs indirectly through the master board. If necessary, you can add a terminal switch box to the system to communicate directly with a slave board.

In addition to one or more single-board computers, RCS includes the following components:

- Shared-memory boards
- Numeric data processors
- Disk/tape controller board
- Winchester disk drive
- Nine-track tape drive
- Terminal

Depending on the RCS application, it may also contain optional components, such as:

- Serial I/O boards
- Parallel I/O boards
- Analog I/O boards
- Joystick
- Printer

RCS can connect directly to, and control the operation of, a wide variety of robotic equipment. See Chapter 5, "RCS Installation Procedures", for a complete description of the system hardware.

MULTIBUS Address Space Organization

In RCS, the address space for the disk control block, FORTH PROMs, and
semaphores are fixed. The user allocates address space for processors and
common memory. RCS supports either 20-bit or 24-bit addressing (24-bit
addressing requires the P2 connector on the MULTIBUS).

With 24-bit addressing, the address space is divided into 16 one-megabyte
pages. Processors must be in page 0. You can distribute common memory over
any two (but only two) other pages.

The RSL application uses 20-bit addressing. See Section C.1, "Multibus
Address Space", for the exact addresses.

MULTIBUS I/O Space Organization

RCS allocates the MULTIBUS I/O space as shown in Section C.2, "Multibus I/O
Space Organization". All unused I/O address space and the J3 and J4 ports are
available for user applications.

RCS Interrupt Structure

Each processor board in the system uses interrupts to control RCS operation.
See Section C.3, "RCS Interrupt Assignments", for the use of each interrupt.

RCS Disk Block Organization

RCS uses the FORTH block structure for all source code. The disk block map in
Appendix D, "RCS Disk Block Organization", shows how RCS allocates blocks on
the Winchester disk for the RSL 1.6 application.

RCS uses a 10-block directory structure within these source code blocks. The
system does not automatically maintain this directory information; you must
update the block-directory blocks when you add, delete, or move blocks. For
more information on directories, see Section 6.3, "Locating Source Code".

4.2 SOFTWARE COMPONENTS OF RCS

The RCS operating system software developed by NBS is based on a compiled
version of the FORTH programming language. This operating system supports
multiple processors, interprocessor communications, and a mid-level high-speed
compiled language called SMACRO.

The operating system provides an environment for the development of applica-
tion programs for real-time control. One such application program is RSL,
which runs under RCS.

The RCS software includes an operating system with system utilities and macros. The utilities enable you to edit source code, communicate with individual computers within the system, debug application programs, back up programs and data, and perform other tasks. The macros form the SMACRO language you can use to create application programs.

Other components of the RCS software include SMACRO files in common memory, system dictionary vocabularies, and the communications utility, COMM.

The Operating System

The RCS operating system includes utilities for booting the system, editing source code, and performing other tasks. It provides multiprocessor operation by using one master processor board to control several slave processor boards. In addition to these features, the RCS operating system supports background tasks, interrupts, and four modes of operation.

System utilities

Many RCS system utilities perform simple tasks, such as printing a block of source code or selecting a specific type of terminal. Other utilities (such as the MBOOT, CUSTOM, and EDITING utilities) are more powerful.

Some MBOOT and CUSTOM utilities enable you to boot the system, load the system software, and load the custom software required for your particular applications. Other MBOOT and CUSTOM utilities enable you to save memory images on the Winchester disk, and then reload them into memory. These utilities are useful when you need to recover from a system crash.

The EDITING utilities enable you to examine and modify source code. RCS supports three kinds of terminals: the TeleVideo Model 950, the Datamedia Elite 1521A, and the DEC VT100.

Multiprocessor operation

To provide multiprocessor operation, the RCS operating system enables you to define one processor board as the master board, and the other processor boards as slave boards. The terminal can communicate directly with only the master processor board. Communication with the slave boards occurs indirectly through the master board.

Background tasks

The RSL application developed by NBS includes tasks that run in the background. Refer to the RSL source code for an example of background task operation. The polyFORTH 1 Reference Manual and the polyFORTH 8086 Operations Manual provide more information on running tasks in background mode.

Interrupt routines

RCS includes specific SMACRO words for interrupt routines. The enter-interrupt SMACRO word prepares an 8086 processor to perform an interrupt routine first by pushing the contents of all registers and then by pointing the DS and ES registers to specific segments.

The exit-interrupt SMACRO word should appear at the end of an interrupt routine, to restore the contents of the 8086 registers and then execute an IRET. You can use the ~INTERRUPT SMACRO word to set the 8086 interrupt vector to point to a selected SMACRO routine.

The operation of these SMACRO words is explained in detail in Section 7.6, "Interrupts and Assembly Language". Refer to Section C.3, "RCS Interrupt Assignments", for a list of the reserved interrupts.

Operating modes

RCS can run in one of four modes: Run, Show, Locate, and Compile. Run mode is the normal operating mode for controlling robotic equipment. Show mode enables you to examine the values of variables. Locate mode enables you to search for the source block of any SMACRO word. Compile mode is for compiling blocks of RCS code.

RCS SMACRO Language

The RCS operating system is based on the FORTH language and operating system. NBS has extended FORTH by adding words to the standard set of FORTH words. This set of extensions comprises the SMACRO language.

Each SMACRO variable is a member of a set of variables belonging to a variable owner. SMACRO variable types include: integer, byte, floating point, array, string, segment, and sequential. The owners in SMACRO include: variable owners, sequential owners, and list owners. In SMACRO, unlike FORTH, you can define a word that is longer than one block by using the SMACRO words routine and end-routine. For a complete description of SMACRO, see Chapter 7, "SMACRO". For a complete list of SMACRO words, see Appendix B, "User Word Summary".

SMACRO Files

RCS operation is based on SMACRO files. A SMACRO file is stored using a linked-list record structure, residing in common memory. The memory-resident SMACRO files provide a means of communication between the processor boards within a system.

Disk Files

RCS does not have traditional disk files. RCS stores source code in blocks.
You keep track of which block holds what source code by maintaining the RCS
system of directory blocks. The directory blocks help you locate code; RCS
does not use the directory blocks.

RCS also provides a mechanism for storing compiled code on the disk. This
method is similar to the method for storing an object code file on a
traditional system. The compiled code is stored in D>Ms, where D>M is simply
a copy of the local RAM for a board. D>Ms are less flexible than the
traditional object code file, but they are faster to load because no linking
is required.

Robot Sensor Language (RSL)

NBS has developed RSL as a sample RCS application you can use and modify for
your own robot system. It includes four control levels, each representing one
level of task decomposition.

The four RSL control levels are TASK, PATH, PRIM, and JOINT. TASK decomposes
a task into a sequence of paths. PATH decomposes each path into sequences of
goal poses. PRIM decomposes the poses into a sequence of intermediate poses.
JOINT decomposes the intermediate poses into commanded joint angles.

System Dictionary Vocabularies

RCS maintains a system dictionary in common memory. The system dictionary
contains entries for every variable and routine in the system. A vocabulary
is a group of related entries in the dictionary. RCS includes a system vocab-
ulary on each board, and a vocabulary for each control level, including RSL.
You can include up to five user-defined vocabularies per board (although you
usually have only one vocabulary per control level).

The Communications Utility (COMM)

The RCS operating system includes the COMM communications utility, which per-
forms communications between processor boards within the system. This utility
enables you to restart the timer, set up communication buffers, and specify
the communications timing. See Chapter 8, "Communications", for more informa-
tion on the communications process.

This chapter lists the hardware required to support the RCS and RSL software, and explains the hardware and software installation procedures.

5.1 HARDWARE REQUIREMENTS

NBS supplies the software for an RCS system; you supply the hardware (see Figure 5-1).
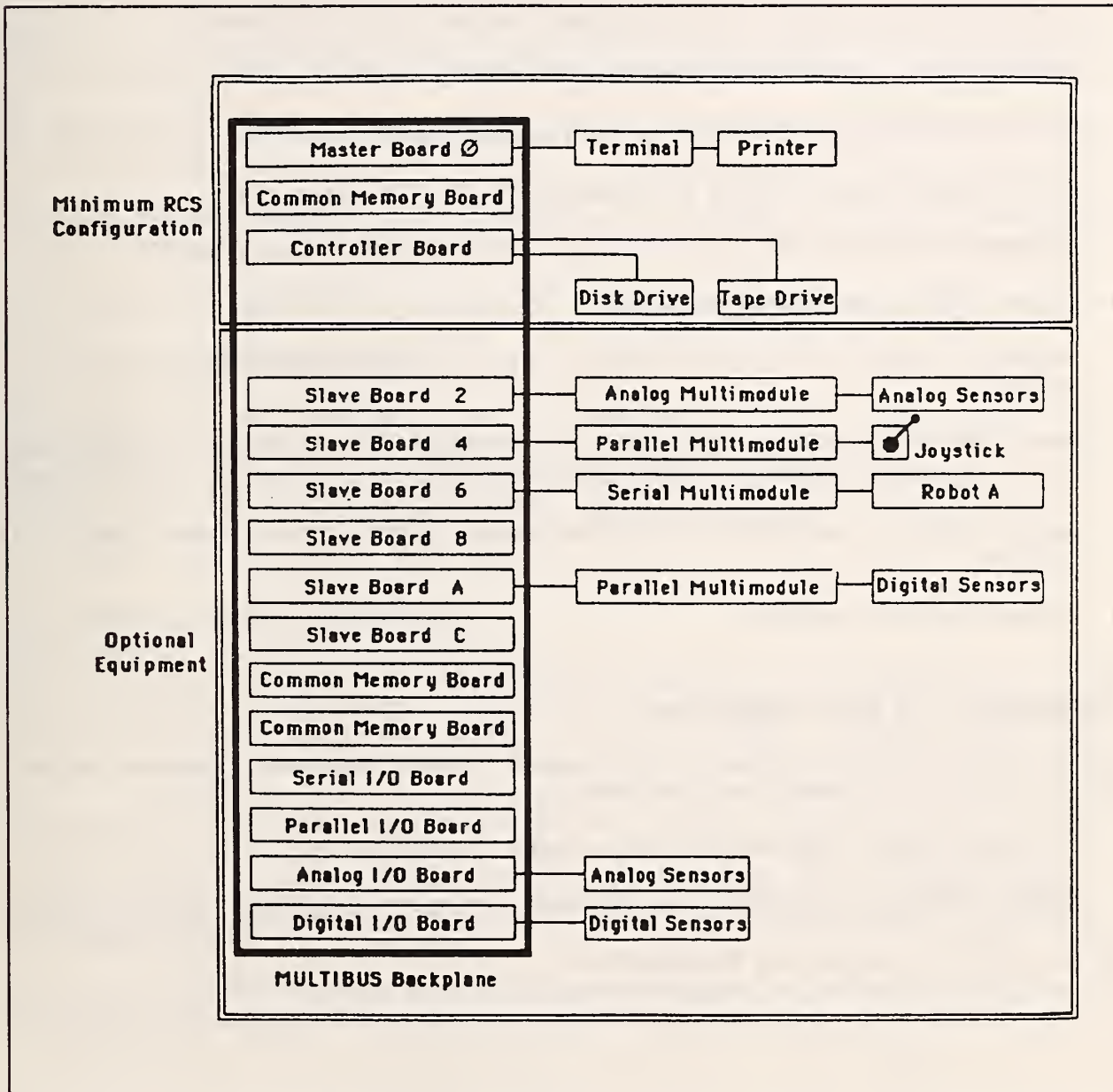
Figure 5-1. Example RCS hardware configuration.

Minimum Hardware Requirements

The following list describes the minimum hardware configuration needed to run RCS:

● Equipment rack.

● MULTIBUS backplane and power supply (for example, the ETI Model 8223 23-slot chassis, including a parallel priority circuit).

● Intel iSBC 86/30 single-board computer configured with a bus clock.

● Intel iSBC 337A numeric data processor module for 86/30 board.

● Plessey Model PSM 512A (or equivalent) memory board.

● Ciprico Rimfire 45 disk and tape controller board.

● Priam Diskos Model 6650-10 66-megabyte Winchester disk drive.

● Priam Model 3 00106-04 ANSI-standard disk interface adapter board.

● Cipher F880 nine-track tape drive.

● TeleVideo Model 950, Datamedia Elite 1521A, or DEC VT100-compatible terminal.

   Note: The NBS-supplied system tape is configured for a Micro-Term ERGO 301 terminal, which is VT100 compatible.

● Apple Imagewriter, DECwriter III, or Integral Data Systems Paper Tiger printer.

● Interconnection cables.

Unimate Puma 760 Robot Requirements

The following list describes the additional system components required to run RSL to control a Unimate Puma 760 robot.

● Three additional iSBC 86/30 single-board computers.

● Three additional iSBC 337A numeric data processor modules.

● One iSBX 351 Serial I/O Multimodule.

Additional Components

To modify RCS to develop other applications or control other types of robotic machinery, you can add the following components:

- Intel MULTIBUS boards and multimodules
  - Up to three additional iSBC 86/30 computers (for a maximum of seven)
  - iSBC 534 Serial I/O board
  - iSBC 519 Parallel I/O board
  - iSBX 351 Serial I/O Multimodule
  - iSBX 350 Parallel I/O Multimodule
  - iSBX 311 Analog Input Multimodule
  - iSBX 328 Analog Output Multimodule

- One to four additional Plessey Model PSM 512A (or equivalent) memory boards (this application requires 24-bit addressing capability).

- MULTIBUS P2 backplane connector installed in chassis (required for 24-bit addressing).

- A switch box, compatible with RS-232 and including one input and seven outputs (required only if you need direct communication with slave boards).

- Joystick, as specified in Appendix F, "Joystick Schematics".

- Robot with optional sensors.

Your system may not require all of the hardware included in these lists. The configuration of your system depends on the requirements of your robot. For example, the Analog Input Multimodule is not required for RCS operation, but may be needed to provide sensor input. However, you should plan ahead by ordering a spare for each critical component in the system.

5.2 ROBOT INTERFACE REQUIREMENTS

RCS provides an environment for developing programs that operate in real time to control robotic equipment. RCS makes no assumptions about the machine it controls; the machine does not even need to be a robot. You must supply the software interface for the specific machine you want to control using RCS.

NBS provides interface software designed to control a Unimate Puma 760 robot through a serial I/O multimodule. This software also can control Unimate robots other than the Puma 760. For more information, see the <u>Unimate Puma Control System SLAVE Interface Specification for External Computer Path Control Using VAL II</u>.

To control robotic devices from other manufacturers, you must develop your own interface software according to the specific requirements of each device.

5.3 SOFTWARE REQUIREMENTS

The software required to run RCS applications includes PROMs containing the basic FORTH operating system, and a magnetic tape containing the SMACRO extensions to FORTH.

The magnetic tape supplied by NBS also includes RSL, an application developed by NBS. You can modify RSL for your application or copy selected RSL procedures as a basis for your own RCS application.

5.4 HARDWARE INSTALLATION PROCEDURES

To install the hardware required to run RCS, you must configure the processor boards, the common memory board, the disk and tape controller board, the disk drive, the terminal, and the printer.

Configuring the Processor Boards

Before installing the 86/30 processor boards in the system, you must change the factory-default configuration of the boards, add the PROMs containing the FORTH operating system, install the 8087 numeric data processors, add heat sinks, set up the bus clock on one of the boards, and set up RCS communications on one of the boards.

Installing processor-board jumpers

Configure each processor board by performing the jumper modifications indicated in Table 5-1. These modifications are from the Intel default jumper configurations.

Table 5-1. Processor-Board Jumper Modifications.

Modification	Result
Add 204-206	Enables bus lock
Pull 205-207, pull 208-209	Disables bus clock
Pull 210-211	Disables serial priority
Pull 213-214, add 212-213	Grounds CBRQ/
Pull 219-225	Sets the RAM address to 2000
Add 218-223, add 238-239	Selects 24-bit addressing
Add 124-125	Selects 32K PROM size
Pull 111-112, add 112-113	Selects 32K PROM size
Pull 151-152, pull 147-158	Deletes interrupt assignments
Add 164-166	Selects 8087 error interrupt
Add 136-154, add 153-157	Selects onboard serial port interrupts
Add 133-165	Assigns the 6-msec time-out interrupt
Pull 175-176, add 175-184	Sets PIT clocks
Add 76-77	Connects RTS to CTS

After making these jumper modifications, cut connection line 32 of the P2 connector to disconnect a non-tristate output.

You may need additional jumpers to configure a processor board for the onboard parallel port or for one of the add-on multimodule ports.

To select the address for the RAM on each 86/30 processor board, configure the jumpers for each starting address as shown in Table 5-2.

Table 5-2. Processor-Board Starting-Address Jumpers.

Board Numbers	Starting Address	Jumpers	RSL Control Level
0	00000	232-233	RSL
2	20000	None	PRIM
4	40000	219-226, 232-233	TASK/PATH
6	60000	219-226	JOINT/COMM
8	80000	219-225, 232-233	not used for RSL
A	A0000	219-225	not used for RSL
C	C0000	219-225, 219-226, 232-233	not used for RSL

Installing the FORTH PROM circuits

Install on each 86/30 processor board the four PROMs containing the FORTH operating system supplied by NBS.

Installing the 8087 numeric data processors

For each processor board, carefully remove the 8086 microprocessor from the board and install it on a small board (Intel 337A) with an 8087 numeric data processor. Next, install the 8087 board into the 8086 socket on the processor board. If you are using an old 8087 that runs at a maximum clock speed of 5 MHz, add jumper 36-37 to the processor board.

Installing heat sinks

After installing the 8087 board, install a heat sink (using silicone heat sink compound) on top of the 8086 and 8087 processors to ensure adequate cooling.

Installing the bus clock

You must enable the bus clock on one, and only one, of the processor boards (usually board 0) within the system. Install jumpers 205-207 and 208-209 to enable the bus clock. These jumpers should not be present on any other processor board in the system.

Configuring interprocessor communications

The processor board responsible for RCS communications between levels is the COMM board (although it may also perform functions not related to communications).

Configure the COMM board to send the COMM bit to the other boards by adding jumper 245-251. This jumper enables status register bit 5 to invoke bus interrupt 2.

Configure the other processor boards to receive the COMM bit by adding jumper 147-148. This jumper assigns bus interrupt 2 to bit 2 of the Programmable Interrupt Controller (PIC).

Configuring the Common Memory Board

Modify the factory-default configuration of the common memory board (Plessey Model PSM 512A) by modifying the jumper wires as indicated in Table 5-3.

Table 5-3.   Common Memory Board Jumper Modifications.

Modification	Result
Pull LK19	Disables the PWRfail interrupt
Pull LK21	Selects parallel priority operation
Pull LK22-31	Disables the error interrupt

To run RSL, set the address and interrupt switches of the common memory board to the settings shown in Table 5-4.

Table 5-4.   Common Memory Board Switch Settings for RSL.

Switch Settings

Pole:	1	2	3	4	5	6	7	8	Result (Pole 1 is at the left)
SW1:	on	off	off	off	off	off	off	off	Disables interrupts
SW2:	off	off	off	off	off	off	off	off	Selects megabyte page
SW3:	off	on	on	on	on	on	on	on	Selects 80000 as first address
SW4:	off	off	off	off	off	off	on	off	Selects EFFFF as last address

Configuring the Disk and Tape Controller Board

Modify the factory-default configuration of the Rimfire 45 disk and tape controller board by installing the jumper wires indicated in Table 5-5.

Table 5-5. Disk and Tape Controller-Board Jumper Modifications.

Modification   Result

Pull 15-16, add 15-17   Selects 16-bit bus operation
Pull 23-26   Selects parallel priority operation
Add 13-14   Enables bus time-out interrupt
Pull 31 through 50
Add 50-49-48-47-45-44-43-42
Add 46-41   Sets the initialization address to EFC06
Add 40-39-38
Add 37-36-35-34-33-32-31

For operation with the RCS system, you must set the channel attention of the
Rimfire 45 controller board to 0052 and the bus width to 16. You must also
set the DIP switches on the Rimfire controller board to the settings shown in
Table 5-6.

Table 5-6. Disk and Tape Controller-Board Switch Settings.

Switch Settings

Bit:	1	2	3	4	5	6	7	8
SW1:	off	on	off	on	off	off	on	on
SW2:	off	off	off	off	off	off	off	off

Configuring the Disk Drive

You can order Priam Diskos Model 6650-10 disk drives from the factory,
equipped with an ANSI standard adapter. Refer to the Priam documentation if
you have a drive that requires installing this adapter.

Modify the factory-default configuration of the Priam 6650-10 disk drive by
setting the Sector DIP switch (located under the adapter board) for 18 sectors
per track according to the settings shown in Table 5-7.

Table 5-7. Disk Drive Switch Settings.

Switch Settings

Bit:	1	2	3	4	5	6	7	8
Sector Switch:	off	on	off	off	on	off	off	off

Caution: Make sure you have unlocked the disk heads and spindle before turn-
          ing on the disk power. New Priam disk drives have a label indicat-
          ing which lever performs this function. Old drives have two levers;
          one releases the heads and the other releases the spindle. Refer to
          the manufacturer's instructions for more information on preparing
          the disk drive for use.

Configuring the Terminal

Installing the terminal requires configuring both the hardware and software. The steps involved depend on the terminal you are using. This section describes the steps for the terminals that RCS supports.

To configure the hardware, set up the terminal to communicate with RCS. The computer port on the terminal must be configured for RS-232C, 9600 baud, 8 data bits, no parity, and one stop bit. Refer to the terminal manual for information on how to set up the terminal. If you have Micro-Term ERGO 301, the function key format must be set to TV970.

To configure the software, modify the system to load the proper block for the terminal being used and define the programmable function keys (if any). See Steps 6 and 7 in Section 5.5, "Software Installation Procedure", for the exact steps involved.

Your NBS-supplied system tape is configured for an ANSI terminal, specifically the Micro-Term Model ERGO 301. The Micro-Term has programmable function keys and tabs. The RCS VT100 utility contains additional words to program these keys. Similarly, the RCS TeleVideo utility contains words to program the TeleVideo function keys. Tables 5-8 and 5-9 list the programmable function keys as defined for these two terminals. Note that the Datamedia 1521A does not have function keys.

Note: Terminals that are compatible to VT100 terminals conform to the ANSI standard for terminals. You can use any ANSI standard terminal with the RCS VT100 screen editor. However, most terminals add features on top of the ANSI standard, such as programmable function keys and tabs. Therefore, the protocol for programming function keys and tabs differs from one terminal to another, even if both terminals are ANSI. If you do not have a Micro-Term or TeleVideo terminal, you have to write your own words to program the function keys for your terminal.

Table 5-8. Function Keys Defined on the Micro-Term ERGO 301.

Key	Function	SHIFT-Key Function	CTRL-Key Function
F1	printer on	X	printer off
F2	form feed	X	X
F3	^X	X	X
F4	move to TASK&PATH board	X	X
F5	move to PRIM board	X	X
F6	move to JOINT/COMM board	X	X
F7	X	X	X
F8	X	X	X
F9	X	boot commands*	X
F10	X	2 D>M	X
F11	X	3 D>M	X

Table 5-8. Function Keys Defined on the Micro-Term ERGO 301. (continued)

Key	Function	SHIFT-Key Function	CTRL-Key Function
F12	X	5 D>M	X
F13	X	X	X
F14	X	X	X
F15	X	X	X
F16	^E	X	X
PF1	home	X	X
PF2	clear	X	X
PF3	X	X	X
PF4	X	X	X

*The boot commands are <u>HEX F7 C9 0 CBOOT 0 MBBOOT init-cm</u>. SHIFT-F9 does not include a carriage return.

Note: The keys PF1 through PF4 are not programmable. The keys F1 through F16 are programmed in the RCS Function-Keys block. The SHIFT-Key sequences are programmed in EAROM.

For the VT100, pressing ^<ENTER> toggles the selection of the printer.

Table 5-9. Function Keys Defined on the TeleVideo 950.

Key	Function	SHIFT-Key Function	CTRL-Key Function
F1	printer on	X	X
F2	printer off	X	X
F3	printer form feed	X	X
F4	move to TASK/PATH board	X	X
F5	move to PRIM board	X	X
F6	move to JOINT/COMM board	X	X
F7	X	X	X
F8	X	X	X
F9	X	X	X
F10	boot commands	X	X
F11	2D>M	X	X

Configuring the Printer

Connect the printer to the printer port on the terminal you are using. Make sure the printer and terminal have the same port configurations, such as baud rate and stop bits. Consult the printer and terminal manuals for more infor- mation. If your terminal does not have a transparent mode (where the terminal passes all control codes through to the printer), some of the RCS printing utilities will not work. In this case, you need to write a small amount of FORTH code to communicate with a separate printer port. The TeleVideo 950 and VT100 terminals have transparent modes.

In addition to configuring the ports on the printer and terminal, it is necessary to modify the system for the particular printer being used. The steps involved are given in Section 5.5 in Step 8.

Preparing to Install the RCS Software

After configuring the boards, the disk, the printer, and the terminal, install them and any other components of the system according to the manufacturer's instructions. Although different applications require different configurations of the system hardware, you must have at least the minimum hardware configuration defined in Section 5.1, "Hardware Requirements", to install the RCS system on a blank disk. If you want to install the full RSL application, you must have three additional 86/30 processor boards configured as shown in Table 5-2 (board numbers 2, 4, and 6).

5.5 SOFTWARE INSTALLATION PROCEDURE

You install the RCS and RSL software by transferring it from the NBS-supplied magnetic tape to your Winchester disk, and then compiling it on your system. To install the software, follow this procedure:

Note: If you make an error in typing any of the required input statements, use the "delete" key to backspace over the error and correct it. Do not use the "backspace" or cursor control keys to correct an error.

1. Make sure the disk heads are unlocked. Then turn on the system and verify that the disk is spinning.

2. At the terminal, type the first digit of the master board address (that is, the board number) followed by a space and the word CBOOT. For example type RPB 4 ERASE Ø CBOOT and press RETURN.

    After you press RETURN, the system initializes the disk semaphore and control block for that board. Then the system loads the heads on the disk to prepare it for use and displays the FORTH **ok** prompt.

3. Formatting the disk takes approximately 3 minutes. To format the disk, enter the following commands exactly as shown:

        HEX
        RPB 1C ERASE
        24 RPBPREP
        Ø4ØØ RPB 4 + ORM
        4 RPB ØA + !
        RIMFIRE-GET RDOP CØ8Ø FFFF ?WERROR RIMFIRE-FREE
        DECIMAL

Refer to the Rimfire controller manual for information on any error messages that appear during the formatting process. Repeat the commands listed in this step if formatting does not proceed as expected. If the problem persists, make sure that the addressing jumpers and switches are correctly positioned on the memory board, the processor board, and the Rimfire controller board.

4. To rewind the tape, move the tape past the first file mark, and read in the MBOOT file, load the RCS system tape into the tape drive and enter the following commands exactly as shown:

        TREWIND
        TSKIP
        1000 1349 88 T/F-TAPE

    Note: Appendix B, "User Word Summary", does not contain these words because they are used only for this initial installation.

5. If the commands listed in Step 4 execute correctly, enter the following commands to load MBOOT and the normal TAPE utility, and to rewind the tape. Enter the commands exactly as shown, but substitute the [#] with the first hex digit of the starting address for the 86/30 processor board designated for RSL. If you configured your system as described in this chapter, the first hex digit of the starting address for the RSL board is 0.

        [#] MBOOT
        Basic TAPE
        TREWIND

    Now load the rest of the source code from the tape. After each FROM-TAPE command, the specified blocks are read from the tape, and the message **tape is at file #** (where # is the current file number on the tape) is displayed. If an error message appears, do not execute the rest of the commands (see Section 6.10, "Using Tape Utilities", for information on solving the tape problem). To load the source code, enter:

        2 TGOTO
        1350 1499 FROM-TAPE
        1500 1599 FROM-TAPE
        7000 7999 FROM-TAPE
        8000 8999 FROM-TAPE
        9000 9999 FROM-TAPE
        10000 10999 FROM-TAPE
        11000 11999 FROM-TAPE
        12000 12999 FROM-TAPE

    After each FROM-TAPE command, the specified blocks are read from tape, and the message **tape is at file #** will be displayed, (where # is the current file # on the tape). If any error messages appear, do not execute the rest of the commands (see Section 6.10, "Using Tape Utilities").

6. Create the tape and print D>M by pressing the master reset switch and entering the following commands on the master board:

        HEX F7 C9 OUTPUT
        RPB 4 ERASE
        Ø CBOOT
        Ø MBOOT

    Depending on the type of terminal being used, enter:

        [#] CUSTOM

    Where [#] is 7 for Datamedia, 8 for TeleVideo, and 9 for VT100-compatible terminals. Note that after you enter [#] CUSTOM, the system prompt changes to **list&tape>**.

    Now enter:

        Ø OFFSET !
        5 MEM>DISK

7. If you are using a Micro-Term ERGO 301 terminal, skip to Step 8. If you are using either a TeleVideo or Datamedia terminal, you must reconfigure the system.

    For the TeleVideo 950, perform the following steps:

    ● In block 1370, the Ø CUSTOM block, use the screen editor to change VT100 in line 4 to Televideo.

    ● Change VT100-Terminal in line 6 to Televideo-terminal.

    ● Enter the following commands to copy block 1166 to block 1405:

            1000 OFFSET !
            166 405 1 BLOCKS

    For the Datamedia, perform the following steps:

    ● In block 1370, the Ø CUSTOM block, use the screen editor to change VT100 in line 4 to Datamedia.

    ● Change VT100-Terminal in line 6 to Datamedia-terminal.

    ● In block 1405, insert %% at the beginning of line Ø. Inserting %% disables the programming of function keys since the Datamedia 1521A has none.

Note: For information on using the screen editor, see Section 6.7, "Editing a Block of Code".

8. If you are using an Imagewriter printer, skip to Step 9. If you are
    using either a DECwriter III or Integral Data Systems Paper Tiger
    printer, you must reconfigure the system. For the DECwriter III, change
    Image-writer to Dec-writer in blocks 1377, 1378, and 1379. For the Paper
    Tiger, change Image-writer to Paper-tiger in these three blocks.

9. Create the base system by pressing the master reset button to turn the
    hardware on and off, and then entering the following commands to the mas-
    ter 86/30 processor board. (If the system does not have 24-bit address-
    ing the first command is not needed.) After you enter RCS, the system
    responds with a variety of loading messages, followed by a :R prompt.
    After you enter 1471 LOAD, the system prompt becomes :R rsl>.

        HEX F7 C9 OUTPUT
        Ø CBOOT
        Ø MBOOT
        init-cm
        RCS
        1471 LOAD

    After you enter these commands, the system loads Ø CUSTOM and performs
    the 1 PRESERVE and 1 PRESERVE-FILE commands. CUSTOM loads a block that
    customizes the board for a specific application (RSL on the tape supplied
    by NBS). PRESERVE writes the current system dictionary to disk.
    PRESERVE-FILE writes the current user files to disk.

10. As prompted, enter the 1 MEM>DISK command. This command writes an image
    of the board's local RAM to the disk. Then enter Y at the make image?
    prompt.

11. A system running RSL requires four processor boards. Other applications
    may require more or fewer processor boards. If you are installing equip-
    ment other than that listed for a system running RSL, you must edit
    blocks 1472 through 1479 to reconfigure the base system to accommodate
    these components. For information on how to edit blocks, see Section
    6.7, "Editing a Block of Code".

12. Enter the following command to load each slave board through CUSTOM and
    to execute the 1 MEM>DISK command:

        1470 LOAD

    Loading the base system takes about 14 minutes for the three slave boards
    in a system configured to run RSL. The previous command causes each
    slave board to execute the following commands:

        [#] MBOOT
        Slave
        REMOTE-SLAVE
        RCS
        [#] CUSTOM
        1 PRESERVE 1 PRESERVE FILE 1 MEM>DISK

Where [#] is the first hex digit of the 86/30 processor board address given in Table 5-2.

13. Enter the following command to load each slave board with the corresponding control level of the RSL sample application:

    1480 ØLOAD

    Loading RSL takes about 7 minutes. If you are using an application other than RSL, you must first define slave address constants in block 1404 (loaded by the master board) and reconfigure BOOT-SYSTEM. Blocks 1460 through 1469 are reserved for booting slave boards; BOOT-SYSTEM loads block 1460.

14. When loading is complete, the system prompts you to enter the following commands on the master board:

    8ØØØ OFFSET !
    2 MEM>DISK
    Y
    3 MEM>DISK
    Y

At this point, the RCS and RSL software is installed.

This chapter provides the step-by-step procedures for performing basic RCS operations. The operations include starting up the system; finding, loading, and editing code; saving and rebooting the system; using printer and tape utilities; and shutting down the system.

The procedures in this chapter describe how to use RCS user command words to perform these basic operations. For a complete list of RCS user words, see Appendix B, "User Word Summary".

6.1 STARTING THE SYSTEM

This section describes how to start the system when you have a working application in the 2 D>M area of the disk. A D>M is a 120 consecutive block area on the disk. Your system tape comes with the RSL application in the 2 D>M area of memory.

RCS enables you to maintain up to five copies of local memory on the disk. Each copy is called a disk image or D>M. The RCS word D>M enables you to move one of the copies from the disk to memory. Alternatively, MEM>DISK moves a disk image from local memory to the disk. On the system tape provided by NBS, 1 D>M contains the base RCS version 2.2, 2 D>M contains RSL version 1.6, 3 D>M and 4 D>M are free for expansion, and 5 D>M contains additional RCS features such as the editor and the print and tape utilities.

For information on starting the system for the first time, including a more detailed explanation of the start-up command words, see Chapter 5, "RCS Installation Procedures".

Note: If you make an error in typing any of the required input statements, use the "delete" key to backspace over the error and correct it. Do not use the "backspace" or cursor control keys to correct an error.

To start the system, follow these steps:

1. Turn on rack power to the RCS hardware.

2. Press the RETURN key until the terminal responds **ok**.

3. Enter <u>RPB 4 erase 0 CBOOT 0 MBOOT init-cm 2 D>M</u> and wait for the **:R rsl>** prompt. (Remember that the system is case sensitive. You must enter the uppercase and lowercase characters as shown.)

    The commands in Step 3 boot the RSL application. The 0 CBOOT command initializes the Winchester disk, 0 MBOOT loads the base FORTH system, init-cm initializes memory, and 2 D>M moves the application image to memory and executes the auto-load block. The auto-load block initializes the communications process, the 8087 chip, the function keys, the system dictionary, and the SMACRO files. The auto-load block also calls BOOT-SYSTEM to boot the slave boards in the system.

Note: At this point you can use the system for programming and debugging without running the robot.

4. Turn on power to the robot.

5. Prepare the robot for RCS control. The exact procedures for this step depend on the type of robot you are using with RCS. Typically, the steps include turning on power to the robot controller, initializing the controller and the interface to RCS, turning on arm power to the robot, and moving the robot to a safe starting position.

6. Enter GO to start all the control levels and the communications process. RCS is now waiting for the robot to start communications.

7. Command the robot controller to start the RCS interface.

8. Enter ^X to return to the master board. You must press RETURN after ^X.

RCS now controls the robot.

6.2 MOVING FROM ONE BOARD TO ANOTHER

To find a block of code in the memory on a specific board, you must move to that board to search for the block. Moving to a board means that you make the terminal communicate directly with the specified board. RCS enables you to use either software switches or a hardware switch for moving between boards. After you move to the correct board, you must use the correct vocabulary on that board.

The RSL example includes four processor boards. The prompt that appears on the terminal identifies the board with which the terminal is currently communicating. In addition, the first two characters of the prompt indicate the current operating mode of the system.

Table 6-1 lists the boards and their prompts for the RSL example system.

Table 6-1. Board Names and Prompts.

Board Name	Prompt
RSL (the master board)	:R rsl>
TASK&PATH	:R task&path>
PRIM	:R prim>
JOINT	:R joint/comm>

Note: The RCS prompts for each board were named with the RSL application in mind. If you add a new application, you can change the prompts to correspond to the control levels of your application. The prompt for each board is defined by the word :OK in the CUSTOM block for that board.

Using Software Switches

The software switch is the code on the master and slave boards that enables you to select the board with which the terminal is communicating. For example, enter [slave board name] REMOTE to make your terminal communicate with a specified slave board. Enter ^X to make your terminal communicate with the master board again.

The NBS-supplied system tape includes code to define the function keys on the Micro-Term terminal. Function keys correspond to each slave board, eliminating the need to type [slave board name] REMOTE. See Table 5-8 in Chapter 5, "RCS Installation Procedures", for the definition of all Micro-Term function keys.

If you have a different terminal, you can customize the function keys for that terminal by editing the block that defines the word Function-keys (absolute block number 1405). If you have defined function keys for the slave boards in your system, you can move between boards by pressing the function key for the board you want.

You must move to a slave board from the master board; you cannot move from one slave board to another. To return to the master board from any slave board, enter ^X.

Using a Hardware Switch

If your system includes a switch box for the terminal, you can communicate with another board by moving the switch to the position corresponding to the appropriate board.

You can also use this switch to perform a soft reset of a board by setting the switch for that board and entering ^C. You can perform a hard reset of the entire system by using the master reset button on the chassis.

Changing Vocabularies

Each board contains a system vocabulary, called SDEF, and up to five user-defined vocabularies. To locate code on the system, you must be on the correct board and in the correct vocabulary on that board. To display the current vocabulary name and size, enter V-SIZE. Enter SDEF to change to the system vocabulary on any board.

The RSL application includes a predefined vocabulary for each control level. These vocabulary names are the same as the names of the RSL control levels: TASK, PATH, PRIM, and JOINT. The word $DEF sets the vocabulary to be the vocabulary of the current board. For example, if you are on the PRIM board, enter $DEF to move to the PRIM vocabulary. Because the TASK and PATH levels are on the same board, RSL defines the words TDEF and PDEF to move between the TASK and PATH vocabularies on the TASK&PATH board.

Alternatively, you can enter [name] DEFINITIONS, where [name] is the name of
the desired vocabulary. For example, enter PRIM DEFINITIONS to use the PRIM
vocabulary.

6.3 LOCATING SOURCE CODE

Locating source code requires an understanding of the LOC command, the Locate
mode, directory block conventions, relative and absolute blocks, and offsets.

This section discusses these topics, including an example of how to locate
source code using the RCS directory block system.

Most code creates entries in the system dictionary. This code can be located
by name using the LOC command or Locate mode. To locate code which does not
make entries in the system dictionary, you must use the directory block
system.

Using the LOC Command

When you are on the correct board, using the correct vocabulary, use the LOC
command to find the block where a specific word is defined. Enter LOC fol-
lowed by a space and the word you want to locate. The system displays a list-
ing of the source block in which the word is defined.

Some words cause RCS to issue the message **Pre-locate**. This message indicates
that the word is a system word, not a user application word, and that you can-
not access it. However, some system words are accessible using the LOC
command.

Using the Locate Mode

You can also find a specific block using Locate mode. To use Locate mode,
when you are on the correct board, using the correct vocabulary, enter :L. In
Locate mode, :L prefixes the system prompt.

Enter the word that you want to locate and the system lists the block that
defines that word, instead of executing the word. To exit Locate mode, enter
:R. (For more information on RCS modes, see Section 7.4, "Modes".)

Understanding Directory Block Conventions

The RCS disk is organized into sections containing 1000 blocks each. For
example, the source code for RCS resides in the 7000-block section, and the
source code for RSL resides in the 8000-block section. For a complete map
showing these blocks, see Appendix C, "System Maps".

All source code on the disk is organized according to the FORTH block struc-
ture; a block contains 16 lines of 64 characters each. RCS uses a hierarchi-
cal directory block structure to organize these blocks on the disk. A direc-
tory block exists for each 1000-, 100-, and 10-block section of disk.

Note that if a block is 0 or a multiple of 10 or 100, the next block (block 1,
block 11, or block 101, respectively) is also a directory block that lists
blocks at the next directory level. For example, block 11 lists the directory
for blocks 12 through 19.

The directory blocks contain comments to help you locate code on the disk.
You must maintain directory blocks. When you add, delete, or change code, be
sure to update the affected directory blocks.

Using Relative and Absolute Block Addresses

RCS uses a system of relative block addresses to help you locate blocks.
The absolute block number is the actual block number on the disk; the
relative block number is the absolute block number minus the offset.

Specifying an Offset

The offset is the value of the special FORTH variable OFFSET. The offset is
usually a multiple of 1000 that indicates the board with which you are cur-
rently communicating. Using an offset decreases the number of characters you
must enter to identify a block.

If a board boots with the offset set at 8000, you can access blocks 8000
through 8999 using the relative block numbers 0 through 999.

Note that there may be more than one control level on the same processor
board. In this case, the first level resides in blocks 0 through 999, the
second level resides in blocks 1000 through 1999, and so forth.

Use !, the FORTH store command, to change the offset. For example, to set the
offset at 8000, enter 8000 OFFSET !.

Note: If you reconfigure the disk, you must edit the code in the application-
load blocks to change the offsets.

An Example of Using the RCS Directory Block System

This section explains how to use the RCS directory block system to locate a
block of code. Figure 6-1 shows the directory blocks for a 1000-block section
of the disk.
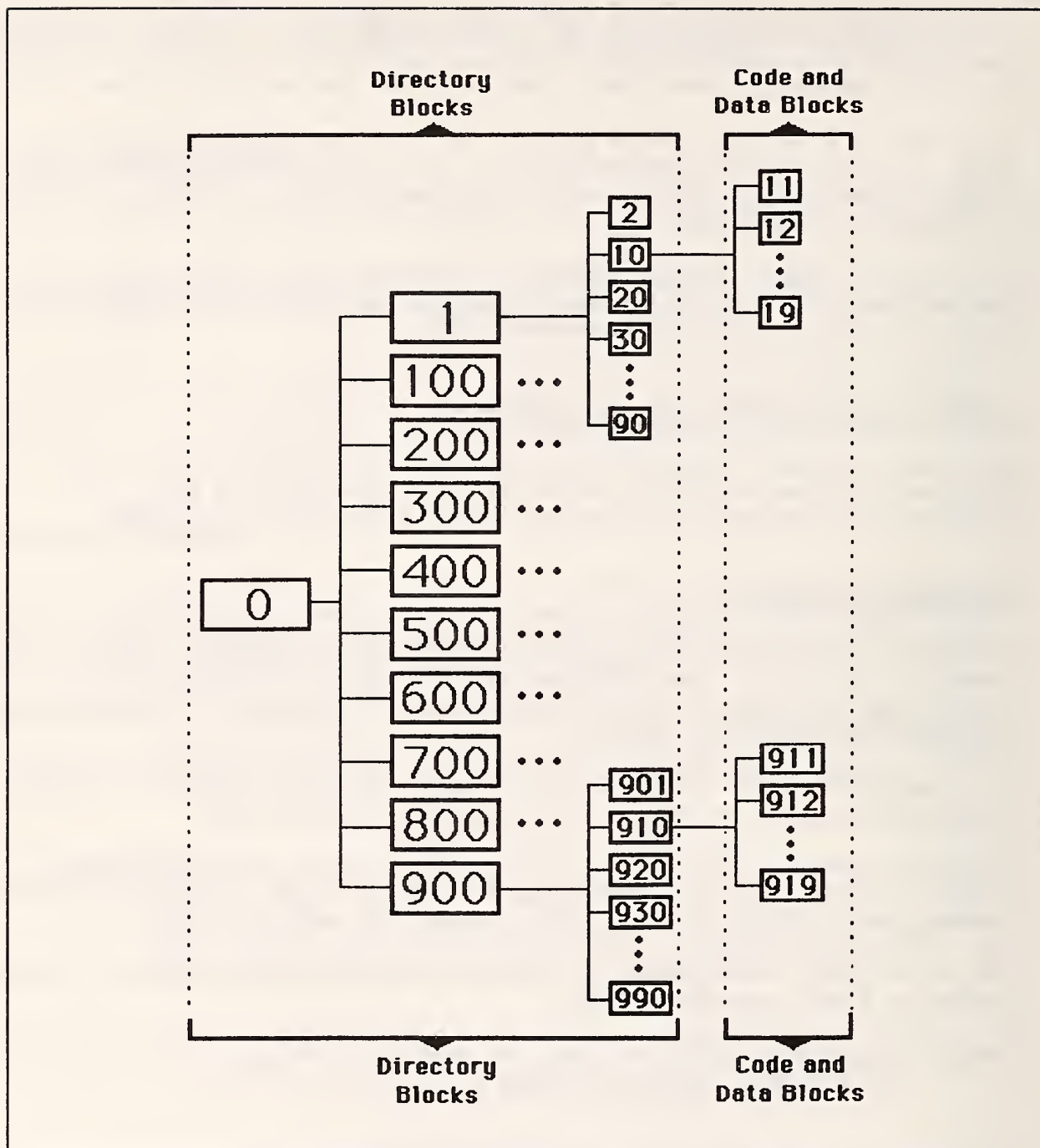
Figure 6-1. Directory blocks for a 1000-block section of the disk.

You use these directory blocks to locate code; for example, to find the block that contains a TRANSFER task. Tasks are contained in blocks on the TASK level. To find where TASK is located on the disk, boot the system (Steps 1 through 3 in Section 6.1, "Starting the System"), then enter MAP to list the first block of the directory of the disk.

```
       -10640        1360 ABS

       220/A366 Development Disk Directory 03/05/86
       *******  SYSTEM BLOCKS ************

            0 -    999    FLOPPY BLOCKS
         1000 -   1349    MBOOT 2.2
         1350 -   1499    CUSTOM
         1500 -   1599    screen EDIT
         1600 -   5999    D>M images
         6000 -   6999    TAPE TRANSFER
         7000 -   7999    RCS 2.2
         8000 -   8999    RSL  1.6
         9000 -   9999    TASK 1.6
        10000 -  10999    PATH 1.6
        11000 -  11999    PRIM 1.6
        12000 -  12999    JOINT 1.6


          :R rsl>
```

As you can see, MAP lists absolute block 1360, which shows TASK at 9000 OFFSET. (You can see the rest of the MAP directory block by entering N L.) Enter 9000 OFFSET ! to set the offset to the location of the TASK level. Enter 0 LIST to list the first directory block for the TASK level.

```
   0
   0  ( TASK 1.6 5/19/86   for RSL 1.6b
   1  ------------------------------------------------------
   2      1   load, list, debug
   3    100   variables
   4    200   pre-process
   5    300   command : primitives
   6    400   command : path search
   7    500   command : tasks, COMMAND-PROCESS
   8    600
   9    700
  10    800   post-process
  11    900   user commands, level, power-up
  12  ------------------------------------------------------
  13
  14
  15
  :R rsl>
```

Because the TRANSFER command is a user command, you can see on line 11 that
TRANSFER should be in the 900 100-block section. Enter 900 LIST to display
the next directory-level listing.

```
900
  0   ( TASK : user commands, level, power-up
  1  ------------------------------------------------------
  2    01  Display, time
  3    10  user commands
  4    20
  5    30
  6    40
  7    50
  8    60
  9    70
 10    80  power-up load block
 11    90  TASK LEVEL
 12  --------------------------------------------------)
 13    00 ref-blk
 14      01 load ( 10 load   20 load   30 load   40 load
 15      50 load   60 load   70 load   80 load ) 90 load
:R rsl>
```

You can see on line 3 that user commands are in the 910 10-block section.
Enter 910 LIST to display the next directory-level listing.

```
910
  0   ( TASK :  user commands
  1  -----------------------------------------------------
  2    1  RESTART
  3    2  PAUSE
  4    3  TRANSFER
  5    4  MOVE-TO nul ARRAY-SAFE
  6    5
  7    6
  8    7
  9    8
 10    9  single-step
 11  -----------------------------------------------------)
 12    0  ref-blk
 13
 14  (   1 load    2 load    3 load    4 load    5 load
 15      6 load    7 load    8 load    9 load )  ~MEM
:R rsl>
```

Finally, you can see on line 4 that TRANSFER is in block 913. Enter 913 LIST
to display the TRANSFER command block.

```
913
   Ø
   1 :R
   2   inc-command-#-in ~@ 1+ ==> inc-command-TASK DEFINITIONS#-in
   3   '' TRANSFER nul Ø1 arr ARRAY ØØ Ø8 ;; loc CONVEYOR "
   4     ==> input-command
   5 :S
   6
   7
   8
   9
  1Ø
  11
  12
  13
  14
  15
  :R   rsl>
```

6.4 LOADING CODE

Loading code in RCS is similar to loading code in FORTH. In fact, in RCS, the
word "load" means the FORTH LOAD operation, which reads a block from the disk
to local RAM, and then interprets all the words in the block. In RCS, the
SMACRO compiler interprets or compiles the words in a block.

The SMACRO compiler in RCS is an incremental compiler. It compiles, links,
and loads code in small pieces, typically one routine at a time. No separate
linker and loader exists as in other systems; the code is completely linked
and ready to run when the compiler finishes with it. The SMACRO compiler is
called by the SMACRO defining words, mainly the word "routine" and variable
declarations. Thus, to compile code, you simply load the blocks containing
it.

Note that loading a block does not necessarily result in compiling code. The
block may contain words that perform other tasks, such as initializing ports
or executing routines. Blocks used this way resemble command files on other
systems.

The SMACRO compiler also enables you to redefine routines. After a complete
system is loaded, you can edit and reload (recompile) any routine at any time,
without reloading or even relinking the rest of the system. Any routine that
calls the edited routine now calls the new version. Combined with the block
screen editor, the ability to redefine routines is extremely useful for
debugging, because bug fixes can be tested with very short edit and compile
cycles.

SMACRO is also interpretive in that you can execute any routine by typing its
name, and you can view and set variables. You cannot execute statements or
fragments in this way, only compiled routines. This restriction retains the
speed of compiled systems, while providing the user-friendliness of inter-
preted systems.

To load a block, enter the relative block number followed by the word <u>LOAD</u>, or the absolute block number followed by the word <u>ØLOAD</u>. You can save the time required to reload code by saving the FORTH and SMACRO segments (the D>M) and the system dictionary to disk, using the MEM>DISK and PRESERVE commands.

The following procedures describe two special situations in which you need to load code: reloading an edited routine and loading code still under development.

Editing and Reloading a Routine

To edit and reload a routine, follow these steps:

1. Boot the system as described in Section 6.1, "Starting the System".

2. Edit the routine as described in Section 6.7, "Editing a Block of Code".

3. Move to the board containing the routine.

4. Use the command LOAD or ØLOAD to reload the source code for the routine.

5. Enter <u>[preserve#] PRESERVE [preserve#] PRESERVE-FILE</u>, where [preserve#] is the number of the PRESERVE area containing the final application, to save the system dictionary and your files.

6. Enter <u>[d>m#] MEM>DISK</u>, followed by a comment, such as the date and a description of the changes you made. The comment must begin with a double quotation mark.

    The MEM>DISK command saves the FORTH and SMACRO segments that are on the board. For example, <u>2 MEM>DISK " Added code for new sensor</u>, saves the 2 D>M image to disk.

(This procedure is illustrated in Section 6.8, "Example RCS Dialogue".)

Loading Routines Under Development

The procedure for loading routines under development is similar to the procedure for reloading a routine. However, because an application under development may contain programming errors, you should load it in segments. After you load each segment of the application and ensure that the code works properly, save the application and the system dictionary to the disk, using the D>M and PRESERVE commands.

To load an application under development, follow these steps:

1. Make the board containing the application the current board.

2. Enter <u>[d>m#] D>M</u> to copy the working Forth and SMACRO segments from the disk into memory, where [d>m#] is the last image saved.

3. Enter [Preserve#] RESTORE [preserve#] RESTORE-FILE to copy the working system dictionary and SMACRO files from the disk into memory.

4. Load the code under development. If the system detects an error, RCS aborts the loading procedure and you must edit the block to correct the error.

   An error may be nonfatal or fatal. If the error is nonfatal (for example, a misspelled variable name), simply reload the block. If the error is fatal (for example, not allowing enough space for a variable owner), reload the application using the D>M, RESTORE, and RESTORE-FILE commands.

   At this point, all of the code is loaded. However, memory space may be wasted as a result of nonfatal errors. To recover this wasted space, repeat Steps 2 through 4 before continuing to Step 5.

5. Enter [preserve#] PRESERVE [preserve#] PRESERVE-FILE, where [preserve#] is the number of the PRESERVE area containing the final application, to save your files and the system dictionary.

6. Enter [d>m#] MEM>DISK, followed by a comment, to save the updated FORTH and SMACRO segments to disk.

Using this procedure, you can restore a system quickly without reloading a list of blocks.

6.5 EXECUTING TASKS AND ROUTINES

With RCS, you can execute robot tasks with an operating robot, or the routines that define that task without an operating robot. RCS also enables you to operate in different modes, control output to the screen, and abort an executing task.

Executing Robot Tasks

To execute a robot task, load the block that defines that task. For example, if the RSL transfer task is defined in block 913 on the TASK board, enter Task/path REMOTE to move to the TASK&PATH board, and then enter 913 LOAD to execute a transfer in which the robot transfers an object to a different location.

Executing Routines

Executing routines without an operating robot is useful when you are debugging an application. First, issue a HALT command to stop all control levels, the communication process, and execution of the robot interface. Then assign values to the input variables needed by the routine, and enter the name of the routine to execute it. If the routine includes many input variables, you may want to set up a load block to assign values to the input variables. This procedure is illustrated in the example in Chapter 13, "Debugging Techniques".

Understanding Modes

RCS includes four operating modes: Run, Show, Locate, and Compile. In Run
mode, the system executes routines previously compiled. In Show mode, the
system displays on the screen the contents of variables. In Locate mode, the
system displays the block defining the word you enter. Section 7.4, "Modes",
explains how these modes affect SMACRO words. RCS uses Compile mode when you
load a block containing defining words.

Controlling Screen Output

To suspend output to the terminal, press ^S. To resume output to the ter-
minal, press ^Q.

Aborting an Executing Task

To send a soft reset to the board to which the terminal is currently connected
(usually the master board), press ^C. If you are using a software switch to
communicate with a slave board, pressing ^C aborts the software switch and
returns you to the master board. The executing task on the slave board is not
aborted. To abort a task on a slave board, use the switch box to access that
board and then press ^C.

6.6 SAVING AND REBOOTING THE SYSTEM

When you change existing code or create new applications, you usually want to
save the changes or the new code to the disk. You may also need to recreate
the base system to reflect hardware changes. This section describes the pro-
cedures for performing these operations.

To understand these procedures, you need to understand the structure of RCS
described in earlier chapters of this manual. RCS stores compiled code, vari-
ables, and routines in the local memory of each processor board. Common mem-
ory contains the system dictionary and user files. RCS also stores compiled
code on the disk in D>Ms, PRESERVEs, and PRESERVE-FILEs, which contain copies
of the compiled code from local and common memory.

Figure 6-2 shows the action of the RCS words D>M, MEM>DISK, PRESERVE, RESTORE,
PRESERVE-FILE, and RESTORE-FILE, used for saving and restoring copies of code.
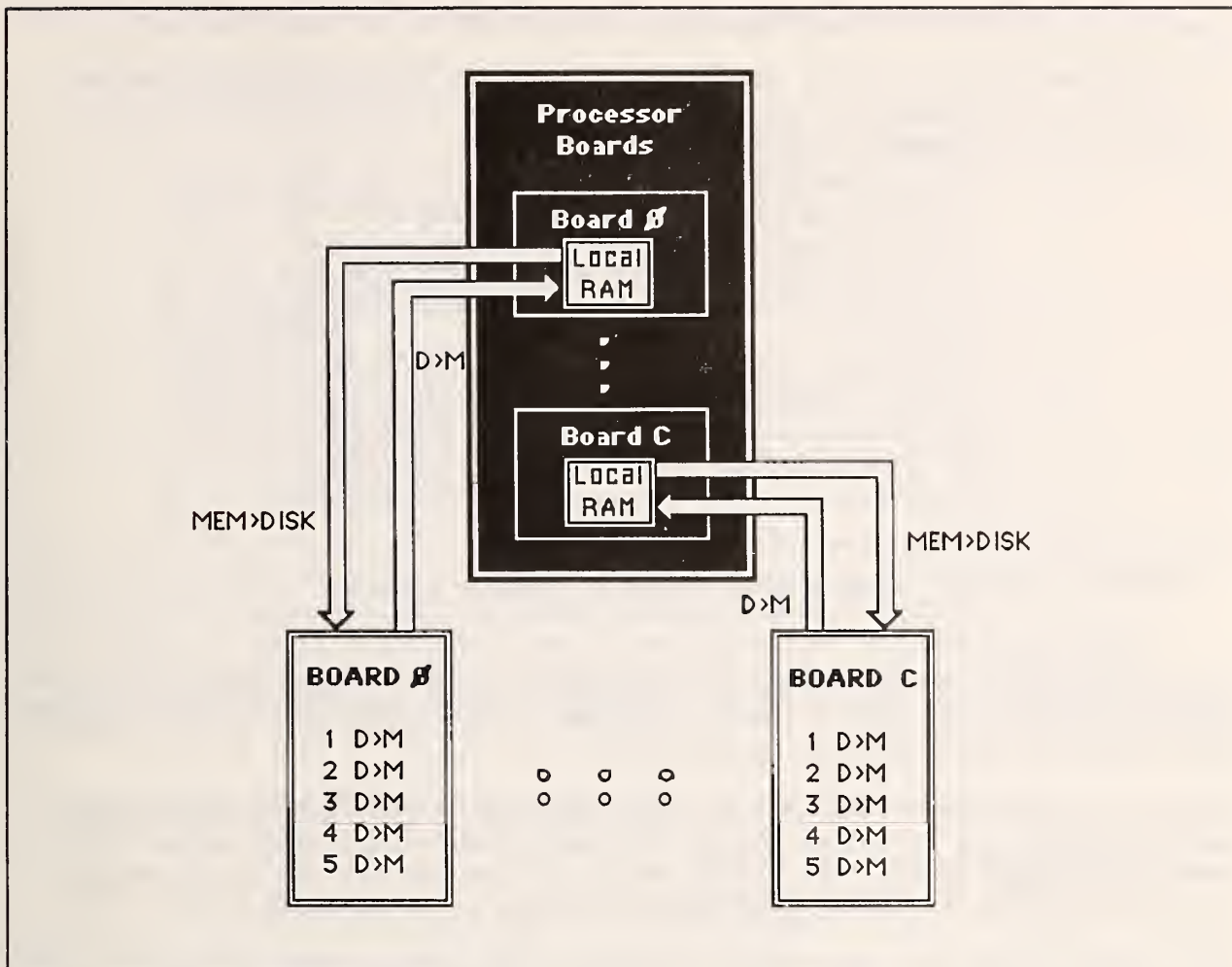
Figure 6-2. Restoring and saving code.

Saving and Restoring Disk Images

A D>M is the name given to a disk area of 120 consecutive blocks containing
the FORTH and SMACRO segments for a processor board. A D>M is a disk image of
the contents of that 120-block area. D>M is also an RCS word that moves the
data in the D>M to local memory.

The disk includes space for seven boards, each with five disk images (D>Ms).
Enter [board#] DM? to list the D>Ms on a board. This listing is called the
D>M map block. The word MBOOT lists the D>M map block for board 0, which you
see every time you start RCS.

Figure 6-3 shows the D>M map block for board Ø of the RSL application.

```
          -7615           1385  ABS
          D>M MAP  : board Ø : RSL
          -----------------------------------------------
          1| 5/19| init-cm RCS 1471 LOAD % RCS 2.2
          -----------------------------------------------
          2| 5/19| 1 D>M 1480 LOAD % RSL ( all boards )
          -----------------------------------------------
          3| 4/11|
          -----------------------------------------------
          4| 5/28| 8 CUSTOM % edit, laser print, type
          -----------------------------------------------
          5| 4/11| 9 CUSTOM % edit, Image print, tape
          -----------------------------------------------
```

Figure 6-3.   Example D>M map block.

In this D>M map, you create the 1 D>M image by entering the commands summarized on line 1. To create the 5 D>M image, enter 9 CUSTOM. You must update this block for your specific application.

The RCS word D>M moves the data in that D>M area on the disk to local memory, and then loads the auto-load block. A reserved auto-load block exists for each D>M on each board. The auto-load block executes all the words necessary to start the D>M, including initializing hardware and software.

For example, when you enter 2 D>M to boot an application, RCS copies the 2 D>M image from disk to local RAM and the auto-load block executes, restoring the system dictionary and SMACRO files from the disk.

The RCS word MEM>DISK copies the contents of the on-board RAM into a D>M space on the disk, saving the current segments. Any words you enter on the same line after the MEM>DISK are executed both after the MEM>DISK word and after the corresponding D>M is executed. Enter words after the MEM>DISK command to add comments to describe the D>M.

The following dialogue illustrates D>Ms, input lines, and auto-load blocks:

```
:R rsl>Joint/comm REMOTE                 Switch to the Joint/comm board.
:R joint/comm>2 AUTO?                     Display the auto-load block for
                                          the 2 D>M on the Joint/comm board.

    -10564 1436 ABS

    % board 6 2 D>M
    CR " Joint/comm level  "
    " NO RESTORE "
    TIME-OUT-INIT 87INIT
     HEX 7FFF ==> control-cycle-#-clks DECIMAL
     RESTART-COMM-TIMER
    CR " Joint init " 12000 980 OLOAD
    CR " Joint/comm inited "
    CR
```

When you load this block, it prints the message **Joint/comm level NO RESTORE**, initializes the time-out and the 8087, initializes the variable control-cycle-#-clks, starts the communications timer, prints the message **Joint init,** loads block 12980 absolute, and prints the message **Joint/comm inited.** Block 12980 loads other blocks that initialize several variables for the JOINT level.

```
:R joint/comm>2 MEM>DISK "hi there-this is the input line"
```

make image? y
                                 Make a new 2 D>M; it overwrites the old 2 D>M. Confirm the command.

```
Joint/comm level NO RESTORE
Joint init
Joint/comm inited
hi there-this is the input line
```

RCS loads the auto-load block when MEM>DISK executes. The auto-load block displays the message on the input line.

```
:R joint/comm>2 D>M                       Executing 2 D>M now reads into RAM
                                          the copy just written, loads the
                                          auto-load block, and displays the
                                          message on the input line.

Joint/comm level NO RESTORE
Joint init
Joint/comm inited
hi there-this is the input line
```

All essential start-up procedures should reside in the auto-load block. Use the D>M input line only for comments.

Saving and Restoring the System Dictionary

Use the words PRESERVE and RESTORE to move the system dictionary between com-
mon memory and the disk. PRESERVE moves the system dictionary from common
memory to the disk, and RESTORE moves the system dictionary from the disk to
common memory. The disk contains space for nine copies of the system diction-
ary. The base RCS system dictionary resides in the 1 PRESERVE area.

Saving and Restoring User Files

Use the words PRESERVE-FILE and RESTORE-FILE to save and retrieve SMACRO
files. (RCS creates user files using the SMACRO FILE declaration. See Sec-
tion 7.2, "SMACRO Syntax", for more information.) PRESERVE-FILE saves your
files to the disk, and RESTORE-FILE retrieves them. The disk contains space
for nine copies of your files.

Note: Be careful when using more than one version of an application. If you
do not enter the PRESERVE, PRESERVE-FILE, and MEM>DISK commands after
making changes to the system, the versions in the D>M and the source
code will differ.

6.7 EDITING A BLOCK OF CODE

RCS provides line-editing commands and a screen editor. Both these editing
features are loaded in the 2 D>M and 5 D>M on the master board. You have to
be on the master board to use the screen editor.

To edit the current block of code using the screen editor, enter ED. To edit
any other block, enter [block#] ED. RCS displays the block and puts you in
the screen editor. In the editor, a block consists of 16 lines of 64 charac-
ters each. The screen editor does not recognize characters that exceed the
FORTH block boundaries. Be careful not to lose characters off the end of a
line or the end of a block.

The source code on your supplied tape is spread out over many blocks. The
empty blocks are provided so you can expand the system. If new or added code
does not fit in a block, use editing commands to move part of the block to the
next block and load both blocks together. Do not put a vocabulary name in the
continuation block. This technique is shown for an example SMACRO routine in
Figure 6-4.

```
Ø                                                              JOINT DEFINITIONS
1   routine CARTESIAN
2     %  Input:  pose-^-in, scaling-var
3     %  Output: servo-com-joint, scaling-var
4     if servo-status (EQ) error
5     then error => status-report lower-level => status-arg-out
6     else
7       POSE-FILE pose-^-in => record#
8       retrieve-from-fields pose conf-flag  pose
9       REACH-CHECK
10      if status (EQ) noerror
11      then CART>JOINT  CART-CONFIGURE
12        if status (EQ) noerror
13        then 1.# .=>. j-acc 1.# .=>. j-vel
14          SCALE
15          servo-point => output-command inc-command-#-out INC

Ø   ( CARTESIAN cont )
1              JOINT-LIMIT-TEST
2              is status (EQ) error
3              then error => status-report
4                 status-arg => status-arg-out
5                 old-ja S=> servo-com-joint
6              else CART-STATUS
7              endif
8            else error => status-report
9              status-arg => status-arg-out
10           endif
11        else error => status-report
12          status-arg => status-arg-out
13        endif
14      endif
15  end-routine
```

Figure 6-4. Using continuation blocks.

Using Screen-Editor Commands

To move the cursor in the screen editor, use the four arrow keys. If you hold
down an arrow key, the key repeats until you release the key. The cursor
never leaves the block; if the cursor reaches the end of a line, it wraps
around to the beginning of that line. The HOME key moves the cursor to the
top left corner of the block. All screen-editor commands use relative block
numbers.

When you enter the screen editor, RCS displays the four categories of editing commands, as shown in Figure 6-5. The vertical lines on the right of the figure indicate the end of the 64-character line.

```
CHARACTER OPS        LINE OPS          BLOCK OPS           SPECIAL OPS
^A Insert On/Off    ^C Copy Line      ^F Forward Block    PF1 Home   PF2 Clear
^E Erase Char       ^D Delete Line    ^P Previous Block   ^U Undo Block
^K Mark to Keep     ^O Open Line      ^G Goto Block       ^W Want String
^Z Input Keep                         ^T Transfer         ^N Next Want
                                      ^R Retire(quit)     ^X Cancel


    BLOCK      Ø

 Ø                                                                          |
 1                                                                          |
 2                                                                          |
 3                                                                          |
 4                                                                          |
 5                                                                          |
 6                                                                          |
 7                                                                          |
 8                                                                          |
 9                                                                          |
10                                                                          |
11                                                                          |
12                                                                          |
13                                                                          |
14                                                                          |
15                                                                          |
```

Figure 6-5.   RCS screen-editor display for the VT100.

The control characters listed on the screen are for the VT100. Other terminals may have other control characters that perform the same function. The commands the control characters perform are listed on this screen. Table 6-2 describes these editing commands.

Note: The screen editor must be configured for the terminal being used. See Section 5.5, "Software Installation Procedure", for the procedure.

Character operations

In the screen editor, you can edit characters using the four character-editing commands shown in Table 6-2.

Table 6-2.   Character-Editing Commands.

Command	Description
^A (Insert On/Off)	Inserts characters when on and writes over characters when off. After you press ^A, * INSERT * appears at the top of the screen, and any characters you enter are inserted at the cursor position. When you press ^A again, the insert indicator leaves the screen and any character you enter replaces the character at the cursor position.
	Caution: Remember not to shift characters past the end of the line.
^E (Erase Character)	Erases the character at the cursor position and moves the remaining characters in the line one space to the left.
^K (Mark to Keep)	Marks code to be copied into a Keep buffer that you can copy to other locations within the block or to another block. Use ^K to delimit the string you want to copy to the buffer.
	Position the cursor on the first character to include and press ^K once. * KEEP * appears at the top of the screen. Then move the cursor to the first position after the last character to include and press ^K again. If the last character you want to save is the last character in the line, position the cursor at the first character in the next line and press ^K.
^Z (Input Keep)	If the insert indicator is on, inserts the string contained in the Keep buffer starting at the cursor position. If the insert indicator is off, enters the string in the Keep buffer at the cursor position, overwriting the characters already there.

Line operations

In the screen editor, you can edit lines using the three line-editing commands shown in Table 6-3.

Table 6-3.   Line-Editing Commands.

Command	Description
^C (Copy Line)	Moves all lines after the line containing the cursor down one line, and copies the line containing the cursor on the resulting blank line. The last line of the block is lost; it does not move to the next block or wrap around to the top of the block.
^D (Delete Line)	Deletes the line containing the cursor and moves all subsequent lines up one line, leaving the last line in the block empty.
^O (Open Line)	Moves the line containing the cursor and all subsequent lines down one line, providing a blank line for new input. The last line of the block is lost. If you want to insert more lines than the block can hold and the next block is empty, use the Keep buffer or the Transfer command to copy part of the block into the next block. Make sure both blocks are loaded together.

Block operations

You can save and move code between blocks using the five block-operation commands shown in Table 6-4.

Table 6-4.   Block-Operation Commands.

Command	Description
^F (Forward Block)	Saves changes to the current block and displays the next block. The next block appears in the screen editor, with the cursor at the same position as it was in the saved block.
^P (Previous Block)	Saves changes to the current block and displays the previous block. The previous block appears in the screen editor, with the cursor at the same position as it was in the saved block.

Command	Description
^G (Goto Block)	Displays the block you specify. When you enter ^G, the system displays a **Go To Block** _____ prompt at the bottom of the screen, requesting a block number. After you enter the relative block number, the current block is saved and the specified block appears in the editor.
^T (Transfer)	Transfers lines within a block or from one block to another. Start the transfer operation with the cursor at the destination location.

When you enter ^T, the system displays the prompt **Transfer Block** _____. Enter the relative block number of the block containing the information you want to transfer. The system then displays the prompt **From Line** _____. Enter the number of the first line you want to transfer. Then respond to the **To Line** _____ prompt with the number of the last line you want to transfer. The transfer lines overwrite existing characters in the destination block.

For example, to transfer lines 0 through 5 from block 99 to block 100, display block 100 and place the cursor at the position where you want the transferred information to appear. Then press ^T, and respond to the three prompts with <u>99</u>, <u>0</u>, and <u>5</u>, respectively.

Caution: Insert mode should be off. Transfer lines overwrite existing characters in the destination block.

^R (Retire)	Saves the current block and exits the screen editor. The message **Bye** appears on the screen, and you return to the master board.

Special operations

Table 6-5 describes the commands you can use for special editing operations in Screen Edit mode.

Table 6-5. Special Editing Commands.

Command	Description
PF1-HOME	Moves the cursor to the home position in the block.
PF2 (Clear)	Erases the contents of the block. If you press the CLEAR key unintentionally, enter ^U to undo the Clear operation.
^U (Undo Block)	Restores the screen to its condition before the last Save operation. Note that several editing commands save the contents of a block before performing their assigned functions. For example, ^F saves a block before moving to the next block.
^W (Want String)	Enables you to search for a string of up to 20 characters. After you press ^W, the system displays the prompt **Search Input** _____ . Enter the search string. After you enter the search string, the system displays the **From Block** _____ and **To Block** _____ prompts, enabling you to specify beginning and ending block numbers for the search. After you answer these prompts, the system displays the first block in the specified range that contains the search string. The characters must match exactly.
	While the system is searching for the string, **AT** and the number of the block currently being searched appear at the top of the screen.
^N (Next Want)	Repeats the last Want String operation specified using ^W, finding the next occurrence of the search string within the specified range.
^X (Cancel Operation)	Cancels an editing operation. For example, to cancel a transfer operation after pressing ^T, press ^X before responding to all three Transfer command prompts.

Using Line-Editor Commands

You can also edit blocks outside the editor by using the RCS line-editor commands. Common line-editor commands are listed alphabetically in Table 6-6. Line-editor commands enable you to perform operations such as listing a block, or clearing or copying a range of blocks. For a complete list of editing commands, see Appendix B, "User Word Summary".

Table 6-6. Line-Editor Commands.

Command	Description
B	Decrements the current block number.
[source block] [destination block] [# of blocks] BLOCKS	Copies blocks, starting at the source block and continuing for the number of blocks specified, to the destination block. The source and destination blocks may overlap. For example, to copy blocks 100, 101, and 102 to blocks 400, 401, and 402, enter <u>100 400 3 BLOCKS</u>.
[start block] [end block] CLEAR	Clears the specified range of blocks with spaces.

Note: Use the BLOCKS and CLEAR commands with extreme caution, because you can lose large sections of source code with a simple typing error.

Command	Description
[start block] [end block] FIND [string^]	Displays each line containing the string in the specified range of blocks. The display shows the line number in the block at the right margin, along with the start block number on the first line followed by the end block number on the last line.
[start block] [end block] FIND-R [string^]	Replaces all occurrences of the string in the specified block range with the string in the insert buffer. You can load the insert buffer using the command R-WITH, described later in this table.
L	Lists the current block, including the line numbers. <u>N L</u> lists the next block, <u>B L</u> lists the previous block.
[block#] LIST	Lists the specified block, including the line numbers.
[absolute block#] ØLIST	Lists the specified block, including the line numbers. You must specify the absolute block number.
[block#] LLIST	Lists the specified block without line numbers.
[absolute block#] ØLLIST	Lists the specified block without line numbers. You must specify the absolute block number.
N	Increments the current block number.

Command	Description
[start block] [end block] QR	Searches for a string and either replaces it or does not replace it, based on your answer to a query. QR prompts you for the search and replace strings.
	The system searches for the first occurrence of the search string. When the system finds the string, QR prompts you to confirm the replacement by positioning the cursor at the end of the string. You enter Y, y, or space to replace the search string with the replace string. You can enter ? to display a help menu.
R-WITH [string^]	Loads the insert buffer with the specified string.

6.8 EXAMPLE RCS DIALOGUE

This section gives a possible dialogue for a user of the NBS RSL application. The dialogue contains examples of most of the procedures described in sections 6.2 through 6.7. The dialogue locates the word Display in the vocabulary of the PATH level on the TASK&PATH board. The word Display displays the contents of certain variables.

After the dialogue locates Display, it executes Display, edits Display to label the variables displayed, and saves the updated routine on the disk. The dialogue indicates each of these steps with a separator shown in all uppercase characters. Information that you type appears underlined in the dialogue. Information that the system displays appears in boldface in the dialogue. Brief explanations are included in parentheses.

Remember that this example is specific to the NBS implementation of RCS, and the RSL application of RCS. If you are working with the NBS implementation, you may want to use this dialogue as a tutorial to get acquainted with basic RCS procedures. Centered headings appear in the tutorial to indicate the function of each group of commands.

To start the tutorial, boot the system as described in Steps 1 through 3 of Section 6.1, "Starting the System". After you boot the system, it displays the prompt for the master RSL board.

STEP 1: LOCATE Display FOR THE PATH LEVEL

  :R rsl> <u>Task/path REMOTE</u>   (Moves to the task/path board.)

  :R task&path> <u>PDEF</u>   (Makes the path vocabulary current.)

  :R task&path> <u>LOC Display</u>   (Lists the source block for Display.)

```
1909      10909  ABS
                                    PATH DEFINITIONS
routine Display
  if print-f (EQ) true
  then
    ~F CR
    ~PRINT" path: "
    ~PRINT inc-command-#-in
    ~PRINT input-command
    ~PRINT status-report
    ~PRINT status-arg-out
    ~PRINT ppt-command
    ~PRINT ppt-done
  endif
end-routine
```

STEP 2: EXECUTE Display

  :R task&path> <u>Display</u>   (Executes the word Display.)

  path: 0 0 0 0 0 0

STEP 3: EDIT Display TO ADD A LABEL

  :R task&path> <u>^X</u>   (Returns to the master board containing the editor.)

  :R rsl> <u>red</u>   (Edits the block most recently accessed on the most recent slave board.)

STEP 3:   EDIT Display TO ADD A LABEL (cont.)

```
        CHARACTER OPS        LINE OPS         BLOCK OPS           SPECIAL OPS
        ^A Insert On/Off   ^C Copy Line     ^F Forward Block    PF1 Home    PF2 Clear
        ^E Erase Char      ^D Delete Line   ^P Previous Block   ^U Undo
        ^K Mark to Keep    ^O Open Line     ^G Goto Block       ^W Want string
        ^Z Input Keep                       ^T Transfer         ^N Next Want
                                            ^R Retire(quit)     ^X Cancel


        2909            10909
                                                      PATH DEFINITIONS
    0
    1   routine Display
    2      if print-f (EQ) true
    3      then
    4         ~F CR
    5         ~PRINT" path: "
    6         ~PRINT inc-command-#-in
    7         ~PRINT input-command
    8         ~PRINT status-report
    9         ~PRINT status-arg-out
   10         ~PRINT ppt-command
   11         ~PRINT ppt-done
   12      endif
   13   end-routine
   14
   15
```

Use the arrow keys to position the cursor at the first character in line 10.

<u>^A</u>   (Enables you to insert characters. Notice
                                        the insert indicator appears after the abso-
                                        lute block number.)

<u>~PRINT" ppt: "</u>   (Labels the path-point output. Do not put a
                                        space before the first quotation mark. Do
                                        put a space before and after the second quo-
                                        tation mark.)

<u>^A</u>   (Turns insert off.)

<u>^R</u>   (Exits the editor.)

Bye

:R rsl> <u>L</u> 2909   (Lists the current block with your editing
                                        changes.)

STEP 3: EDIT Display TO ADD A LABEL (cont.)

```
2909
  0                                          PATH DEFINITIONS
  1   routine Display
  2     if print-f (EQ) true
  3     then
  4        ~F CR
  5        ~PRINT" path: "
  6        ~PRINT inc-command-#-in
  7        ~PRINT input-command
  8        ~PRINT status-report
  9        ~PRINT status-arg-out
 10        ~PRINT" ppt: " ~PRINT ppt-command
 11        ~PRINT ppt-done
 12     endif
 13   end-routine
 14
 15
```

STEP 4: LOAD THE BLOCK AND EXECUTE THE ROUTINE

```
:R rsl> ^X                      (Returns to the most recent slave board.)

:R task&path>
:R task&path> 1909 ELOAD        Display REDEFINED

                                (Empties the local block buffers and then
                                loads the specified block.)

:R task&path> Display           (Executes the word.)

path: 0 0 0 0 ppt: 0 0
:R task&path>
```

STEP 5: SAVE THE UPDATED ROUTINE

```
:R task&path> 6 PRESERVE 6 PRESERVE-FILE

                                (Writes the system dictionary and SMACRO
                                files to the 6 PRESERVE area on the disk.)
```

:R **task&path>** 3 MEM>DISK " Patched Display 5/23 "

> (Writes the current D>M, D>M number 3, from the local RAM on the TASK&PATH board, to the disk. The text within quotation marks is a comment briefly describing the update you made, followed by the date. The comment appears as a message the next time you execute a 3 D>M. You may want to save comments in a logbook to track the changes you make to the system.)

STEP 5: SAVE THE UPDATED ROUTINE (cont.)

make image? Y

> (Confirms the MEM>DISK command and writes the image to disk.)

Task/path levels
NO RESTORE
Task init
Path init
sonar not inited

Task/path inited
Patched Display 5/23
:R task&path>

6.9 USING PRINTING UTILITIES

To use the RCS printing utilities, enter 5 D>M on the master board for the printing application. After you enter 5 D>M, you can use the printing words described in the following sections and in Appendix B, "User Word Summary". These commands enable you to print a range of blocks and to print block directories and programs. For information on configuring your printer, see Section 5.4, "Hardware Installation Procedures".

Printing a Range of Blocks

You can print a range of blocks with 10 blocks on each page by using the CPRINT command. Enter the start block and the end block, separated by a space. Then enter the word CPRINT. For example, to print blocks 10 through 19 on one page, enter 10 19 CPRINT.

To print a range of blocks with three blocks on each page, use the same procedure, but enter the word Print instead of CPRINT. For example, to print blocks 1 through 9 with three blocks on a page, enter 1 9 Print.

Printing Block Directories and Programs

The words List-directory and List-programs enable you to print the block directories and the programs, respectively. For more detailed information on these commands, see Appendix B, "User Word Summary".

Note: When using a TeleVideo 950, prefix the printer commands with the word Thru-tv. Using these words puts the terminal in transparent mode so that printer control codes are passed to the printer; for example for a Televideo 950, <u>Thru-tv 10 19 CPRINT</u>.

6.10 USING TAPE UTILITIES

To use the RCS tape utilities, enter <u>5 D>M</u> on the master board for the tape application. After you enter 5 D>M, you can use the tape words described in the following sections and in Appendix B, "User Word Summary". These commands enable you to back up the system on tape, solve a bad-tape problem, and read a tape.

Backing Up the System on Tape

The word BACKUP lists the backup block that contains the commands to back up the system on tape. BACKUP uses the ADD-TO-TAPE command to write a file to the tape. To back up the system on tape, load the backup block. You must edit the backup block to conform to your applications.

Solving Bad-Tape Problems

If you receive a bad-tape message for an ADD-TO-TAPE command, use the command BAD-TAPE preceded by the start and end blocks of the file to extend the file to cover the bad section and preserve the file numbering sequence. You cannot use this command if the bad section of tape is in the first file. In that case, start the tape operation using a new tape.

Reading a Tape

To read a tape, use the command FROM-TAPE preceded by the start and end blocks of the file you want to read. FROM-TAPE reads the range of blocks from the tape, beginning from the current tape position. To use this command, you need a listing of the BACKUP block that contains the current block numbers for the files.

6.11 SHUTTING DOWN THE SYSTEM

To shut down the system, follow this procedure:

Note: If you are using the system without running the robot, start with Step 4.

1. Move the robot to a safe place.

2. Enter <u>HALT</u>. The HALT command aborts communications through the robot interface, turns off the background task on each board, and turns off the communications process.

3. Turn off the robot.

4. If you want, save any changes you made to the code, using the MEM>DISK, PRESERVE, and PRESERVE-FILE commands. Making and saving changes are described under Section 6.6, "Saving and Rebooting the System", earlier in this chapter.

5. Enter <u>WUNLOAD</u>. The WUNLOAD command shuts down the Winchester disk. Always enter this command before you turn off rack power to the RCS hardware.

6. Turn off rack power to the RCS hardware.

The shut-down procedure is now complete.

RCS contains code written in SMACRO, FORTH, and 8086 assembly language. This chapter describes when to write code in the different languages and gives a comprehensive description of SMACRO, the primary language used in RCS. The chapter assumes that you know the FORTH programming language.

7.1 OVERVIEW

The base operating system of RCS is polyFORTH 1. SMACRO is an extension of polyFORTH, containing a set of macros that enable you to write structured programming code similar to high-level languages like Pascal and C. SMACRO is a high-level assembler and, like most assemblers, it generates code that usually executes faster and is more compact than similar code written in a high-level, structured language.

In addition to the speed of SMACRO, SMACRO is easy to debug because of the interactive nature of FORTH and SMACRO. You can execute a single SMACRO routine, or you can edit and recompile one routine of a larger application and then execute the application without recompiling the rest of the code.

NBS developed SMACRO to make writing structured programming code easy. However, SMACRO may not be suited for all tasks. If SMACRO is not suited for a particular task, you can include FORTH or 8086 assembly language within a block of SMACRO code, or you can write blocks of code entirely in FORTH or assembly.

For example, if timing is important for a routine, you may need to use assembly language, to make the routine operate fast enough to execute in one control cycle. Also, because SMACRO does not support block and disk access, you may have to write some routines in FORTH. The read routines in the TASK level that access the system dictionary are written in FORTH.

Your NBS-supplied system tape also contains Robot Sensor Language (RSL) code. RSL is a language for controlling robot motions; it is one specific application that runs in RCS. Chapter 9, "Robot Sensor Language (RSL)", describes RSL in more detail.

7.2 SMACRO SYNTAX

This section describes the syntax of the SMACRO language, including programming conventions, variable declarations, members and owners, file declarations, operators, and statements. See Appendix B, "User Word Summary", for a complete list of SMACRO words.

In general, the SMACRO compiler does not detect syntax errors. Using DBG-ON catches some errors, but not all. You should test routines to ensure that the algorithm, as well as the syntax, is correct. To verify that each routine runs correctly, test each routine individually.

Programming Conventions

The SMACRO code that is on the system tape follows several programming conventions. These conventions include:

- The vocabulary name is in the top right corner of the first line of the block.

- A comment describing the purpose of the routine and the input and output variables appears at the beginning of the routine.

- Routine names appear in uppercase characters.

- Variable names appear in lowercase characters.

- Code is indented two spaces.

To keep your system organized and easy to maintain, continue to follow these conventions.

Figure 7-1 shows an example block of SMACRO code to illustrate SMACRO programming conventions:

```
  Ø                                                                    SDEF
  1   routine SMACRO-EXAMPLE
  2     % Example routine to illustrate SMACRO programming conventions
  3     % Input: variable1, variable2, ...
  4     % Output: variableA, variableB, ...
  5
  6     SMACRO routine statements
  7
  8   end-routine
  9
 1Ø
 11
 12
 13
 14
 15
```

Figure 7-1. Example SMACRO routine.

The vocabulary identifier on the first line of a SMACRO block automatically makes the vocabulary you specify the current vocabulary when you reload the block. The line also displays the current vocabulary when you use the LOC command.

Percent symbols in SMACRO code indicate that the rest of the line is a comment. List the input and output variables at the beginning of each routine to make code easier to read and debug.

The convention of using all uppercase characters for routine names and all lowercase characters for variable names is used throughout the system. RCS will be easier to maintain if you follow this convention when you add code to the system.

Variable Declarations

You must declare a variable before you use it, and the variable you declare must be in a vocabulary. RCS already contains a system vocabulary for each board. RSL contains the vocabularies TASK, PATH, PRIM, and JOINT. Make sure you are in the correct vocabulary before you declare a variable. For information on changing vocabularies, see Section 6.2, "Moving From One Board to Another".

Table 7-1 shows how to declare a variable for the SMACRO variable types.

Table 7-1. SMACRO Variables.

Variable Type	SMACRO Declaration
16-bit integer	iv [variable name]
8-bit integer byte	bv [variable name]
32-bit floating point	fv [variable name]
1-dimensional integer array	[# elements] 1:a [variable name]
2-dimensional integer array	[# rows] [#columns] 2:a [variable name]
1-dimensional floating point array	[# elements] 1:fa [variable name]
2-dimensional floating point array	[# rows] [#columns] 2:fa [variable name]
string	[# bytes] strv [variable name]
segment	[segment] [address] [# bytes] segv [variable name]
sequential	seqv [variable name]

On your system tape, variables tend to be declared at the beginning of each control level, as they are in high-level languages like Pascal. However, in SMACRO and FORTH, this method is only a convention; you can declare variables at any place before you use them.

Remember that all variables in RCS are global within a vocabulary. A SMACRO variable name can be up to 31 characters long, and can contain any ASCII character, except a space. Variable names must be unique within a vocabulary.

To refer to an array element in SMACRO code, enclose the indices in braces. For example, A1 { x } is the xth element in array A1. A2 { x y } is the element in the xth row and yth column of array A2. The indices must be integer or sequential variables, and the first element in the array is 0.

In addition to the SMACRO variable types listed in Table 7-1, RCS uses matrix, pose, quaternion, and vector variables to represent robot positions and movements. SMACRO represents these variables in floating point arrays.

A vector consists of three consecutive floating point values. A pose consists of seven consecutive floating point numbers. The first four numbers represent the quaternion (or orientation) part of the pose, and the last three numbers represent the vector (or position) part of the pose.

A rotation matrix consists of nine consecutive floating point numbers, stored in the order: m11, m21, m31, m12, m22, m32, m13, m23, m33. Using this order, the matrix represents a coordinate frame with the first column representing the x unit vector, the second column representing the y unit vector, and the third column representing the z unit vector.

A quaternion consists of four consecutive floating point numbers. The first number represents the scalar part of the quaternion, and the last three numbers represent the vector part of the quaternion.

Table 7-2 gives an example declaration for representing a vector, pose, matrix, and quaternion.

Table 7-2.   Matrix, Pose, Quaternion, and Vector Declarations.

Variable Type	SMACRO Declaration
Vector named V1	3 1:fa V1
Pose named P1	7 1:fa P1
Pose named PQ	4 1:fa PQ 3 1:fa PV
Matrix named M1	9 1:fa M1
Matrix named M2	3 3 2:fa M2
Quaternion named Q1	4 1:fa Q1

Members and Owners

Variables are always grouped as members under an owner. Members include all SMACRO variable types. The three types of owners include: variable owners (VAR-O), sequential variable owners (S-VAR-O), and list owners (LIST-O).

Variable owners

The following list gives the syntax, function, and members allowed for a variable owner.

Syntax: [# bytes] bytes VAR-O [name]

Function: Enables you to group variables by allocating space in the SMACRO segment.

Members: integer, byte, floating point, string, segment, one-dimensional integer array, two-dimensional integer array, one-dimensional floating point array, two-dimensional floating point array.

Figure 7-2 presents an example variable owner that contains each type of member a variable owner can have.

```
 Ø                                                              SDEF
 1      125   bytes      VAR-O         VO-EXAMPLE
 2              iv       I1
 3              bv       B1
 4              fv       F1
 5        1Ø    1:a      IARRAY1
 6      3  3    2:a      IARRAY2
 7         4    1:fa     FARRAY1
 8      2  6    2:fa     FARRAY2
 9        1Ø    strv     STR1
1Ø   9ØØØ 8Ø 4 segv     SEG1
11
12
13
14
15
```

Figure 7-2. Example variable owner.

Table 7-3 gives the action of each line in Figure 7-2. In Table 7-3, the value in parentheses is the number of bytes allocated.

Table 7-3. The Variable Owner VO-Example.

Line Number	Action
Ø	Puts the contents of this block in the SDEF vocabulary.
1	Allocates a 125-byte buffer, named VO-EXAMPLE, in the SMACRO segment. Defines the variable owner, VO-EXAMPLE. The number of bytes, 125, is the sum of the bytes required for all the members. The word "bytes" is a null word to make the source code more readable. If the members allocate more than the specified number of bytes, RCS issues a buffer overflow error message.
2	Assigns a 16-bit integer variable, I1, to the VAR-O. (2 bytes)
3	Assigns an 8-bit integer variable, B1, to the VAR-O. (1 byte)
4	Assigns a 32-bit floating point variable, F1, to the VAR-O. (4 bytes)
5	Assigns a 1Ø-element one-dimensional 16-bit integer array, IARRAY1, to the VAR-O. (2Ø bytes)

Line Number	Action
6	Assigns a 3 x 3 two-dimensional 16-bit integer array, IARRAY2, to the VAR-O. (18 bytes)
7	Assigns a 4-element one-dimensional 32-bit floating point array, FARRAY1, to the VAR-O. (16 bytes)
8	Assigns a 2 x 6 two-dimensional 32-bit floating point array, FARRAY2, to the VAR-O. (48 bytes)
9	Assigns a string with a maximum of 10 characters, STR1, to the VAR-O. (12 bytes: 10 for the string, 1 for the maximum character count, and 1 for the actual character count)
10	Assigns a 4-byte section of common memory, SEG1, whose absolute address is at offset 80, segment 9000. (6 bytes: 2 bytes for length and 4 bytes for the 32-bit address)

Sequential variable owners

The following list gives the syntax, function, and allowable members for a sequential variable owner.

Syntax: [# members] mem S-VAR-O [name]

Function: Enables you to group sequential variables by allocating space in the SMACRO segment

Members: sequential variables

Figure 7-3 presents an example sequential variable owner that contains three members:

```
     0                                                   SDEF
     1    3    mem        S-VAR-O      SVO-EXAMPLE
     2         seqv                    SA
     3         seqv                    SB
     4         seqv                    SC
     5
     6
     .
     .
     .
    14
    15
```

Figure 7-3. Example sequential variable owner.

Table 7-4 lists the action of each line in the preceding figure:

Table 7-4. The Sequential Variable Owner SVO-Example.

Line Number	Action
Ø	Puts the contents of this block in the SDEF vocabulary.
1	Creates a 6-byte buffer, named SVO-EXAMPLE, in the SMACRO segment. The buffer contains consecutive integers starting at Ø. The word "mem" is a null word to make the source code more readable. The maximum number of members is 3.
2	Assigns the variable SA with a value of Ø to the S-VAR-O.
3	Assigns the variable SB with a value of 1 to the S-VAR-O.
4	Assigns the variable SC with a value of 2 to the S-VAR-O.

List owners

The following list gives the syntax, function, and allowable members for a list owner.

Syntax: LIST-O [name]

Function: Enables you to group any type of member together for display

Members: Any type of variable

Figure 7-4 presents an example list owner that contains an integer and two owners.

```
    Ø                                                         SDEF
    1           LIST-O      LO-EXAMPLE
    2      m    A
    3      m    IARRAY1
    4      m    SA
    5
    6
    .
    .
    .
   14
   15
```

Figure 7-4. Example list owner.

Table 7-5 lists the action of each line in the preceding block.

Table 7-5. The List Owner LO-EXAMPLE.

Line Number	Action
Ø	Puts the contents of this block in the SDEF vocabulary.
1	Groups the members under the owner LO-EXAMPLE.
2	Assigns an integer variable A to the LIST-O.
3	Assigns an integer array, IARRAY1, to the LIST-O.
4	Assigns a sequential variable, SA, to the LIST-O.

Note: You must define all list owner members before you add them to the list
owner. The numbers must be in the same vocabulary as the owner.

For a complete list of the RCS words for members and owners, see Appendix B,
"User Word Summary".

File Declaration

Use the SMACRO word FILE to declare SMACRO files. This declaration creates a
SMACRO file, using the most recently declared variable owner as the template.
(Include the file declaration in the source block that declares the variable
owner.)

RCS stores SMACRO files in common memory, providing the primary method of com-
munication between control levels. SMACRO files consist of a linked list of
records. Record numbers identify individual records in a file. The record
number is the address of the record in the file segment of common memory.

Header variables contain information about the file, such as the number of
records available, the address of the first record, and the record size. The
header variables are stored in common memory with the file and retrieved to
local variables when you open the file.

SMACRO Operators for Standard Programming Operations

The SMACRO operators that enable you to perform most standard programming
operations are:

- Arithmetic
- Assignment
- Relational
- File

In SMACRO, you perform operations using infix notation as in mathematics.
Different operators are available for different types of variables. The oper-
ator types include: integer, byte, floating point, string, pose, matrix, qua-
ternion, and vector.

In general, SMACRO encloses most integer operators in parentheses, precedes most byte operators with a capital B, and encloses most floating point operators in periods. Operands must be of the same type as the operator. Conversion operators convert integers to floating point numbers and floating point numbers to integers.

Arithmetic operators

SMACRO includes arithmetic operators for adding, subtracting, multiplying, and dividing integers, bytes, and floating point numbers. Table 7-6 lists these operators.

Table 7-6. SMACRO Arithmetic Operators.

Integer Operators	Byte Operators	Floating Point Operators
(+)	B+	.+.
(-)	B-	.-.
(*)	B*	.*.
(/)	B/	./.

Integer operations produce integer results. When you use integer division, remember that SMACRO truncates the fractional part of the result. For example, if you enter 5 (/) 3, the result is 1. SMACRO operations proceed from left to right; there is no precedence for integer and byte expressions.

You can use parentheses enclosed in periods to enforce precedence, but only for floating point numbers. You can nest scalar operations up to eight levels. You can nest vector operations only one level, and pose and quaternion operations to any level.

Here are some example SMACRO arithmetic operations and the results:

Statement	Result
I1 (*) I2	Multiplies the integer variables I1 and I2.
B1 B+ B2	Adds the byte variables B1 and B2.
F1 .-. F2	Subtracts the floating point value of F2 from the floating point value of F1.
I1 (+) I2 (*) I3	Adds integers I1 and I2 and multiplies the result by integer I3.
F1 .+. .(F2 .*. F3).	Multiplies the floating point numbers F2 and F3, and then adds the result to the floating point value in F1.

Be careful not to mix variable types in arithmetic operations. You may not get an error message, but you might get incorrect results. SMACRO does not allow literals in statements. To include constants in a statement, declare a variable with an appropriate name and initialize it.

Assignment operators

SMACRO includes assignment operators for integer, byte, floating point, string, pose, quaternion, matrix, and vector variables.

An assignment operator stores the variable or expression on the left side of the operator in the variable location specified on the right side. The arrow indicates the direction of the assignment. (Most high-level languages use the opposite direction.) Table 7-7 lists the assignment operators.

Table 7-7. SMACRO Assignment Operators.

Operator	Type
=>	Integer
B=>	Byte
.=>.	Floating Point
S=>	String
.P=>.	Pose
.Q=>.	Quaternion
.M=>.	Matrix
.V=>.	Vector

Here are some example assignment operators:

I1 (+) I2 => I1	Assigns the sum of integer variables I1 and I2 to the integer variable I1.
A2 { x y } => I1	Stores the element in row x, column y, of the integer array A2, to the integer variable I1.
B1 B* B2 B=> B3	Assigns the product of byte variables B1 and B2 to the byte variable B3.

Relational operators

Relational operators enable you to compare variables of the same type. You can use relational operators only in the conditional statements "if then else endif", "while do end-do", and "repeat until end-repeat". You cannot use relational operators in assignment statements. Table 7-8 lists the SMACRO relational operators.

Table 7-8. SMACRO Relational Operators.

Integer Operators	Byte Operators	Floating Point Operators	
(EQ)	EQ_B	.EQ.	.EQZ.
(NE)	NE_B	.NE.	.NEZ.
(LT)	LT_B	.LT.	.LTZ.
(LE)	LE_B	.LE.	.LEZ.
(GT)	GT_B	.GT.	.GTZ.
(GE)	GE_B	.GE.	.GEZ.

These operators perform the comparisons equal to, not equal to, less than, less than or equal to, greater than, and greater than or equal to, respectively. The second column of floating point operators compares floating point expressions to Ø. The floating point expression goes before the operator. Relational operators produce Boolean results of true or false. For example:

I1 (EQ) I2   results in the Boolean value of true if
                         integer I1 is equal to integer I2.

F1 .GEZ.   results in the Boolean value of true if the
                         floating point variable F1 is greater than
                         or equal to Ø.

You can also use arithmetic expressions on the left side of a relational test. For example:

I1 (+) I2 (/) I3 (EQ) I4   results in a Boolean value of true
                            if the result of the integer expression
                            I1 (+) I2 (/) I3 equals integer I4.

SMACRO also includes a string comparison operator, S-EQ, which compares two strings of equal length using the ASCII character values.

The SMACRO logical (AND) enables you to compare two Boolean expressions. The result is true only if both expressions are true.

File operators

File operators enable you to perform operations such as storing data from the local template to a record, retrieving the current record from the current file, and returning the current list to the free list. Appendix B, "User Word Summary", contains a list of the operators for manipulating files.

SMACRO also includes four Boolean file operators: matches, matches-r, matches-fields, and matches-fields-r. Use these Boolean file operators to search for a variable in the file and, if desired, to retrieve the local template of the first record that matches the variable.

In other systems, files reside on the disk, and you must open and close them. You can open only one file at a time, and you can only read or write to that file. Closing the file enables other processes to access it.

In SMACRO, files reside in common memory, and you must open but you do not need to close them. To open a file, you execute its name. You can open a file from any number of boards; no inherent protection mechanism exists. You must ensure that two boards do not try to access the same file simultaneously. This structure increases the access speed of the files. Potential read/write conflicts between files arise rarely, so RSL handles these conflicts as a special case using round-robins.

The control levels of RCS communicate through SMACRO files in common memory. The file structure consists of linked lists of records. For each file declaration, SMACRO sets up a file using the most recently declared variable owner as the template. The members of the variable owner define the fields for the records in the linked list. The file declaration also adds two fields to each record: a link field that points to the next record in the linked list, and a source block field that points to the source block that contains the data in the record.

The following SMACRO code declares a file named DATA-FILE:

```
16 bytes VAR-O file-rec
15 strv "field1"
   iv   field2

 5 rec FILE DATA-FILE
```

The first three lines of the example define a variable owner named file-rec that serves as the local template for DATA-FILE. The last line of the example allocates space in common memory for a file named DATA-FILE with five records. The file declaration fills the file with a list of empty records called the free list. The linked list for the file is terminated by a record whose link field contains Ø.

Figure 7-5 shows a representation of the file as initialized by re-init-file.
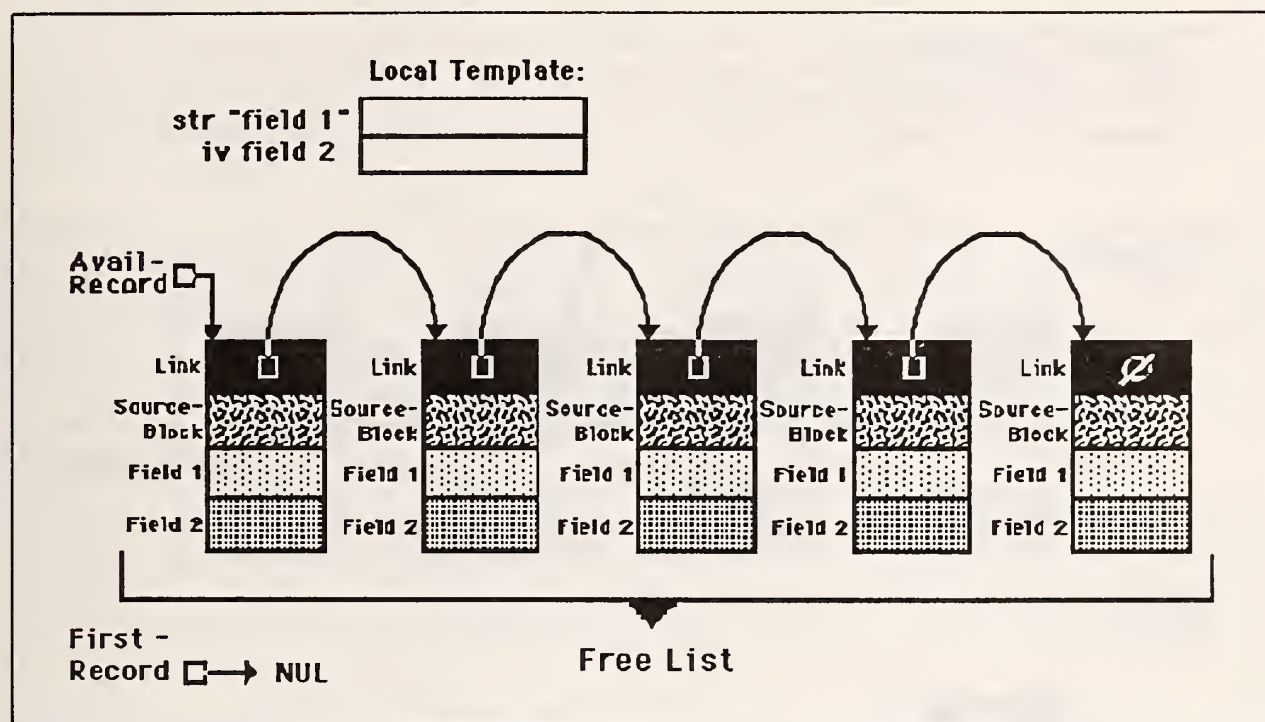
Figure 7-5. An example SMACRO file in common memory.

You create the file represented in Figure 7-5 by loading the block that contains the file declaration and initializing the file with the work re-init-file. RCS maintains the free list. When you add a record to a list, the record comes from the free list. When you remove a record from a list, the record returns to the free list.

You open a file by executing the file name. When you execute the file name, RCS retrieves header variables that contain information about the file from common memory to local variables.

Figure 7-6 shows the file after a record is added. Assume that the local template variables contain the data shown in the figure. To use DATA-FILE, you execute DATA-FILE to open the file, and then execute add-record to store the data in the local template to a record, remove the record from the free list, and add the record to the end of the current list. After add-record executes, DATA-FILE looks like Figure 7-6.
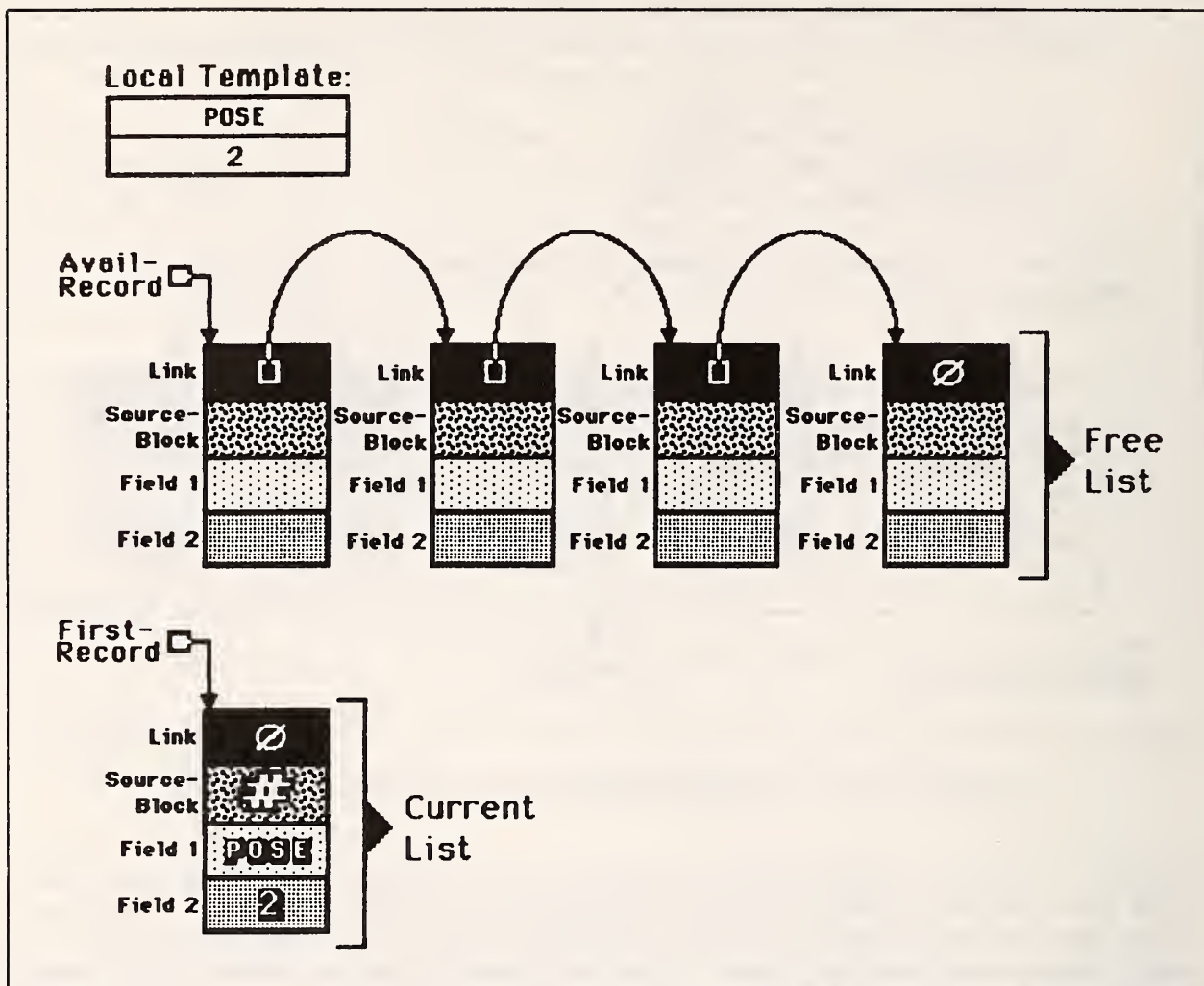
Figure 7-6. SMACRO file after the execution of add-record.

Additional SMACRO Operators

SMACRO includes additional operators that enable you to perform the following types of operations:

- Bit
- I/O
- Stack

- Matrix
- Pose
- Quaternion

- Vector
- Others

The bit, I/O, and stack operators enable you to perform operations similar to those in assembly language. The matrix, pose, quaternion, and vector operators make representing robot positions and movements easier. For the exact syntax of these operators, see Appendix B, "User Word Summary".

Bit operators

Several operators perform bit-wise operations. The operator ^EQ^ performs a bit-wise logical AND of two integer variables, compares the result with the second variable, and returns true if the variables are equal. The operators set-bit-in and zero-bit-in enable you to define a bit mask to set specific bits in a word.

Use the bit operators 1-? and Ø-? in conditionals. The operator 1-? performs a bit-wise logical AND of two integer variables and returns a true value if the result is not Ø. The operator Ø-? takes the complement on the first integer variable and then performs a bit-wise logical AND with the second integer variable. The operator returns a true value if the result is not Ø.

I/O operators

SMACRO includes the in-port and out-port I/O operators. The in-port operator enables you to read a value from the port you specify. The out-port operator enables you to send an integer expression to the port you specify. Use these operators when you want to communicate with sensors in the system.

Stack operators

Stack operators enable you to transfer values to and from the 8Ø86 processor stack. Table 7-9 lists the integer and byte stack operators. (You also can access an internal 8Ø87 stack through assembler code.)

Table 7-9. SMACRO Stack Operators.

Integer Operators	Byte Operators
to-stack	B-to-stack
from-stack	

The to-stack operator stores a variable or the result of a calculation onto the stack. For example:

I1 (+) I2 to-stack	Moves the sum of integers I1 and I2 to the stack.
A2 { x y } to-stack	Moves the element in row x, column y, of integer array A2, to the stack.
B1 B+ B2 B-to-stack	Moves the sum of byte variables B1 and B2 to the stack.

The from-stack operator takes values from the processor stack. You can assign
the values to variables or use the values in calculations. The from-stack
operator must appear on the left side of an assignment. For example:

    from-stack => I1   moves the integer value from the processor
                                stack and stores it in the variable I1.

Matrix, pose, quaternion, and vector operators

RCS uses matrices, poses, quaternions, and vectors, stored as floating point
arrays, to represent robot positions and movements. Most other robot applica-
tions use 4 x 4 homogeneous matrices to represent robot movements. RCS uses
quaternions, which are more efficient. SMACRO includes operators to make vec-
tors, matrices, and quaternions easier to use.

For more information on how to use quaternions in robotics, refer to Robot
Motion: Planning and Control, part of the MIT Press series in artificial
intelligence. You will find specific information for quaternions on pages
240 to 265.

Note: All quaternions in RCS are rotation quaternions with a magnitude of 1
         and a non-negative scalar element. When performing quaternion opera-
         tions, RCS uses the 8086 stack for temporary storage because these
         operations require the use of all 8087 registers.

Therefore, you can nest quaternion operations to a depth limited only by the
size of the 8086 stack. However, because RCS stores all vectors in the 8087
registers, a sequence such as vexp .V+. .(qexp .Q*V. vexp). overflows. On
the other hand, a sequence such as qexp .Q*V. vexp .V+. vexp does not
overflow.

The SMACRO matrix operator words operate on 3 x 3 rotation matrices only.

A pose consists of a quaternion part and a vector part. The quaternion part
is a rotation quaternion. The 8086 stack is used for temporary storage of
poses, so you can nest pose expressions to any depth for which there is enough
space on the stack.

Other SMACRO operators

SMACRO includes many additional operators that perform operations such as cal-
culating trigonometric functions, performing indirect addressing, converting
an integer to a floating point number or a floating point number to an inte-
ger, reading and writing strings from the current input stream, and indexing
arrays. You can also use FORTH operators. The SMACRO word ~F calls a FORTH
word. For a complete list of SMACRO operators, see Appendix B, "User Word
Summary".

SMACRO Statements

SMACRO includes the structured programming statements if, while, repeat, and case. SMACRO also includes an enhanced version of the case statement called a state-table. Using the state-table statement, you can test the state of up to seven variables. If all the variables are equal to the corresponding test variables, then the statement executes the code following that state line.

Table 7-10 presents the syntax for each of the SMACRO statements. Additional statements are in Appendix B.

Table 7-10. Syntax for SMACRO Statements.

Statement Name	Syntax
if	if [Boolean exp] then [code] else [code] endif
while	while [Boolean exp] do [code] end-do
repeat	repeat [code] until [Boolean exp] end-repeat

case	case [ivar1]
	case: [ivar2] [code]
	   . . .
	   . . .
	   . . .
	default: [code]
	end-case

state-table	state-table [state-var1] [state-var2] ... [state-var7]
	state: [test-var1] [test-var2] ... [test-var7] [routineA]
	   . [test-var8] [test-var9] ... [test-var14] [routineB]
	   . . .
	   . . .
	default-state: [default-routine]
	end-state-table

7.3 SMACRO ROUTINES

All SMACRO routines start with the word routine and end with the word
end-routine. Figure 7-7 presents an example SMACRO routine:

```
        BLOCK 8106

   0   $DEF
   1   routine POSE-^ ( - pose name - )
   2     % find record# of named pose
   3     % output:  record# (0 if not found)
   4     POSE-FILE WREAD S=> "pose-name"
   5     first-record => record#
   6     if "pose-name" matches "pose-name"
   7     then endif
   8   end-routine
   9
  10
  11
  12
  13
  14
  15
```

Figure 7-7. Example SMACRO routine.

In SMACRO, routines can be longer than one block. To make a routine longer
than one block, put the additional code that does not fit in the first block
into the next block. Use the screen editor described in Section 6.7, "Editing
a Block of Code", to move existing code to another block. Do not put a vocab-
ulary name in the continuation block.

7.4 MODES

SMACRO words function differently depending on the current mode of RCS. The
three RCS modes are Run, Show, and Locate. To set or change the mode, enter
:R, :S, or :L (or, :r, :s, or :l), respectively. To change modes and
re-execute the most recent word in the new mode, enter \R, \S, or \L (or \r,
\s, or \l). To display the most recent word, enter \N (or \n).

A fourth mode called compile mode, indicated by :C, is used exclusively by the
SMACRO compiler. You see the :C prompt only when an error occurs while a
routine is compiling. Change to one of the other modes to continue.

In Locate mode, entering a SMACRO word lists the source block for that word.
In Run and Show modes, the results of a SMACRO word depend on the type of the
SMACRO word. Table 7-11 lists the results of using SMACRO words in Run and
Show modes.

Table 7-11. SMACRO Words in Run and Show Modes.

SMACRO Word Type	In Run mode	In Show mode
VAR-O, S-VAR-O	Returns the address of the first member on the stack.	Displays all members.
LIST-O	Displays all members.	Displays all members.
iv, bv, fv, 1:a, 1:fa, strv, seqv	Returns the address of the variable to the stack.	Displays the variable name and value.
2:a, 2:fa	Returns the address of the variable to the stack.	Displays the variable name and values, one row per line.
segv	Returns the segment and address of the variable to the stack, leaving the address on the top of the stack.	Displays the name and contents of the data area of the variable, as unsigned 8-bit integers, in hex.
routine	Executes the routine.	Executes the routine.
FILE	Makes the file current.	Makes the file current.

7.5 BOARD LEVEL PROCESSES

RCS executes tasks in the foreground and the background. You run a task in the foreground when you execute a task at the terminal, and when you single-step each control level. You cannot access the terminal or perform any terminal operations from a routine running in the background task.

RSL has one background task per board that runs the control task, named BACK-TASK, for that board. You execute the background task by entering the word BGO. For examples of background tasks and broad level processes, see the RSL application (blocks 8020 through 8049).

7.6 INTERRUPTS AND ASSEMBLY LANGUAGE

You can write interrupt routines by beginning the routine with the word enter-interrupt and ending the routine with the word exit-interrupt. The word ~INTERRUPT sets the specified interrupt vector to point to your interrupt routine.

Figure 7-8 shows how to set up an interrupt routine.

```
 Ø                                                             SDEF
 1        routine   INTERRUPT-SERVICE
 2           %
 3           %
 4           enter-interrupt
 5
 6                (interrupt routine code)
 7
 8           exit-interrupt
 9
10        end-routine
11
12
13
14
15        8 ~INTERRUPT INTERRUPT-SERVICE
```

Figure 7-8.   Setting up an interrupt routine.

To enable the interrupt, you have to install the appropriate jumpers and clear
the interrupt mask in the Programmable Interrupt Controller.   Refer to the
manual and schematics that come with the board for details.   Also be careful
not to disturb any of the interrupts currently implemented in the system.   See
Appendix C, "System Maps", for a list of the interrupts.

If you need to use assembly language code to write an interrupt routine or
another routine, refer to the FORTH documentation for 8Ø86 assembler, and
Appendix E, "8Ø87 Operation Codes For RCS", for 8Ø87 assembler.

In addition to data, RCS can pass command and status information between con-
trol levels. Normal data consists of information such as robot poses, task
descriptions, and relative moves. Command and status information consists of
the control-level inputs and outputs that control task decomposition.

This chapter briefly explains that memory-resident files provide the medium
for data transfer and then describes the communications process provided by
NRS to transfer command and status information between control levels. Fol-
lowing a description of how the communications process works, this chapter
explains how to program the communications process to transfer command and
status information between control levels on different boards and between
control levels on the same board.

8.1 USING MEMORY FILES TO PASS DATA

The different control levels within the system use common memory to pass data
in the form of files. The control levels must implement the protocol to
resolve file read/write conflicts. RSL uses round-robins to resolve these
conflicts.

8.2 USING COMM TO PASS COMMAND AND STATUS INFORMATION

COMM is an RCS utility that provides a communications process for passing com-
mand and status information between control levels. Each control level can
have an input status buffer, an input command buffer, an output status buffer,
and an output command buffer. The output command buffer and the input status
buffer of a control level communicate with the level below. The input command
buffer and the output status buffer communicate with the level above. (See
Figure 8-1.)
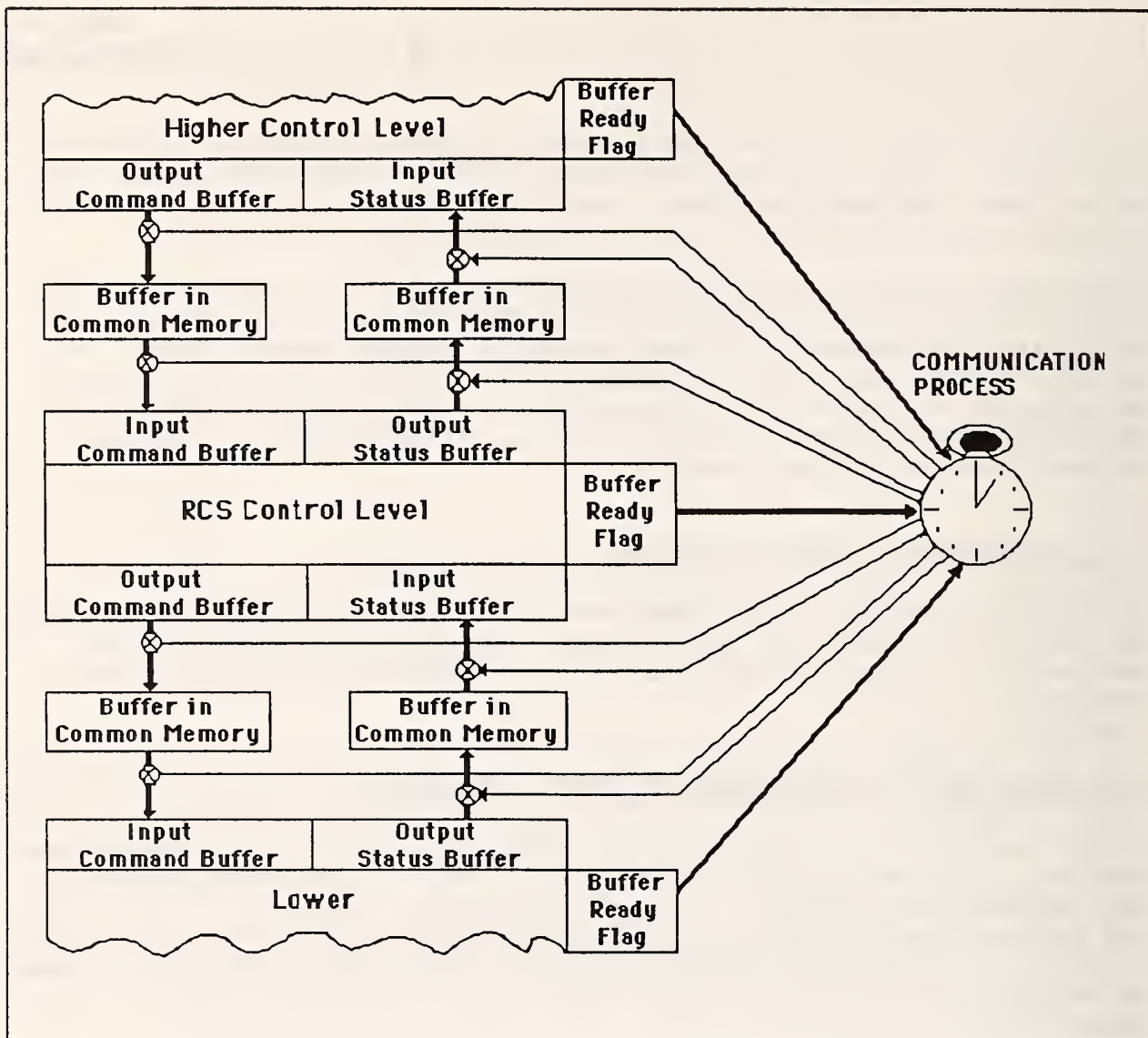
Figure 8-1. Command and status communication paths.

The communications process passes command and status information by moving the contents of the output buffer on one level to the corresponding input buffer on another level. This process operates in cycles to synchronize the flow of command and status information. Communication buffers in common memory enable the communications process to proceed in an asynchronous fashion. That is, these buffers can temporarily store command and status information until the control level is ready to accept it.

The period of the communications cycle is user-defined using a SMACRO variable called control-cycle-#-clks. COMM uses timer 0 to generate the communications cycle period. You can also synchronize the communications cycle to the operations of the robot.

A combination of ready flags on each level and a communications bit on the
bus provide a means of resolving read/write conflicts. See Section 5.4,
"Hardware Installation Procedures", for information on how to use one of the
MULTIBUS interrupt lines as the communications bit.

No other process can execute while the communications bit is set and the com-
munications process is moving the contents of the communication buffers
between control levels. At the beginning of each cycle, the communications
process resets the communications bit. Each level waits for this bit to be
reset before starting execution.

While each level is executing, it sets the variable buffer-ready-f to
not-ready to indicate that its buffers are not ready. When the level finishes
executing, it waits for the system to reset the communications bit (which nor-
mally occurs immediately). Then the level sets buffer-ready-f to ready to
indicate that the buffer is ready.

At the end of each cycle, the communications process sets the communications
bit and moves all ready output buffers to an intermediate buffer in common
memory. It then moves all data from the intermediate buffer to the corre-
sponding input buffer, assuming the input buffer is ready. This protocol
allows levels to overrun the cycle time without affecting communications.

The communications period during which no other process may execute is called
communications dead time. To minimize this dead time, you must restrict
buffers to the smallest possible size.

For example, to minimize the communications dead time, RSL communicates pose
information between levels by passing pointers into a round-robin group of
poses. This technique reduces the required buffer size (and speeds communica-
tion) because the levels communicate only the name of each pose rather than
the information to describe a pose completely.

8.3 PROGRAMMING COMM

The program for the communications process consists of a table of buffer moves
called a communications table. You must first enter the ERASE-COMM-TABLE
statement and then repeat the following two statements for each internal
buffer move desired:

        TRANSFER-FROM [vocabulary] [output buffer]
        TO-DESTINATION [vocabulary] [input buffer]

The ERASE-COMM-TABLE statement clears the contents of the communications
tables on all the boards in the system. The TRANSFER-FROM statement selects
the output buffer from which to send command and status information. The
TO-DESTINATION statement selects the corresponding input buffer that is to
receive the command and status information.

Each vocabulary specified with TRANSFER-FROM or TO-DESTINATION must include a
semaphore variable named buffer-ready-f, which COMM uses to synchronize com-
munications. Thus, each vocabulary actually has its own buffer-ready-f rather
than a flag for each buffer. The communications process determines the

address of this variable when it compiles the communications table. If you compile the communications table and this variable is missing, RCS returns the "no buffer-ready-f" message.

8.4 COMMUNICATING ON THE SAME BOARD

Two processes running on the same processor board do not need the communications process to resolve read/write conflicts. Processes running on the same processor board can use the S=> SMACRO operator.

For example, in RSL you can use the following two statements to move the contents of TASK's output command buffer to PATH's input-status-buffer:

    TASK path-command-var PATH S=> input-command-var
    PATH output-status-var TASK S=> path-status-var

This chapter describes the Robot Sensor Language (RSL), an example of a real-time application that NBS developed within the RCS environment. RSL is a high-level, task description language designed for programming robotic tasks, in which the control system, RCS, uses sensors to control the robot. This chapter defines RSL, describes RSL syntax, and gives procedures for entering, editing, and executing RSL code.

9.1 WHAT IS RSL?

RSL is a data-driven, semi-interpreted, user-extensible language that supports user-designed sensors, hierarchical task decomposition, and real-time execution. RSL is extensible; you can add a new sensor to a robot, and then extend RSL, enabling you to program robot tasks that use the new sensor.

RSL consists of two main programming structures: data and algorithms. Data is information about the robot environment such as the name, size, or location of an object. Robot sensors supply data to RSL, or you may enter the data directly from the keyboard.

An algorithm is the RSL code you use to accomplish a task. RSL compiles algorithms into a linked-list representation. Then the RSL control levels interpret the algorithm, using environmental data to command the robot to execute a task.

RSL decomposes tasks hierarchically, from the top down, using the RCS methods of cyclic execution, task decomposition, and control levels described in Chapter 2, "RCS Overview", and Chapter 3, "RCS Architecture". The four RSL-specific control levels are: TASK, PATH, PRIM, and JOINT, as shown in Figure 9-1.

```
                        User
                         │
                         ▼
                  ┌───────────────┐
                  │     Task      │
                  └───────────────┘
                         ▲│
                         │▼
                  ┌───────────────┐
                  │     Path      │
                  └───────────────┘
                         ▲│
                         │▼
                  ┌───────────────┐
                  │     Prim      │
                  └───────────────┘
                         ▲│
                         │▼
                  ┌───────────────┐
                  │     Joint     │
                  └───────────────┘
                         │
                         ▼
                       Robot
```
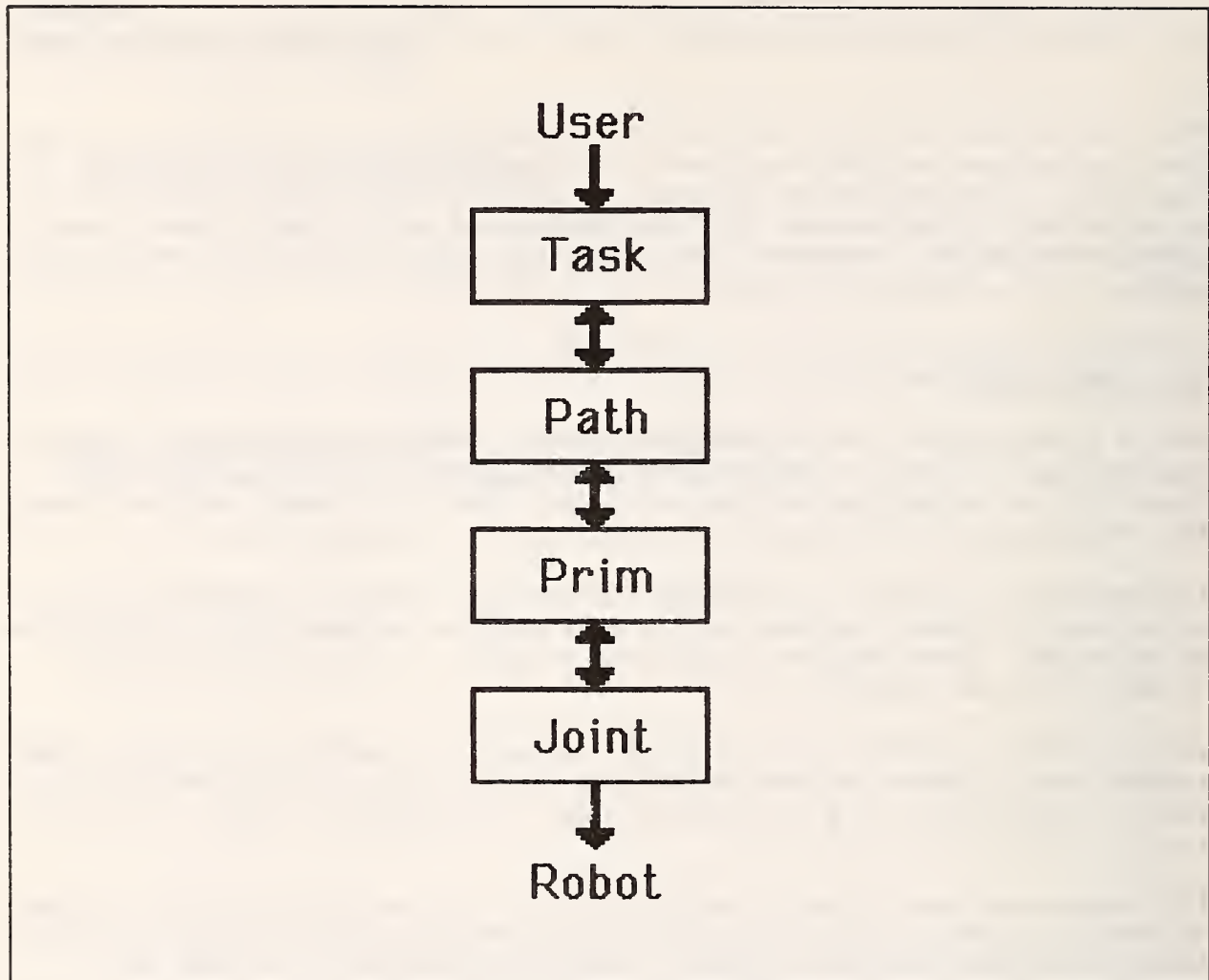
Figure 9-1. RSL control levels.

The code in these control levels defines the types of tasks that you can
accomplish with RSL. You define tasks by writing algorithms, which define how
to accomplish the task. The algorithms include operations such as transfer-
ring parts from a tray to a buffer or loading tools into a machining center.
These algorithms become the input for the RSL control levels.

The TASK level decomposes all tasks into a sequence of path types. The path
type and parameters of the current task identify the specific path to execute.
RSL defines the path types: move-to, approach-pickup, depart-pickup,
approach-release, and depart-release. You can define additional path types as
you need them. A path algorithm specifies a simple path such as moving
between locations or grasping objects. The specific path becomes the input
for the PATH level.

The PATH level decomposes paths into a sequence of path-points. Each path-point consists of a single motion or sensor command. A path-point command performs operations, such as initiating a motion that a sensor condition terminates. You must define additional commands for each type of motion and sensor combination you need. The PATH level further decomposes the path-points into a sequence of trajectories, which become the input for the PRIM level.

The PRIM level decomposes trajectories into a sequence of intermediate points. A trajectory consists of a goal point and parameters describing the path to the goal point. RSL defines the straight-line Cartesian trajectory types and the joint-interpolated trajectory type. The intermediate points become the input for the JOINT level.

The JOINT level transforms intermediate points from Cartesian space to joint space. The joint values are sent to the servo controls in the manufacturer's robot controller.

Note: Keep in mind the different kinds of code in RSL. RSL contains data, such as the name of an object; algorithms, consisting of paths, path-points and trajectories, such as the RSL steps to accomplish a transfer task; and SMACRO code that defines the control levels.

9.2 RSL OVERVIEW

This section describes the syntax of RSL statements. See Appendix B, "User Word Summary", for the exact syntax of each RSL statement. The section also includes some example RSL code.

The Pose Statement

The pose statement, -pose-, defines a position, or the physical location, of the robot. A pose consists of a translation, represented by a vector, and a rotation, represented by a quaternion. The translation and rotation give the tool frame relative to the base frame of the robot.

With a six-axis robot, you may need to use up to three robot arm configuration flags to resolve the ambiguities of the inverse transform operation that transforms a pose into joint angles. These flags depend on the robot you use and the interface between RCS and the manufacturer's robot controller.

You may enter poses directly from the keyboard; or you may position the robot with a joystick or sensor-based algorithm and then record the pose. For information on how to enter a pose, see Section 9.3, "Entering and Editing RSL Source Code", later in this chapter.

The Movetable Statements

A movetable defines relative positions, using a combination of rotations and translations. That is, a movetable defines a coordinate transform. Adding a movetable to an existing pose produces a new location.

For example, if you define a pose at one corner of a table, you can define the other three corners of the table using movetables. If you want to reposition the table, you have to update only one pose--the movetables do the rest.

Defining a movetable requires several RSL statements such as -mtb-, ---, and -mtb-end-. Each transform line, ---, specifies either a vector translation or a rotation. You can also define a movetable that is the exact inverse of another movetable using the -imtb- statement.

The Location Statement

The location statement, -loc-, defines a location as the combination of a pose and a movetable. Locations may be goal points, or the origin of a coordinate frame in which to define motions. RSL adds the movetable and the pose just before the control system needs the result, enabling you to modify the data structures in real time. You can fine-tune a recorded pose by defining a movetable without using the robot. Also, you can define several related locations in terms of the same pose, so that RSL redefines the locations when it redefines the pose.

The Array Statement

Arrays may be one-, two-, or three-dimensional. The statement -arr- defines an array. The origin of an array is a location. A movetable specifies the displacement from one sector to the next sector along each dimension of the array. A sector is an element of an array. Use arrays to make palletizing operations easier.

The Object Statement

The object statement, -obj-, defines an object that consists of the object name and a list of grip numbers and movetables. The grip numbers define different orientations for gripping the object. RSL finds the grip orientation by adding the movetable to the object frame. Note that you may never refer to an object without a grip number.

The Path Statements

A path is an algorithm for performing simple tasks such as moving between locations or grasping an object. The path algorithm may be a simple path in space that guarantees no collisions, or the path may be more complex, requiring sensor input to help locate an object. Paths consist of a sequence of steps called path-points.

The path statement syntax has two parts: the path statement and a sequence of path-point lines. The statement -path- defines the type and goal of the path; the -ppt- lines give the sequence of steps in the algorithm.

The path type identifies the intended purpose of the path. RSL provides five path types: move-to, approach-pickup, depart-pickup, approach-release, and depart-release. You may define other path types, using these types as models. The rest of this section describes each of these five types of paths:

● The move-to path specifies how to move the robot quickly while it is carrying an object from near the starting location to near the destination location. The approach and depart paths handle slower movement closer to the starting and destination locations.

● The approach-pickup path specifies how to move the robot, with an empty end effector, toward an object at the goal location. The approach-pickup path starts from a safe location near the goal and stops at the goal location.

● The depart-pickup path specifies how to move the robot to pick up an object at a goal location. The depart-pickup path starts at the goal location and stops at a safe nearby location while the robot grasps the object.

● The approach-release path specifies how to move the robot while it is grasping an object. The approach-release path starts at a safe location near the goal and stops at the goal location.

● The depart-release path specifies how to move the robot at a goal location to release an object. The depart-release path starts at the goal location and stops at a safe nearby location, leaving the object at the goal location.

The Path-Point Statement

Each path-point consists of a single command. Typically, the commands initiate a motion, which a sensor condition terminates. The structure of the path-points depends heavily on the specific sensors and applications you are using. In general, path-points consist of a command phrase, a location phrase, and a trajectory phrase, although you may define other structures.

The command phrase gives the motion type, and specifies the sensor condition that terminates the motion. The location phrase specifies a location that RSL uses in one of two ways: as an intermediate goal point, or as a coordinate frame with translation along or rotation about an axis. The trajectory phrase specifies the trajectory type (Cartesian straight-line or joint interpolated) and the parameters (acceleration, maximum velocity, and neighborhood) RSL uses during execution of the path-point.

RSL provides only the goto path-point. The goto path-point specifies a motion of the robot to be a goal location using either straight-line Cartesian or joint-interpolated trajectories. You can add other path-points.

The Round-Robin Statement

The round-robin statement defines a round-robin or a circular list in a file.
RSL uses round-robins to pass information between control levels. When one
control level writes a record to the next lower control level, the lower level
reads the record previously written. For a more detailed explanation of
round-robins, see Section 10.2, "RSL Data Structures" in Chapter 10.

Example RSL Code

This section gives some simple examples of RSL code, and explains what each
example does.

```
-pose - TABLE 0.04361    0.999     0.0005033     0.00166
              -39.83     -8.702    0.0216
              1.0        1.0       -1.0
```

This code defines a pose named TABLE. The first four numbers give the orien-
tation expressed as a quaternion. The next three give the position expressed
as a Cartesian vector. The last three give the arm configuration. (For a
PUMA 760, the arm configuration is lefty, elbow up, wrist flipped.) This pose
defines the position and orientation of a table.

```
-mtb- CORNER
  --- t-tool 20.0    0.0    0.0
-mtb-end-

-mtb- TABLE-SAFE
  --- t-tool 10.0    15.0   10.0
  --- r-tool Z       20.0
-mtb-end-

-mtb- UP5
  --- t-tool 0.0     0.0    5.0
-mtb-end-
```

This code defines three movables, intended for use with the TABLE pose. The
first movable defines a corner of the table. The TABLE pose is at one
corner of the table, with the x axis along one edge, the y axis along the
other edge, and z up. CORNER is 20 inches away along the x axis. TABLE-SAFE
is a point above the center of the table that is a pass-through point for
motions to and from the table. The point is rotated 20 degrees about the z
axis. UP5 is a point 5 inches up along the z axis. It defines an intermedi-
ate point for moving to points on the table.

```
-loc- TABLE    TABLE   nul

-loc- CORNER   TABLE   CORNER

-loc- TABLE-SAFE  TABLE  TABLE-SAFE
```

This code defines locations. Locations are always the sum of a pose and a
movetable. They are used in paths and path-points (poses cannot be used
directly). These four locations associate the movetables defined above with
the TABLE pose, indicating the appropriate positions and orientations for the
table.

```
-path- approach-pickup nul  loc CORNER
   -ppt- goto loc TABLE_SAFE joint 10.0  40.0  20.0
   -ppt- goto goal UP5   cart  0.03  0.03  1.0
                              0.25  1.5   6.0
   -ppt- goto goal nul   cart  0.03  0.10  0.0
                              0.25  0.5   0.0
```

This code defines a path used for moving to the corner of the table. The
first path-point moves towards the location TABLE-SAFE (above the middle of
the table). The trajectory is joint-interpolated, with acceleration limited
to 10 percent of maximum and velocity limited to 40 percent of maximum. When
all joints are within 20 degrees of the TABLE-SAFE location, the system steps
to the next path-point.

The second path-point goes towards the intermediate goal defined by the loca-
tion CORNER, plus the movetable UP5. Thus, the intermediate goal is TABLE +
CORNER + UP5, or 5 inches above the corner of the table. The motion is a Car-
tesian straight line. For information on the velocity and acceleration param-
eters, see Appendix B, "User Word Summary". The second path-point is complete
when the tool-point is within 1.0 inch and 6.0 degrees of the intermediate
goal. The last path-point moves to the goal TABLE + CORNER and stops there.

9.3 ENTERING AND EDITING RSL SOURCE CODE

When you build a new application or change the data for an existing applica-
tion, you need to enter or edit RSL source code. To enter new source code,
type the data into a block using the RCS screen editor, described in Section
6.7, "Editing a Block of Code". Also use the screen editor to edit existing
source code.

You can enter new robot poses by using the joystick to position the robot.
Then enter RECORD-POSE [pose-name]. RECORD-POSE stores the current robot
position in the pose with the specified pose-name. RECORD-POSE creates a new
pose record if the pose-name is not already defined.

You can also enter the pose directly into a block by specifying the block num-
ber, the line number, and the name of the pose. For example, to enter SECTOR
into block 23, line 5, enter 23 5 TYPE-POSE SECTOR. TYPE-POSE enters the pose
into the block beginning at the line specified.

9.4 COMPILING RSL SOURCE CODE

Like SMACRO code, you compile RSL code by loading the blocks containing the
source code. The compiling words in RSL compile the code into a linked list
representation in common memory files. Like SMACRO code, you can recompile
all RSL code; you may edit and recompile any piece of code, and any other code
that uses it will use the new version.

Unlike SMACRO, RSL has garbage collection; a path may be recompiled several
times without wasting any space in the files. Other named data structures
have no garbage collection; you cannot remove a pose, for example. Thus, you
may run out of space if you keep defining more and more data structures such
as poses and locations. To avoid running out of space, restore the system to
a clean state and recompile all the RSL source code.

Recompiling code is easier with RSL than with SMACRO; to restore the system to
a clean state, you simply reinitialize all the files using ˜re-init-file
(rather than using D>M and RESTORE on several boards). Block 990 on RSL is
set up to do this restoration, as well as reload the RSL code. (You must edit
block 994 and your directory blocks to be sure all of your code is loaded.)
Note that the control system must not be running the robot when the RSL code
is completely reloaded; 990 executes HALT to guarantee that the robot is not
running. Small pieces of code may be loaded with the control system running,
as long as the control system is not actually using that code. To be safe,
HALT the system before loading RSL code.

If you run out of file space (indicated by a "FILE FULL" message), but do not
have extra code loaded, you can increase the number of records allotted to
each file by editing the file declaration (in the 100 block section on the RSL
board). You must recompile the SMACRO code for all levels and the RSL code
for this change to take effect. You may run out of the common memory space
allotted to files; type F-MEM to display the amount of memory left. To change
the allocation of common memory, edit absolute block 1402 and reload the base
and application code.

In general, RSL checks for errors and gives appropriate error messages. (The
appendices of this manual do not list these messages.) If you get an error
message, simply edit the block to correct the error, then reload the code.
You do not have to use the RESTORE or D>M commands to fix errors with RSL.

When you load block 990 on RSL, it reloads the initialization blocks for each
level after compiling all the RSL source code. This is done because the
levels use several reserved records in RSL (mainly the round-robins) and must
look up record numbers, which may have changed as a result of recompilation.

9.5 EXECUTING RSL COMMANDS

To execute RSL commands, you load a block containing a command for the TASK
level. For example, move to the TASK&PATH board and use the directory block
structure to locate the TRANSFER command. Listing block 0 shows that user
commands are defined in the 900 section. Listing block 900 shows that the
input commands for the task level are in the 910 section. Listing block 910
shows that the TRANSFER command is in block 913.

Load block 913. RCS executes the TRANSFER command specified in block 913. You can also execute the TRANSFER in Show mode, in which case RSL displays the status-report, status-arg-out, and joint angles for each level as the robot executes the transfer.

To see the status of the command being executed, load block 928 on RSL. This block displays the status-report and status-arg-out variables for each level. A status-report of 0 means the command is executing, of 1 means the command is done, and of 2 means an error occurred. The status-arg-out variable gives the error types. (Refer to Chapter 10, "RSL Control Levels", for a description of these errors.) Alternatively, you can display the variable error-list, the owner of the error-report variables, on each level.

To issue another command, simply load another block. Blocks 910 through 979 on TASK are available for user commands. Most RSL commands are interruptible. If you issue a new command, the old command aborts and the new command starts executing. To suspend and then resume command execution, press the HOLD-SET button on the joystick. The HOLD-SET button causes the robot to stop moving and command execution to be suspended. To resume execution, press the HOLD-CLEAR button.

Note that the GO and HALT commands are not commands to the control system. The GO and HALT commands start and stop the control system.

The first three sections of this chapter provide an overview of RSL and describe the RSL data structures and compiler. The last four sections describe TASK, PATH, PRIM, and JOINT, the four hierarchical control levels that make up RSL. These control levels decompose each task you enter at the keyboard into a series of primitive commands that a robot can execute to accomplish a task. The sections describe the function of each control level and provide command descriptions, status information, variable descriptions, control-level routine descriptions, and a discussion of the error conditions for each control level.

10.1 OVERVIEW OF RSL CONTROL LEVELS

The RSL system contains five main segments of code: the RSL compiler and the four control levels TASK, PATH, PRIM, and JOINT. Each segment has its own vocabulary. This chapter refers to segments by using the vocabulary name for each segment. (The context of the discussions distinguishes RSL as the whole system from RSL as the compiler.)

Figure 10-1 gives an overview of the relationships between RSL and the control levels.
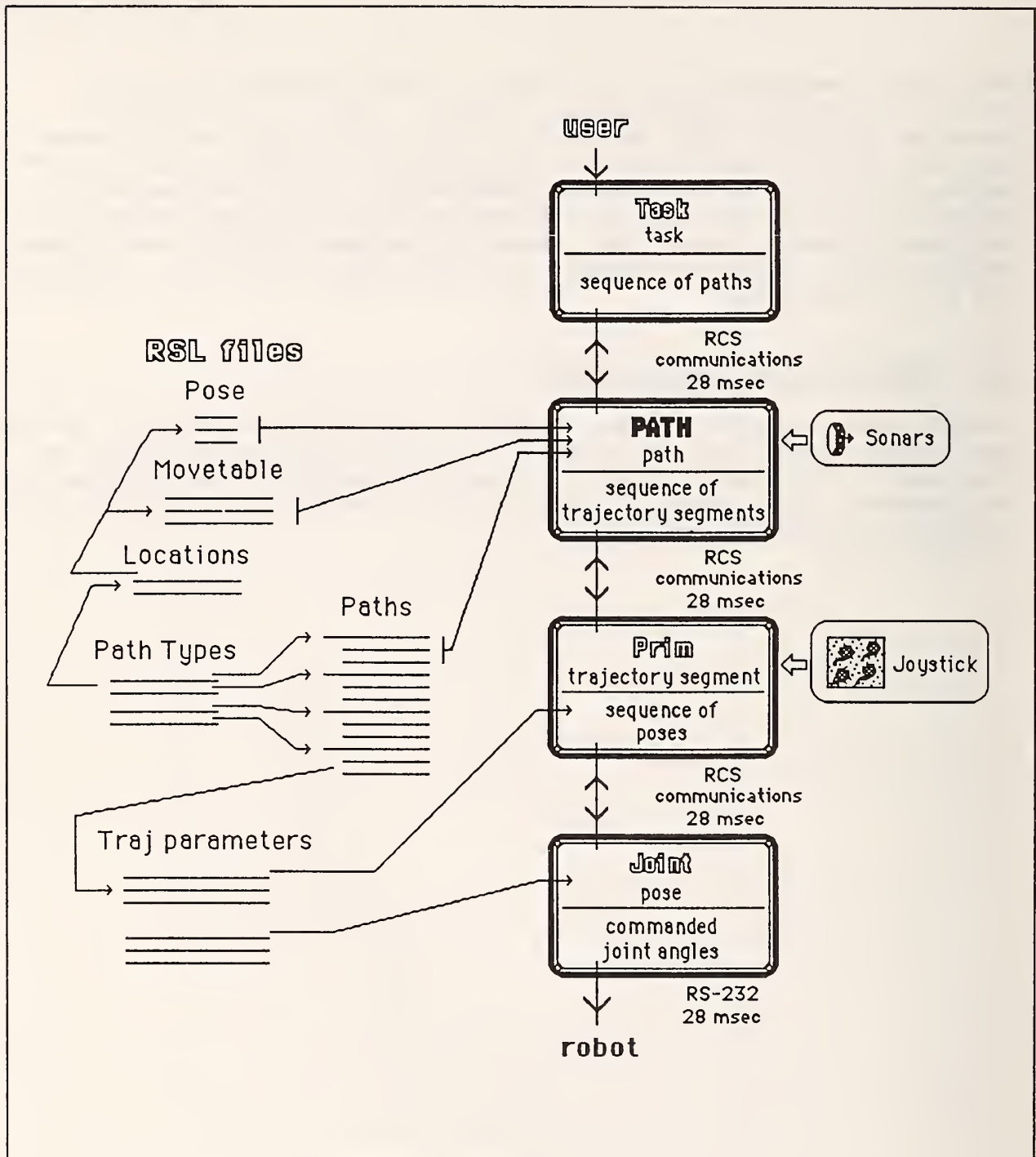
Figure 10-1. RSL files and control levels.

RSL compiles environmental data and algorithms into files in common memory. The control levels use the files to execute commands. The TASK level decomposes user commands into a series of paths. The PATH level decomposes those

paths into path-points and then into trajectories. The PRIM level executes
Cartesian trajectories, by sending a new pose to the JOINT level every cycle.
The JOINT level transforms the poses to joint values, and sends them to the
servo controls in the manufacturer's robot controller. For joint trajecto-
ries, PRIM sends the command to JOINT, which executes it, sending new joint
values to the servo mechanisms every cycle.

The rest of this chapter gives an introductory description of the source code
for all five segments and describes the RSL data structures. The source code
descriptions introduce you to the overall structure of RSL code.

The descriptions of individual routines are not exact translations of the
SMACRO code into English. Rather, they describe the functions of the rou-
tines. When you understand the descriptions in this chapter, you should be
able to understand the source code without the functional descriptions.

The internal structures of the four control levels are similar, but they are
not exactly the same. Each section of this chapter begins with a description
of the input commands and status feedback for the level, followed by an over-
view of the level's structure, the preprocess routines, the command-process
routines, and the postprocess routines.

Note that when a variable owner is given as an input or output for a routine,
the members of the owner are the actual inputs and outputs.

The command descriptions include the command syntax. Commands to the TASK
level are different from those to the other levels. The TASK input is an
ASCII string; the other levels accept numerical data. The user never gives
commands directly to the lower levels, only to the TASK level. So the TASK
level needs to be very flexible and user-friendly. The lower levels have less
flexible inputs and use fixed record descriptions. Thus, the syntax descrip-
tions for the lower levels only indicate which of the fields in the input com-
mand record are actually used by that command.

The command syntax shows parameter names enclosed in square brackets. When
you enter the commands, separate the parameters with spaces.

10.2   RSL DATA STRUCTURES

RSL represents data structures and algorithms as a linked list of records,
kept in files in common memory. These files are the user files described in
earlier chapters of this manual. The data within these files resides in the
user file portion of common memory.

Typically, the records contain pointers to other files, numeric data, and
names. For linear displacement values, the unit of measurement is inches.
For angles, the unit of measurement is degrees. Internally, RSL represents
angles as radians. Names in RSL can have up to 15 ASCII characters, excluding
spaces.

RCS provides each file with a free list of records for garbage collection, and
SMACRO file operators to maintain the free list.

The following sections explain the RSL data structures: pose, movetable, location, array, object, path, path-point, trajectory, and round-robin. Each section describes the record structure of a file for the RSL data structure type. RSL uses the RCS language SMACRO to define the data files. SMACRO provides the linked-list programming structure used for RSL files. A SMACRO variable owner defines the record, with each member of the owner defining a field in the record. The SMACRO file declaration specifies the maximum number of records allowed in the file. You may change this number to fit the size of your application.

The Pose Data Structure

The pose file in common memory has the following structure:

```
55 bytes VAR-0 pose-rec
    15 strv "pose-name"
    7 1:fa  pose
    3 1:fa  conf-flag

50 rec FILE POSE-FILE
```

where:

● "pose-name" contains the name of the pose.

● pose contains the seven numbers giving the rotation quaternion and the translation vector for the pose.

● conf-flag contains the three robot arm configuration flags.

The pose file is a single linked list. When you define a new pose, RSL adds the pose to the end of the list. RSL does not include a provision for removing poses. When you reload the source code for a pose, RSL updates all the fields.

The Movetable Data Structure

The movetable file in common memory has the following structure:

```
127 bytes VAR-0 mtb-rec
    15 strv "mtb-name"
    iv 1st-line-type 3 1:fa 1st-line-para
    iv 2nd-line-type 3 1:fa 2nd-line-para
    iv 3rd-line-type 3 1:fa 3rd-line-para
    iv 4th-line-type 3 1:fa 4th-line-para
    iv 5th-line-type 3 1:fa 5th-line-para
    iv 6th-line-type 3 1:fa 6th-line-para
    iv 7th-line-type 3 1:fa 7th-line-para
    iv 8th-line-type 3 1:fa 8th-line-para

100 rec FILE MOVETABLE-FILE
```

where:

- "mtb-name" contains the name of the movetable.

- 1st-line-type through 8th-line-para contain the lines of the movetable. The first integer in each line contains a code number that identifies the line type, and the next three floating-point numbers contain the parameters for that type of line. Some line types require less than three parameters. (A movetable may contain up to eight lines.) Table 10-1 lists the line types and parameters.

    Note: The line types given in Table 10.1 are used for the internal representation only and are not the same as the line types in the syntax for defining movetables.

Table 10-1. Movetable Line Types.

Code	Line Type	Parameters
0	nul	none.
1	tool-trn	x, y, z components of the vector in the tool frame.
2	base-trn	x, y, z components of the vector in the base frame.
3	tool-rotx	sine and cosine of half the angle about the x axis of the tool frame.
4	tool-roty	sine and cosine of half the angle about the y axis of the tool frame.
5	tool-rotz	sine and cosine of half the angle about the z axis of the tool frame.

The movetable file is a single linked list. When you define a new movetable, RSL adds the movetable to the end of the list. RSL does not include a provision for removing movetables. When you reload the source code for a movetable, RSL updates all the fields.

The Location Data Structure

The location file in common memory has the following structure:

```
19 bytes VAR-O loc-rec
   15 strv "loc-name"
   iv       loc-pose-^
   iv       loc-mtb-^

20 rec FILE LOCATION-FILE
```

where:

- **"loc-name"** contains the name of the location.

- **loc-pose-^** contains a pointer to the pose for "loc-name" in the POSE-FILE. RSL sets the pointer when it defines the location.

- **loc-mtb-^** contains a pointer to the movetable for "loc-name" in the MOVETABLE-FILE. RSL sets the pointer when it defines the location.

The location file is a single linked list. When you define a new location, RSL adds the location to the end of the list. RSL does not include a provision for removing locations. When you reload the source code for a location, RSL updates all the fields.

The Array Data Structure

The array file in common memory has the following structure:

```
88 bytes VAR-0 arr-rec
   10 strv "arr-name"
   iv       base-loc-^
   iv       x-#-sectors
   iv       y-#-sectors
   iv       z-#-sectors
   iv       #-sectors
   iv       x-mtb-^
   iv       y-mtb-^
   iv       z-mtb-^
   20 1:a  sector-list
   iv       arr-pose-^

10 rec FILE ARRAY-FILE
```

where:

- **"arr-name"** contains the name of the array.

- **base-loc-^** contains a pointer to the location in LOCATION-FILE that is the origin of the array.

- **x-#-sectors**, **y-#-sectors**, and **z-#-sectors** contain the number of sectors along the x, y, and z axes of the location frame.

- **#-sectors** contains the total number of sectors.

- **x-mtb-^**, **y-mtb-^**, and **z-mtb-^** contain pointers to the movetables in MOVETABLE-FILE for the displacement from one sector to the next sector along the respective axes of the location frame. The movetables should have only lines of type tool-trn.

- sector-list contains a list of sectors giving the order in which RSL loads or unloads the array.

- arr-pose-^ contains a pointer to the pose that gives the position of the current sector during loading or unloading.

All fields, except sector-list, are set when RSL defines the array. TASK sets the field sector-list when it receives a TRANSFER command to load or unload the array.

RSL reserves a pose record for arr-pose-^ when you declare the array. TASK calculates the value of the pose from the base location and sector movetables at the beginning of execution of a path involving the sector as the source or destination.

RSL numbers sectors starting at the origin of the location frame, sector 0. Then it increments along the x, y, and z axes of the location frame, incrementing x first, y second, and z third.

The array file is a single linked list. When you define a new array, RSL adds the array to the end of the list. RSL does not include a provision for removing arrays. When you reload the source code for an array, RSL updates all the fields, clearing the sector-list.

The Object Data Structure

The object files in common memory have the following structure:

```
17 bytes VAR-O obj-name-rec
   15 strv "obj-name"
   iv      obj-grip-L-^

5 rec FILE OBJ-NAME-FILE

4 bytes VAR-O obj-grip-rec
   iv    grip#
   iv    grip-mtb-^

20 rec FILE OBJ-GRIP-FILE
```

where:

- "obj-name" contains the name of the object.

- obj-grip-L-^ contains a pointer to a list of the grips for each object in OBJ-GRIP-FILE.

- grip# contains the grip number of the object.

- grip-mtb-^ contains a pointer to a movetable that defines the grip in MOVETABLE-FILE.

Typically, grip 1 has a nul movetable and RSL defines other grips relative to grip 1.

OBJ-NAME-FILE contains a linked list of all object names. OBJ-GRIP-FILE contains a list for each object. RSL does not include a provision for removing objects or object grips. When you reload the source code that defines a grip definition, RSL updates the field grip-mtb-^ and preserves all other fields.

The Path Data Structure

The central path file in common memory is the PATH-POINT-FILE. The PATH-POINT-FILE has the following structure:

```
4 bytes VAR-O ppt-rec
    iv    ppt-command
    iv    ppt-para^

100 rec FILE PATH-POINT-FILE
```

where:

● ppt-command contains the path-point command.

● ppt-para^ contains a pointer to the command parameter file.

The path-point file contains one list for each defined path. RSL does not include a provision for removing paths. When you reload a path, RSL returns the current list for that path to the free list and creates a new list. RSL also returns the associated records in the command parameter file to their free lists and creates new lists as needed. You may redefine paths as often as you like without wasting file space.

Each path-point command has one command parameter file. This file contains any parameters related to the path-point. RSL provides only the goto path-point, and thus, only the GOTO-FILE command parameter file.

The move-to path type

The move-to file in common memory has the following structure:

```
12 bytes VAR-O move-to-rec
    iv     move-to-obj-^
    iv     move-to-start-type
    iv     move-to-start-^
    iv     move-to-dest-type
    iv     move-to-dest-^
    iv     move-to-path-^

40 mem FILE MOVE-TO-FILE
```

where:

- **move-to-obj-^** contains a pointer to the object grip record in OBJ-GRIP-FILE.

- **move-to-start-type** contains the starting location type. The location type must be either loc or arr.

- **move-to-start-^** contains a pointer to the starting location in LOCATION-FILE or ARRAY-FILE.

- **move-to-dest-type** contains the destination location type (loc or arr).

- **move-to-dest-^** contains a pointer to the destination.

- **move-to-path-^** contains a pointer to the path in the PATH-POINT-FILE.

The move-to file is a single linked list. A new record is added to this file when a move-to path for a new object/start location/destination is defined. RSL does not include a provision for removing paths. When you reload a move-to path, RSL updates the field move-to-path-^ to point to the new path.

The structures of the other path types are similar to the structure of move-to. Because of the similarity, the following sections give the structure of the path type records without a complete description.

The approach-pickup path type

The approach-pickup file in common memory has the following structure:

```
8 bytes VAR-O approach-pickup-rec
    iv    appr-pick-loc-type
    iv    appr-pick-loc-^
    iv    appr-pick-obj-^
    iv    appr-pick-path-^

40 mem FILE APPROACH-PICKUP-FILE
```

The depart-pickup path type

The depart-pickup file in common memory has the following structure:

```
8 bytes VAR-O depart-pickup-file
    iv    dept-pick-loc-type
    iv    dept-pick-loc-^
    iv    dept-pick-obj-^
    iv    dept-pick-path-^

40 mem FILE DEPART-PICKUP-FILE
```

The approach-release path type

The approach-release file in common memory has the following structure:

```
8 bytes VAR-O approach-release-rec
    iv   appr-rel-loc-type
    iv   appr-rel-loc-^
    iv   appr-rel-obj-^
    iv   appr-rel-path-^

40 mem FILE APPROACH-RELEASE-FILE
```


The depart-release path type

The depart-release file in common memory has the following structure:

```
8 bytes VAR-O depart-release-file
    iv   dept-rel-loc-type
    iv   dept-rel-loc-^
    iv   dept-rel-obj-^
    iv   dept-rel-path-^

40 mem FILE DEPART-RELEASE-FILE
```


The Path-Point Data Structure

The goto file in common memory has the following structure:

```
8 bytes VAR-O goto-rec
    iv   goto-loc-type
    iv   goto-loc-^
    iv   goto-traj-type
    iv   goto-traj-^

100 rec FILE GOTO-FILE
```

where:

• goto-loc-type contains the type of location.

• goto-loc-^ contains a pointer to the location.

• goto-traj-type contains the trajectory type: cart or joint.

• goto-traj-^ contains a pointer to the trajectory parameters in
  CARTESIAN-FILE or JOINT-FILE.

The goto file is a single linked list. When you define a goto path-point, RSL
adds the goto path-point to the end of the list. RSL removes the goto path-
point whenever a path containing goto path-points is deleted as part of
redefinition.

The Trajectory Data Structure

The files for the Cartesian and joint trajectory types in common memory have
the following structure:

```
24 bytes VAR-O cart-rec
    fv    amax
    fv    vmax
    fv    trn-nbrhd
    fv    gmax
    fv    wmax
    fv    rot-nbrhd

100 rec FILE CARTESIAN-FILE
```

where:

- **amax** contains the maximum allowed magnitude of the translational accelera-
  tion, in inches per cycle per cycle.

- **vmax** contains the maximum allowed magnitude of the translational velocity,
  in inches per cycle.

- **trn-nbrhd** contains the translational distance in inches from the current
  goal location at which the trajectory routine reports done.

- **gmax** contains the maximum allowed magnitude of the rotational acceleration,
  in degrees per cycle per cycle.

- **wmax** contains the maximum allowed magnitude of the rotational velocity, in
  degrees per cycle.

- **rot-nbrhd** contains the rotation neighborhood, the rotational distance in
  degrees from the current goal location at which the trajectory routine
  reports done.

```
12 bytes VAR-O joint-rec
    fv    j-acc
    fv    j-vel
    fv    j-delta

100 rec FILE JOINT-FILE
```

where:

- **j-acc** contains the maximum allowed acceleration of any joint, given as the
  percentage (between 0 and 100) of the hardware maximum for each joint.

- **j-vel** contains the maximum allowed velocity of any joint, given as the per-
  centage (between 0 and 100) of the hardware maximum for each joint.

- **j-delta** contains the difference in degrees from the location joint values at which the trajectory routine reports done. When the trajectory reports done, all joint values are within this delta.

Each file is structured as a single linked list. RSL adds records to the appropriate list whenever a path-point is defined. RSL removes records whenever a path-point containing the trajectory is deleted as part of a path redefinition.

The Round-Robin Data Structure

A round-robin is a circular list in a file, called the containing file. Use round-robins to store information temporarily. For example, if you are using a slow sensor, such as a vision sensor that may require up to 15 cycles to take a reading, use a round-robin to store robot poses for the previous 15 cycles. This technique enables the sensor to access the position of the robot at every cycle since the sensor started the reading.

RSL also uses round-robins to pass information between control levels. When one control level writes a record to the next lower level, the lower level reads the record written previously.

As illustrated in Figure 10-2, for example, in cycle 1 PATH writes the goal pose to record 1 and puts the pointer in goal-pose-^-out. Also in cycle 1, PRIM reads the pose from record 3 (put there by PATH in the last cycle). This pose is pointed to by goal-pose-^-in. After cycle 1, COMM moves PATH's output command buffer (containing goal-pose-^-out) to PRIM's input command buffer (containing goal-pose-^-in). Then in cycle 2, PATH writes the goal pose to record 2 and PRIM reads from record 1.
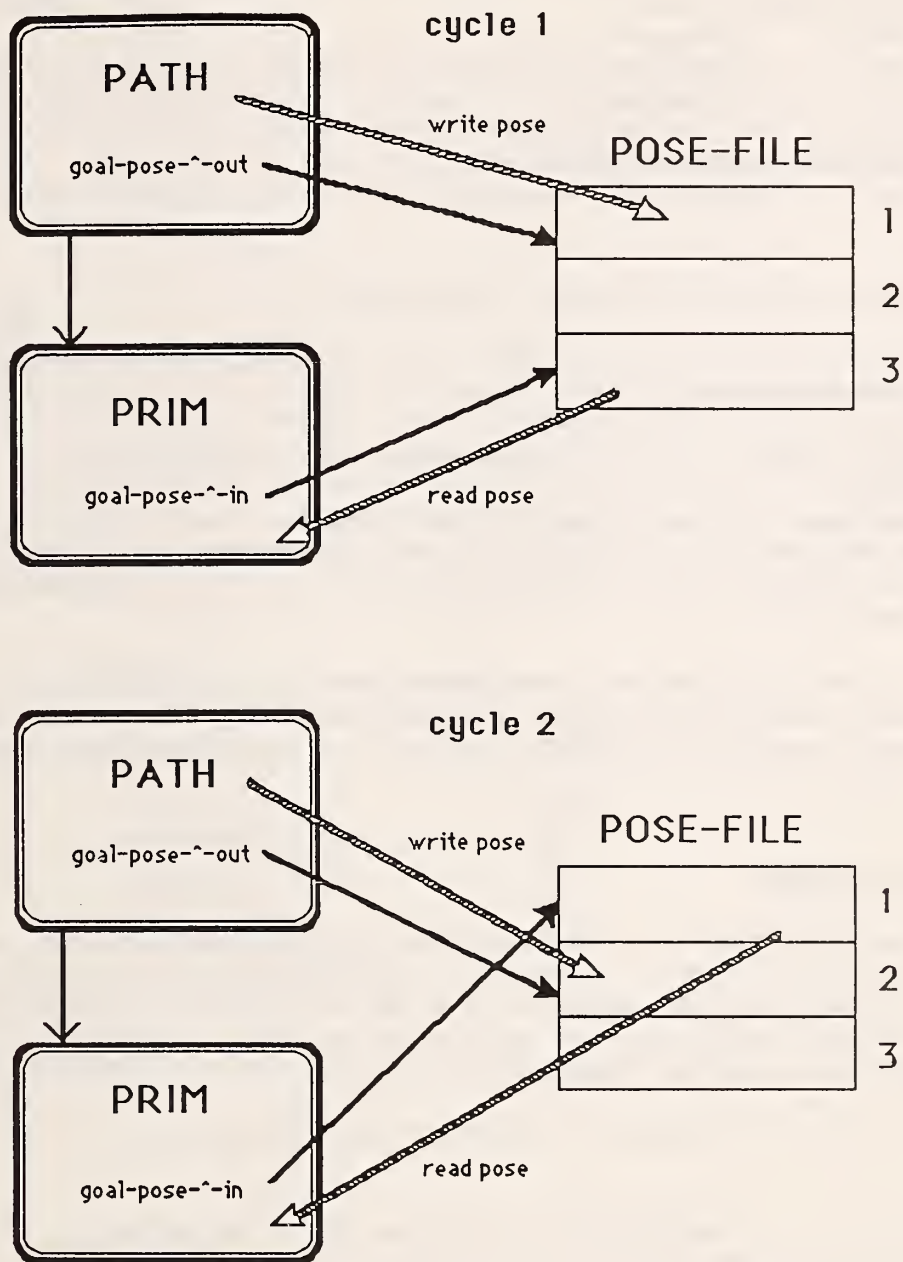
Figure 10-2.   Using a round-robin to transfer information
between control levels.

The round-robin file in common memory has the following structure:

```
17 bytes VAR-0 r-rec
   15 strv    "rr-name"
   iv         rr-^
   iv         rr-size

10 mem FILE ROUND-ROBIN-FILE
```

where:

● "rr-name" contains the name of the round-robin.

● rr-^ contains the record number of the beginning of the circular list in the containing file.

● rr-size contains the number of records in the round-robin.

The round-robin file is a single linked circular list. RSL does not include a provision for removing round-robins. When you redefine a round-robin, RSL returns the records in the containing file to the free list, and then creates a new circular list.

Note: The containing file is not identified by any field in this record. You must manually keep track of which containing file is associated with each round-robin. In RSL, the name of the round-robin denotes the containing file.

10.3 RSL COMPILER

The RSL compiler compiles RSL source code describing locations, movetables, objects, and paths into a linked-list representation, stored in common memory files. The RSL compiler consists of a set of routines that interpret the source code and build the data and algorithm files. Each data type has its own compiling routine or routines.

Table 10-2 lists the compiling words for each data type.

Table 10-2. Data Type Compiling Words.

RSL Data Type	Compiling Word
pose	-pose-
movetable	-mtb-, ---, -mtb-end-, -imtb-
location	-loc-
array	-arr-
object	-obj-
path	-path-, -ppt-
round-robin	-rr-

Note that the compiling word is an abbreviation of the data type name enclosed by dashes. RSL uses these same abbreviations consistently when naming variables and routines.

The rest of this section describes some RSL compiling routines. If you extend RSL to include new path-points, path types, or trajectory types, you have to add new compiling routines, similar to the ones described here to accommodate the extensions. These compiler routines call utility routines to perform common functions. For more information on extensions see Chapter 11, "RSL Extensions".

Utility Routines

Each file that contains a data type name has an associated search routine that reads a name from the input stream, stores the name in the name field of the local template for the file, and searches the file for that name. If the search routine finds the name in the file, the routine sets the record# to the found record. If the search routine does not find the record name in the file, the routine sets the record# to 0. Table 10-3 lists the files and the associated routines:

Table 10-3. Data Type Search Routines.

RSL Files	Routines
POSE-FILE	POSE-^
MOVETABLE-FILE	MTB-^
LOCATION-FILE	LOC-^
ARRAY-FILE	ARR-^
OBJ-NAME-FILE	OBJ-^
ROUND-ROBIN-FILE	RR-^

SAME-BLOCK? is an example of a utility routine called by many of the other compiling routines.

SAME-BLOCK?

    The SAME-BLOCK? utility routine compares the current source block number
    with the block number stored in the current record. If the numbers are
    different, the routine displays the message **redefined in different block**,
    and displays the old block number. This message should prevent you from
    using the same name twice.

RSL includes the location types loc, arr, tool, and goal. When you add location types, you need to add to the routine READ-LOC-PHRASE, which is defined next.

READ-LOC-PHRASE [loc type] [loc name]

    The READ-LOC-PHRASE utility routine stores the location type in the variable loc-type. Then it searches the corresponding file for loc name and stores the record# in loc-^. READ-LOC-PHRASE aborts execution if it does not find the location. Because READ-LOC-PHRASE does not add records to a file, it does not have a STORE or REMOVE routine.

Environmental Data Routines

Environmental data routines compile information about objects in the environment such as the position of an object relative to the robot. The routine -pose- is described here as an example.

-pose- [name] [pose numbers] [configuration flags]

    This environmental data routine calls POSE-^ to read the pose name and check that it is not already defined. Then -pose- calls #.READ 10 times to read in the pose numbers and configuration flags, storing them in the corresponding fields in the POSE-FILE local record, pose-rec. If the pose is already defined, it calls SAME-BLOCK? and stores the local template to the found record. Otherwise, it adds the local template to the list in POSE-FILE, pointed to by the variable first-record.

Routines to Compile Trajectories

READ-TRAJ-PHRASE, STORE-TRAJ-PHRASE, and REMOVE-TRAJ-PHRASE are the highest level compiler routines used with trajectories. Use these routines when you add other trajectory types to RSL.

READ-CART-TRAJ [cart traj parameters]

    READ-CART-TRAJ is an example trajectory type routine that calls #.READ five times to read in the Cartesian trajectory parameters, storing them in the local template of CARTESIAN-FILE.

READ-JOINT-TRAJ [joint traj parameters]

    READ-JOINT-TRAJ is an example trajectory routine that calls #.READ three times to read in the joint trajectory parameters, storing them in the local template of JOINT-FILE.

READ-TRAJ-PHRASE [traj type] [traj parameters]

    READ-TRAJ-PHRASE is a compiling routine that calls #READ to read in the trajectory type, storing it in traj-type. READ-TRAJ-PHRASE aborts if the trajectory type is invalid. READ-TRAJ-PHRASE also executes a case statement to call a routine to read the trajectory parameters for the type.

STORE-TRAJ-PHRASE

> STORE-TRAJ-PHRASE is a compiling routine that stores the traj-type local
> template to its file, adding to the list of file records.
> STORE-TRAJ-PHRASE sets traj-^ to the record# stored. The path-point rou-
> tine calls this routine after checking the rest of the path-point syntax.

REMOVE-TRAJ-PHRASE

> REMOVE-TRAJ-PHRASE is a compiling routine that deletes the trajectory
> parameter record pointed to by the variable traj-^ from the traj-type
> file.

Routines to Compile Path-Points

RSL compiles paths in two stages. First, RSL compiles the path and then the
path-points. The routine -path- compiles the identifying information for the
path, and creates a list in PATH-POINT-FILE. The routine -ppt- compiles the
path-points, adding them to the list in PATH-POINT-FILE.

You must provide two routines for each path-point you add to RSL; one that
compiles the path-point and one that removes it for garbage collection. By
convention, the path-point command consists of lowercase characters, the com-
piling routine has the same name in uppercase characters, and the removing
routine has the same name in uppercase characters with -REMOVE appended to the
end. For example, the goto path-point command is goto, the compiling routine
is GOTO, and the removing routine is GOTO-REMOVE.

The compiling routine must read in all the fields of the path-point, checking
that any referred-to items, such as movetables and locations, are defined
before modifying any files. Then the compiling routine stores the results in
the appropriate files. One of these files must be the primary path-point
parameter file. The record# of the record added to that file must be put in
the variable ppt-para-^ to be stored in PATH-POINT-FILE by the routine -ppt-.

You must add the new compiling routine to the case statement in -ppt-, and you
must add the removing routine to the case statement in PPT-REMOVE. Use the
directory block system in the source code to find empty blocks in which to
write your routines.

The compiling routines for the RSL path-point goto are described below:

GOTO [loc phrase] [traj phrase]

> This routine calls READ-LOC-PHRASE and copies loc-type and loc-^ into the
> variables goto-loc-type and goto-loc-^. (These variables are fields in
> the GOTO-FILE local template goto-rec.) GOTO then calls READ-TRAJ-PHRASE
> and copies traj-type into goto-traj-type. At this point, all fields have

been read and any errors detected so the records may be written to the files. GOTO writes the records to the files by calling STORE-TRAJ-PHRASE, copying traj-^ to goto-traj-^. Then GOTO adds the local template to GOTO-FILE and sets ppt-para-^ to the record# stored.

GOTO-REMOVE

This routine retrieves the record from GOTO-FILE pointed to by ppt-para-^, copies the variables goto-traj-type and goto-traj-^ into traj-type and traj-^, calls REMOVE-TRAJ-PHRASE, and removes the record from GOTO-FILE.

-ppt- [ppt command] [ppt parameters]

This routine stores the ppt command type in ppt-command, executes a case statement to call the corresponding compiling routine, then adds the ppt record to the current path in PATH-POINT-FILE. (Note that -path- puts an invalid ppt record at the beginning of the list when it is created. Therefore, -ppt- checks first-ppt to see if it should store to that record or add a record to the list.)

Routines to Compile Paths

Each path type you add to RSL must have enough parameters to identify individual paths of that type. You provide a routine that reads the identifying parameters, creates a list in PATH-POINT-FILE, and stores the data to the path-type file. When a path is redefined, you must call PATH-CLEAR to delete the old path from PATH-POINT-FILE and the path-point command parameter files. You must also modify the path files. You must add your routine to the case statement in -path-.

Two typical parameters that identify a path are locations and objects. The utility routine READ-LOC-PHRASE may be used to read location phrases. A routine used to read object phrase, a compiling routine for the system path type move-to, and some associated routines are described below.

READ-OBJ-PHRASE [obj name] [grip#]

This routine searches the object files for the name and grip number. If they are not found, the routine aborts. Then the routine sets obj-grip-^ to the record# in the OBJ-GRIP-FILE.

PATH-CLEAR

This routine deletes the path in PATH-POINT-FILE starting at path-^, executing PPT-REMOVE for each path-point. PPT-REMOVE deletes all records added to path-point parameter files for the path.

MOVE-TO [obj phrase] [start loc phrase] [destination loc phrase]

> This routine calls READ-OBJ-PHRASE and copies obj-grip-^ to
> move-to-obj-^. MOVE-TO then calls READ-LOC-PHRASE, and copies loc-type
> and loc-^ into move-to-start-type and move-to-start-^. Then MOVE-TO
> calls READ-LOC-PHRASE again, and copies loc-type and loc-^ into move-to-
> dest-type and move-to-dest-^. MOVE-TO has now read all input fields, and
> is ready to write the data to the files.
>
> MOVE-TO searches MOVE-TO-FILE for the object, start location, and desti-
> nation location. If a match is found, the old path is removed. If not
> found, a record is added to the MOVE-TO-FILE list. In either case,
> path-own-^ is set to the record# in MOVE-TO-FILE, so that move-to-path-^
> may be set later.
>
> After the correct MOVE-TO-FILE record is found, a list is created in
> PATH-POINT-FILE, and move-to-path-^ is set. The ppt-command is set to -1
> for a path with no path-points. If such a path is redefined, PPT-REMOVE
> does not abort.

-path- [path-type] [parameters]

> This routine sets path-type to the path type. It then executes a case
> statement to execute the corresponding routine, which reads the param-
> eters and creates a list in PATH-POINT-FILE. The variable first-ppt is
> set to true, so that -ppt- stores to the first record in the list, rather
> than adding a record to the list.

10.4 THE TASK LEVEL

The TASK level interprets and executes robot task commands entered at the key-
board, or more commonly, loaded from a block. You can define your own tasks
using state tables, or you can use the MOVE-TO and TRANSFER tasks provided on
your system tape. You must use the TASK utility routines when you create rou-
tines to perform other tasks.

TASK Commands

The following commands execute at the TASK level: RESTART, PAUSE, MOVE-TO,
and TRANSFER. This section explains the function and provides the syntax of
each command.

RESTART command

The syntax of the RESTART command is:

    RESTART

RESTART sends RESTART to PATH, and sets the current location and object to nul. After sending the RESTART command, TASK reports its status as executing, until the PATH level reports done. Then TASK level also reports its status as done.

PAUSE command

The syntax of the PAUSE command is:

    PAUSE

PAUSE sends PAUSE to the PATH level, and sets the current location and object to nul. After you issue PAUSE, the TASK level reports its status as executing until the PATH level reports its status as done. Then the TASK level also reports its status as done.

MOVE-TO command

The syntax of the MOVE-TO command is:

    MOVE-TO [object] [grip#] [destination location type] [destination]
        [sector]

where:

• object specifies the name of the object you are directing RSL to move.

• grip# specifies the number of the grip for the specified object.

• destination location type can be array (arr) or location (loc).

• destination specifies the destination for the MOVE-TO command.

• sector specifies the array sector containing the destination. This field
  is included only if the destination location type is an array (arr).

MOVE-TO sends a single move-to path to the PATH level. MOVE-TO uses the current location as the start location. The destination becomes the current location when the path is complete.

MOVE-TO reports an error if it does not find the path. After you issue MOVE-TO, the TASK level reports its status as executing until the PATH level reports its status as done. Then the TASK level also reports its status as done.

TRANSFER command

The syntax of the TRANSFER command is:

    TRANSFER [object phrase] [source location phrase] [source sector list]
        [destination location phrase] [destination sector list]

where:

- <u>object phrase</u> contains the object name and grip number.

- <u>source location phrase</u> contains the location type and name of the source.

- <u>source sector list</u> is a list of numbers, terminated by ;; and giving the sectors of the source array. This field is included only if the source location type is an array (arr).

- <u>destination location phrase</u> contains the location type and name of the destination.

- <u>destination sector list</u> is a list of numbers, terminated by ;; and giving the sectors of the destination array. This field is included only if the destination location type is an array (arr).

TRANSFER sends a sequence of path commands to the PATH level and updates the current location each time it completes the execution of a path.

TRANSFER sends the following sequence of paths, in the order shown, to the PATH level:

1. move-to [object] [source] [destination]
2. approach-pickup [object] [source]
3. depart-pickup [object] [source]
4. move-to [object] [source] [destination]
5. approach-release [object] [destination]
6. depart-release [object] [destination]

If the source or the destination is an array, RSL repeats the specified sequence of paths for each sector in the sector list. If both the source and the destination are arrays, the sector lists must have the same lengths.

After you issue TRANSFER, the TASK level reports its status as executing until the PATH level indicates that all paths are complete by reporting its status as done. Then the TASK level also reports its status as done.

TASK Input Command Buffer

The TASK input command buffer consists of the following variables:

inc-command-#-in
> The user increments this integer variable each time the user issues a new command.

input-command
> The user stores each new command in this 128-character string variable.

TASK Status Information

To provide status feedback, the TASK level returns an echo of the input command, and a status report.

The TASK output status buffer consists of the following five variables:

cycle-#-status-out
    Returns the cycle count when TASK returns its status. The changing value
    of this integer variable verifies that the TASK level is running.

inc-command-#-echo-out
    Returns a copy of the inc-command-#-in variable. This information
    enables you to know for which command TASK is returning status
    information.

command-echo
    Returns a copy of the string stored in input-command. This information
    enables you to know for which command TASK is returning status
    information.

status-report
    Returns the current status of TASK. The possible values for this integer
    variable and their meanings are:

Value	Meaning	Description
0	executing	The current command is still executing.
1	done	The current command is finished executing.
2	error	An error occurred. (See status-arg-out.)

status-arg-out
    Returns the error status. The possible values for this integer variable
    and their meanings are:

Value	Meaning	Description
0	noerror	TASK detected no errors.
1	path-error	PATH reported an error to TASK.
2	command-error	TASK received an invalid command or parameters.
3	nul-path	TASK could not find one of the specified paths.
4	programmer	TASK detected a programming error.

TASK Variables

This section describes internal TASK variables.

t->IN
    TASK uses this variable as a pointer to the current position in the
    input-command buffer variable.

t-word
     This variable holds a word read from the current position in the
     input-command buffer variable.

t-#
     This variable holds a number read from the current position in the
     input-command buffer variable.

state-label
     This variable holds the label for the current state. TASK routines
     derived from state graphs use this variable.

cur-loc-type
     The cur-loc-type variable specifies the current location type.

cur-loc-^
     The cur-loc-^ variable points to the current location.

cur-obj-^
     The cur-obj-^ variable points to the current object.

com-loc-type
     The com-loc-type variable holds the commanded location type determined by
     READ-LOC-PHRASE.

com-loc-^
     The com-loc-^ variable holds the commanded location pointer determined by
     READ-LOC-PHRASE.

com-obj-^
     The com-obj-^ variable holds the commanded object pointer determined by
     READ-OBJECT-PHRASE.

search-result
     This variable owner contains the variables that hold the output of
     path-search routines.

goal-type, goal-^, obj-^, path-^
     These variables hold the output of path-search routines. These variables
     are members of the search-result variable owner.

arr-pose-^
     This variable points to the pose for the current sector in the current
     array. ARRAY-POSE is used as a dummy name for this pose.

TASK Errors

TASK uses the variable status as an error flag. At the beginning of each
cycle, the value of status is noerror. Any routine that detects an error sets
status to indicate an error. TASK notes this error, sets status-arg-out to
the appropriate value, and sends a PAUSE command to the PATH level. TASK does
not finish executing the current task after detecting an error.

TASK Utilities

This section provides general descriptions of the TASK utilities listed below.
Use the LOC command to find the exact code for each routine on your system.

WREAD-COMMAND	READ-SECTOR-LIST
#READ-COMMAND	CALC-SECTOR-POSE
READ-OBJ-PHRASE	WAIT-PATH-DONE
READ-LOC-PHRASE	TASK=>PATH

The description of these utilities begins with a list of the input and output
variables.

WREAD-COMMAND

Input Variables	Output Variables
input-command	t-word
t->IN	t->IN
	status

Reads a word, delimited by a space, from the input-command buffer vari-
able. The routine stores the word in t-word and increments t->IN by the
number of characters in the word.

#READ-COMMAND

Input Variables	Output Variables
input-command	t-#
t->IN	t->IN
	status

Reads a string, delimited by a space, from the input-command buffer vari-
able and increments t->IN by the number of characters in the string. It
then searches for the string in the system dictionary, using the current
vocabulary. If the string is in the dictionary, #READ-COMMAND checks to
see that it is an integer or sequential variable and, if it is, stores
the value in t-#.

If the string is not in the system dictionary or if it is not an integer
or sequential variable, #READ-COMMAND converts the string to an integer
and stores the result in t-#. If the string is not a valid integer,
#READ-COMMAND aborts.

READ-OBJ-PHRASE

Input Variable	Output Variables
input-command	com-obj-^
t->IN	status

Calls WREAD-COMMAND and #READ-COMMAND to read an object name and grip number from the input command buffer. READ-OBJ-PHRASE then finds the record# of the corresponding entry in the object data structure.

READ-LOC-PHRASE

Input Variable	Output Variables
input-command	com-loc-type
	com-loc-^
	status

Calls #READ-COMMAND and WREAD-COMMAND to read a location type and name from the input command buffer. READ-LOC-PHRASE stores the location type in the com-loc-type variable. READ-LOC-PHRASE searches the location data structure for the name and sets com-loc-^ to the record# of the record containing the name.

READ-SECTOR-LIST

Input Variables	Output Variables
input-command	sector-list
com-loc-^	status

Calls #READ-COMMAND until it reads the entire sector list, which is terminated by ;;.

CALC-SECTOR-POSE

Input Variables	Output Variable
sector	ARRAY-POSE
arr-rec	

Calculates the pose for the sector of the array in arr-rec and stores the pose in the RSL data structure POSE-FILE at the position pointed to by arr-pose-^.

WAIT-PATH-DONE

Input Variable	Output Variables
path-status	status-report
	cur-var

Checks if the path-status variable indicates done and, if so, sets the status-report variable to done, sets cur-loc-type to equal goal-loc-type,

sets cur-loc-^ to equal goal-loc-^, and sets cur-obj-^ to equal
obj-^-out. WAIT-PATH-DONE does nothing if the path-status variable indi-
cates executing.

TASK=>PATH

Input Variable	Output Variable
search-result	path-command-var
inc-command-#-out	inc-command-#-out

Sets the value of output-command to PATH, copies the value of
search-result to the corresponding fields in path-command-var, and incre-
ments the value of inc-command-#-out.

TASK Processing

The three stages for the TASK level are PRE-PROCESS, COMMAND-PROCESS, and
POST-PROCESS, which correspond to the preprocessing, decision-processing, and
postprocessing stages discussed in Chapter 2, "RCS Overview".

PRE-PROCESS reads the command and status inputs, and sets the flags needed by
COMMAND-PROCESS. COMMAND-PROCESS, the decision-processing stage, reads the
command parameters, searches for paths, and sends commands to the command buf-
fer of the PATH level. POST-PROCESS performs the "housekeeping" required to
prepare TASK for the next command.

TASK preprocessing

The TASK routine PRE-PROCESS calls READ-COMMAND and PATH-STATUS.

READ-COMMAND

Input Variables	Output Variables
input-command	"command-name"
inc-command-#-in	new-command
old-inc-command-#-in	status
	status-arg
	t->IN
	old-inc-command-#-in

Checks if the value of inc-command-#-in has changed since the last cycle
and, if so, sets the status report and status-arg-out variables to indi-
cate no error, sets the new-command variable to true, and copies the
value of inc-command-#-in to old-inc-command-#-in. Calls WREAD-COMMAND
to read the first word contained in the input-command buffer variable.
Stores the first word in the "command-name" variable. (The "command-
name" variable includes the double quotation marks.)

PATH-STATUS

> Input Variables   Output Variable
>
> status-in   path-status
> inc-command-#-out
> inc-command-#-echo-in

> Verifies that inc-command-#-out matches inc-command-#-echo-in, indicating
> that the PATH level responded to the current command and that the value
> of the status-in variable is valid. PATH-STATUS then copies the value of
> status-in to the path-status variable. If the PATH level has not
> responded, PATH-STATUS sets path-status to executing.

TASK decision processing

The TASK routine COMMAND-PROCESS executes the current task routine. If the
value in status-report is error, COMMAND-PROCESS executes only the RESTART
command.

If neither status-report nor status indicates an error, COMMAND-PROCESS exe-
cutes the task routine corresponding to the "command-name" set in PRE-PROCESS.
If "command-name" does not contain a valid command, COMMAND-PROCESS sets
status-report to error and sets status-arg to command-error. After
COMMAND-PROCESS executes the specified task routine, it copies the value of
status-arg to status-arg-out.

The following is a list of routines used in COMMAND-PROCESS for the RESTART,
PAUSE, and MOVE-TO commands. This list does not include the routines for
TRANSFER, most of which are similar to the routines for MOVE-TO.

> TASK-RESTART
> TASK-PAUSE
> MOVE-TO
> MOVE-TO-PARAM
> MOVE-TO-SEARCH

The descriptions of these routines follow.

TASK-RESTART

> Input Variable   Output Variables
>
> new-command   path-command-var
> inc-command-#-out   process-var
>   status-report

> Sends RESTART to the PATH level and waits for prim-status to indicate
> done.

TASK-PAUSE

Input Variable	Output Variables
new-command	path-command-var
	status-report

Sends PAUSE to the PATH level.

MOVE-TO

Input Variables	Output Variables
new-command	path-command-var
input-command	status-report

Reads the command parameters and finds the path by calling MOVE-TO-PARAM
and MOVE-TO-SEARCH. If MOVE-TO-SEARCH finds the path without finding any
errors, MOVE-TO calls TASK=>PATH. If new-command indicates false,
MOVE-TO calls WAIT-PATH-DONE. MOVE-TO sets the status as described under
the "MOVE-TO" command.

MOVE-TO-PARAM

Input Variables	Output Variables
input-command	move-to-rec
cur-loc-type	sector
cur-loc-^	ARRAY-POSE
	status
	status-arg

Reads the rest of the parameter information in the input-command buffer
variable by calling READ-OBJ-PHRASE, READ-LOC-PHRASE, and #READ-COMMAND.
MOVE-TO-PARAM then uses this information to set the parameters for
MOVE-TO-SEARCH.

MOVE-TO-SEARCH

Input Variable	Output Variables
move-to-rec	search-result
	status
	status-arg

Searches the MOVE-TO-FILE for a record that matches move-to-rec and sets
the fields of search-result if it finds a match.

TASK postprocessing

The TASK routine POST-PROCESS calls CLEAN-UP.

CLEAN-UP

Input Variable	Output Variable
input-command-var	output-status-var

Echoes the input-command and inc-command-#-in, and then sets
cycle-#-status-out.

10.5 THE PATH LEVEL

The PATH level interprets and executes path and path-point commands received
from the TASK level. PATH executes paths by retrieving each successive path-
point and waiting for the lower levels, PRIM and JOINT, to complete the exe-
cution of the path-point. PATH executes path-points by reading the appropri-
ate sensors and sending motion commands to the PRIM level.

PATH Commands

The following commands execute at the PATH level: RESTART, PAUSE, and PATH.
This section describes the function and provides the syntax of each command.

RESTART command

The syntax of the RESTART command is:

    RESTART

RESTART sends RESTART to PRIM and resets the debug variables. After issuing
the RESTART command, PATH reports its status as executing until PRIM reports
done.   Then PATH reports done to TASK.

PAUSE command

The syntax of the PAUSE command is:

    PAUSE

PAUSE sends PAUSE to the PRIM and JOINT levels. After issuing PAUSE, PATH
reports done to the TASK level immediately, without requesting confirmation
from PRIM and JOINT.

PATH command

The syntax of the PATH command is:

    PATH [path-^] [goal-type] [goal-^] [obj-^]

where:
- path-^ points to the path to be executed.

- goal-type can be either a location (loc) or an array (arr).

- goal-^ points to the goal location or the array describing the path. Path-point commands use this information to determine paths for the PRIM and JOINT levels to execute.

- obj-^ points to the current object. Some path-point routines use this information to obtain the grip movetable or other object-dependent data.

PATH executes the path pointed to by path-^. The PATH level reports its status as executing until it completes the execution of all path-points. Then the PATH level reports done to the TASK level.

PATH Input Command Buffer

The PATH input command buffer consists of the following variables:

inc-command-#-in
    TASK increments this integer variable each time it sends a new command to the PATH level.

input-command
    TASK sends this integer variable to PATH to identify the command. Commands are numbered as follows: 0-RESTART, 1-PAUSE, and 2-PATH.

path-^
    TASK sends this integer pointer variable to PATH to identify the path.

goal-type
    TASK sends this integer variable to PATH to indicate the type of goal location.

goal-^
    TASK sends this integer pointer variable to PATH to identify the goal location.

obj-^
    TASK sends this integer pointer variable to PATH to identify the current object.

PATH Status Information

To provide status feedback to the TASK level, the PATH level returns a status report, and echoes the input command and incremental command number.

PATH uses the following five variables to return status to the TASK level:

cycle-#-status-out
     Returns the cycle count when PATH returns its status. The changing value of this integer variable verifies that the PATH level is running.

inc-command-#-echo-out
     Echoes the integer count of new commands received by the PATH level as indicated by the inc-command-#-in variable. This information enables TASK to know for which command PATH is returning status information.

command-echo
     Echoes the string stored in inc-command-#-in. This information enables you to know for which command PATH is returning status information.

status-report
     Returns the current status of PATH. The possible values for this integer variable and their meanings are:

Value	Meaning	Description
Ø	executing	The current command is still executing.
1	done	The current command is finished executing.
2	error	An error occurred. (See status-arg-out.)

status-arg-out
     Returns the error status. The possible values for this integer variable and their meanings are:

Value	Meaning	Description
Ø	noerror	PATH detected no errors.
1	prim-error	PRIM reported an error to PATH.
2	command-error	PATH received an invalid command or parameters.
3	ppt-para	PATH detected invalid ppt-command parameters.

PATH Errors

When PATH detects an error of any type, it sets the status-report variable to indicate an error, stores the label for the error in the status-arg-out variable, and sends the PAUSE command to the PRIM level. PATH does not complete the execution of a path-point after detecting an error. (The ppt-done variable remains set to false.)

PATH utility routines set the status and status-arg variables. The calling routine must set the status-report and status-arg-out variables.

PATH Processing

The three processes for the PATH level are PRE-PROCESS, COMMAND-PROCESS, and POST-PROCESS. PRE-PROCESS reads the command, status, and sensor inputs for COMMAND-PROCESS. COMMAND-PROCESS, the decision-processing stage, interprets the command and the command parameters, executes paths and path-points, and sends commands to the command buffer of the PRIM level. POST-PROCESS sends the TASK level confirmation for each command received and performs the "house-keeping" required to prepare PATH for the next command.

The output command from PATH to PRIM consists of a pose, configuration flags, trajectory type, and trajectory parameters. The path-point routines in PATH store the pose, configuration flags, and trajectory type in the variable owner prim-com-var, and the trajectory parameters in the local template of the file corresponding to the trajectory type. The POSE-ROUND and TRAJ-ROUND routines in the POST-PROCESS stage of the PATH level put the trajectory parameters into the PATH>PRIM round-robins.

PATH preprocessing

The PATH routine PRE-PROCESS calls NEW-COMMAND?, PRIM-STATUS, and TOOL-POSE-^. If you add sensors to your system, you can have PRE-PROCESS call your sensor routines also.

NEW-COMMAND?

Input Variables	Output Variables
inc-command-#-in	new-command
old-inc-command-#-in	old-inc-command-#-in
	status
	status-arg

Sets the new-command flag to true if the value of inc-command-#-in has changed since the last cycle. (That is, if inc-command-#-in does not equal old-inc-command-#-in.) NEW-COMMAND? also sets the status and status-arg variables to noerror.

PRIM-STATUS

Input Variables	Output Variables
status-in	prim-status
inc-command-#-out	
inc-command-#-echo-in	

Sets prim-status to the same value as status-in if inc-command-#-out matches inc-command-#-echo-in. This match indicates that the PRIM level responded to the current command, and that the status-in variable repre-sents the current PRIM status. If these variables do not match, PATH sets prim-status to executing.

TOOL-POSE-^

Input Variables	Output Variables
tp-cycles	tool-pose-^
rbt-pose-^	

Sets tool-pose-^ to the best guess of the tool pose of the robot for the current cycle. For the best guess, TOOL-POSE-^ uses the pose stored in the RBT-POSE round-robin tp-cycles before the current cycle.

PATH decision processing

The PATH routine COMMAND-PROCESS reads the input command and uses a case statement to determine which of the COMMAND-PROCESS commands to execute. If the status-report variable indicates an error, COMMAND-PROCESS freezes the error state and will not execute any command other than RESTART.

See "PATH Status Information" earlier in this chapter for a description of the status information that the COMMAND-PROCESS routines return in the status-report and status-arg-out variables.

PATH-RESTART

Input Variables	Output Variables
new-command	prim-command-var
prim-status	status-report
	status-arg-out

Sends RESTART to the PRIM level and waits for prim-status to indicate done.

PATH-PAUSE

Input Variables	Output Variables
new-command	prim-command-var
prim-status	status-report
	status-arg-out

Sends PAUSE to the PRIM level.

PATH-PATH

Input Variables	Output Variables
new-command	prim-command-var
prim-status	status-report
input-command-var	status-arg

Initializes the PATH variables if new-command is true. Then, if the last
path-point is complete, PATH-PATH calls NEW-PPT? to retrieve the next
path-point and calls PATH-POINT to execute the path-point. If
prim-status is error, PATH-PATH sets status-report to error, sets
status-arg to prim-error, and does not execute PATH-POINT.

NEW-PPT?

Input Variables	Output Variables
ppt-done	ppt-rec
last-ppt	new-ppt
next-ppt-^	last-ppt
	ppt-done
	path-done
	next-ppt-^

Reads the next path-point record from the current path and sets flags
ppt-done, new-ppt, and last-ppt. NEW-PPT? stores the current path-point
information in ppt-rec, the PATH-POINT-FILE local template. NEW-PPT?
does not retrieve the ppt command parameter record; the path-point rou-
tines (for example, GOTO) retrieve this record.

To indicate the start of a new path-point, NEW-PPT? sets new-ppt to true
during the cycle in which a path-point routine is retrieving a new path-
point record. NEW-PPT? sets new-ppt to false during other cycles.

The path-point routines set ppt-done to true when they finish executing
each path-point. NEW-PPT? sets ppt-done to false when it retrieves the
next path-point record.

NEW-PPT? sets last-ppt to true if the current path-point is the last
path-point in the current trajectory.

GOAL-POSE

Input Variables	Output Variables
goal-type	prim-com-conf-flag
goal-^	pose-add
obj-^	status
	status-arg

Calculates the goal pose for the current path. If the goal-type is
invalid, GOAL-POSE sets status to error and status-arg to command-error.

TRAJ-PHRASE

Input Variables	Output Variables
traj-type	prim-com-traj-type
traj-^	traj para file local template
	status
	status-arg

Sets prim-com-traj-type to traj-type and retrieves the trajectory param-
eters and stores them in the local template of the corresponding file.
Your sensor routine can modify the trajectory parameters before PATH
sends them to PRIM so that sensor path-point servo algorithms can control
the velocity and acceleration of the robot.

TRAJ-PHRASE sets status to error and status-arg to ppt-para if the
traj-type parameter is invalid.

LOC-PHRASE

Input Variables	Output Variables
loc-type	prim-com-pose
loc-^	prim-com-conf-flag
	status
	status-arg

Interprets a location phrase in a path-point by calculating the pose for
the specified location and storing the pose in the prim-com-pose and
prim-com-conf-flag variables. LOC-PHRASE sets status to error and
status-arg to ppt-para if the loc-type parameter is invalid.

GOTO

Input Variables	Output Variables
ppt-rec	prim-com-var
new-ppt	traj para file local record
prim-status	ppt-done
	status
	status-arg

Executes the goto path-point. If new-ppt is true, GOTO retrieves the ppt
parameters from GOTO-FILE and sets the specified pose and trajectory
parameters by calling LOC-PHRASE and TRAJ-PHRASE. If new-ppt is false,
GOTO waits for prim-status to indicate done and then sets ppt-done to
true.

PATH postprocessing

The PATH routine POST-PROCESS sends the TASK level confirmation for each command received and performs the "housekeeping" required to prepare PATH for the next command. POST-PROCESS calls CLEAN-UP, POSE-ROUND, and TRAJ-ROUND.

CLEAN-UP

Input Variables	Output Variables
inc-command-#-in	inc-command-#-echo-out
cycle-count	cycle-#-status-out
input-command	command-echo

Echoes the command and inc-command-# to the TASK level.

POSE-ROUND

Input Variables	Output Variables
prim-com-pose	path-pose-^
prim-com-conf-flag	goal-pose-^-out
path-pose-^	PATH>PRIM-POSE round-robin

Puts prim-com-pose and prim-com-conf-flag into the PATH>PRIM-POSE round-robin.

TRAJ-ROUND

Input Variables	Output Variables
prim-com-traj-type	path-cart-^
traj-para-file-local-record	path-joint-^
path-cart-^	traj-type-out
path-joint-^	PATH>PRIM-CART round-robin
	PATH>PRIM-JOINT round-robin

Puts the traj-para-file-local-record corresponding to prim-com-traj-type into the PATH>PRIM-CART or PATH>PRIM-JOINT round-robin.

10.6 THE PRIM LEVEL

The PRIM level receives trajectories from the PATH level, transforms these trajectories into positions, and sends these positions to the JOINT level. The JOINT level converts the positions to the primitive commands sent to the robot controller.

PRIM Commands

The following commands execute at the PRIM level: RESTART, PAUSE, and TRAJ. This section explains the function and provides the syntax of each command.

RESTART command

The syntax of the RESTART command is:

    RESTART

RESTART clears any error conditions, sets the hold-set variable to false, and sends RESTART to the lower level, JOINT. After executing RESTART, PRIM reports its status as executing until the JOINT level reports its status as done. When JOINT reports done, PRIM sets the current location to the feedback position, sets the current velocity and acceleration to 0, and resets the debug variables. Then PRIM reports done to PATH.

PAUSE command

The syntax of the PAUSE command is:

    PAUSE

PAUSE sends the PAUSE command to JOINT when the joystick is inactive. The PAUSE command ensures that JOINT performs its processing only when you are using the joystick. After executing PAUSE, PRIM reports its status as executing when the joystick is active, and done when the joystick is inactive.

TRAJ command

The syntax of the TRAJ command is:

    TRAJ [traj-type] [traj-para-^] [goal-pose-^]

where:

● <u>traj-type</u> specifies the type of trajectory, either Cartesian or joint.

● <u>traj-para-^</u> points to the trajectory parameters.

● <u>goal-pose-^</u> points to the goal pose.

TRAJ executes the specified trajectory. The traj-type parameter can have a value of either 0 or 1 as follows:

0 (Cartesian)
    Specifies that the type of trajectory is a straight line in Cartesian
    space from the start pose to the goal pose. While executing a Cartesian
    TRAJ command, PRIM reports its status as executing until the system

detects that the actuator is within a specified range of the goal. The
variables trn-nbhrd and rot-nbhrd specify this range. After the system
verifies that the robot is within range, PRIM reports its status as done
to PATH.

1 (Joint)
  Specifies that the type of trajectory is linear interpolation in joint
  space from the start pose to the goal pose. While executing a joint TRAJ
  command, PRIM reports its status as executing until the robot reports
  that all joint angles are within the target range. The variable j-delta
  specifies the target range for joint angles. PRIM reports its status as
  done when the system verifies that the joint angles are within range.

  Note: The joint trajectory algorithm does not decelerate to a stop at
       the goal. If the robot reaches the goal, it oscillates around the
       goal rather than stops. Use the Cartesian trajectory algorithm to
       stop the robot at a goal.

PRIM Input Command Buffer

The PRIM input command buffer consists of the following variables:

inc-command-#-in
  PATH increments this integer variable each time it sends a new command to
  the PRIM level.

input-command
  PATH sends this integer variable to PRIM to identify the command. Com-
  mands are numbered as follows: Ø-RESTART, 1-PAUSE, and 2-TRAJ.

traj-type-in
  PATH sends this integer variable to PRIM to indicate the type of
  trajectory.

traj-^-in
  PATH sends this integer pointer variable to PRIM to identify the
  trajectory parameters, which are in a file corresponding to the
  trajectory type in traj-type-in.

goal-pose-^-in
  This integer pointer variable identifies the current pose in POSE-FILE.

PRIM Status Information

To provide status feedback to the PATH level, the PRIM level returns a status
report and a feedback pose, and echoes the input command and its incremental
command number.

PRIM uses the following six variables to return status to the PATH level:

cycle-#-status-out
Returns the cycle count when PRIM returns its status. The changing value
of this integer variable verifies that the PRIM level is running.

inc-command-#-echo-out
Echoes the integer count of new commands received by the PRIM level as
indicated by the inc-command-#-in variable. This information enables
PATH to know for which command PRIM is returning status information.

command-echo-out
Echoes the string stored in inc-command-#-in. This information enables
you to know for which command PRIM is returning status information.

status-report
Returns the current status of PRIM. The possible values for this integer
variable and their meanings are:

Value	Meaning	Description
0	executing	The current command is still executing.
1	done	The current command is finished executing.
2	error	An error occurred. (See status-arg-out.)

status-arg-out
Returns the error status. The possible values for this integer variable
and their meanings are:

Value	Meaning	Description
0	noerror	PRIM detected no errors.
1	joint-error	JOINT reported an error to PRIM.
2	command-error	PRIM received an invalid command or parameters.
3	hold	The HOLD-SET joystick button paused the robot.

Note: The hold status argument is not an error. PRIM sets the
status-report variable to executing when you push the HOLD-SET
button. You can clear this status by pushing the HOLD-CLEAR
button or by sending the RESTART command to PRIM.

rbt-pose-^
Returns a pointer to the feedback pose calculated by adding the tool
movetable to the JOINT feedback pose.

PRIM Trajectory Information

RSL supports two types of trajectories: Cartesian straight-line and joint
interpolated. The PRIM level executes the Cartesian trajectories and the
JOINT level executes the joint trajectories. Therefore, this section dis-
cusses the joint trajectories only when they affect the execution of Cartesian
trajectories. See Section 10.7, "The Joint Level", for information on joint
trajectories.

The differences between the two types of trajectories can cause problems when you follow one type of trajectory with the other. Ideally, the transition from the tool-point velocity and acceleration of one trajectory to the next should be as smooth as possible. To accomplish this smooth transition, PRIM must track the output of the joint algorithm and maintain current information on position and velocity.

To maintain current position and velocity data, PRIM uses the joint feedback pose to update this data for the Cartesian trajectory algorithm during every cycle of a joint trajectory motion. Because PRIM and JOINT execute on separate boards, communication timing delays the feedback pose information by one cycle. Output commands incur an additional delay of one cycle. Therefore, PRIM calculates the appropriate current position by adding twice the current velocity (in inches per cycle) to the feedback pose. PRIM uses the history of the feedback pose to calculate the approximate velocity.

Another problem arises during Cartesian motion. Because JOINT limits the joint velocity and acceleration, the actual output from JOINT may be different from the command that PRIM sends to JOINT. If JOINT reports its status as next-point or done, PRIM executes the trajectory routine to generate the next point. However, if JOINT reports its status as executing, PRIM updates the current position using the history of the feedback pose, rather than generating a new point. This procedure produces errors in the velocity and acceleration profiles, but minimizes path errors. To minimize velocity and acceleration profile errors, try to set the Cartesian trajectory parameters so that JOINT does not have to limit them.

Joystick HOLD-SET and HOLD-CLEAR Buttons

The PRE-PROCESS stage of the PRIM level sets the hold-set variable to true when you push the HOLD-SET button on the joystick controller. When the hold-set variable is true, COMMAND-PROCESS ignores the input command (except RESTART) and sends PAUSE to the JOINT level to stop the robot. In this case, PRIM sets the status-report variable to executing and the status-arg-out variable to hold. When you push the HOLD-CLEAR button, PRIM sets hold-set to false, sets new-command to true, and restarts the current input command.

PRIM Variables

This section describes internal PRIM variables.

joint-com-pose
    This variable (along with joint-com-conf-flag) holds the current command
    that PRIM is sending to JOINT. The joint-com-pose and current-pose vari-
    ables may contain different values when JOINT is executing a joint tra-
    jectory or scaling a Cartesian point to limit the motion of the joint.

joint-com-conf-flag

    The joint-com-conf-flag (along with joint-com-pose) holds the current command that PRIM is sending to JOINT. The joint-com-conf-flag and current-conf-flag variables may contain different values when JOINT is executing a joint trajectory or scaling a Cartesian point to limit the motion of the joint.

current-pose

    This variable (along with current-conf-flag) holds the current position of the robot. The command routine executing during the current cycle sets the current-pose variable.

current-conf-flag

    The current-conf-flag variable (along with current-pose) holds the current position of the robot. The command routine executing during the current cycle sets the current-conf-flag variable.

current-vel

    This six-element array holds the current velocity. The first three elements represent the rotation velocity vector and the last three elements represent the translation velocity vector. The command routine executing during the current cycle sets the current-vel variable.

last-pose

    This variable holds the last position of the robot. At the beginning of each cycle, PRE-PROCESS copies the value of current-pose to last-pose. The command routines use last-pose as the current position when they build a trajectory.

last-vel

    This six-element array holds the last velocity. As with the current-vel array, the first three elements of the last-vel array represent the rotation velocity vector and the last three elements represent the translation velocity vector. At the beginning of each cycle, PRE-PROCESS copies the value of current-vel to last-vel. The command routines use last-vel as the current velocity when they build a trajectory.

feedback-pose

    PRIM transforms the feedback position from JOINT to the tool-point pose and stores this information in the feedback-pose variable.

feedback-conf-flag

    PRIM copies the feedback configuration flags from JOINT and stores this information in the feedback-conf-flag variable.

last-feedback-pose

    The last-feedback-pose variable (along with last-feedback-conf-flag) holds the last feedback position. Before updating the feedback-pose variable, PRE-PROCESS copies the value of feedback-pose to last-feedback-pose.

last-feedback-conf-flag

    The last-feedback-conf-flag variable (along with last-feedback-pose)
    holds the last feedback position. Before updating the feedback-conf-flag
    variable, PRE-PROCESS copies the value of feedback-conf-flag to
    last-feedback-conf-flag.

hold-set

    This variable indicates the state of the HOLD-SET and HOLD-CLEAR buttons
    on the joystick controller. The hold-set variable indicates true after
    you press the HOLD-SET button, and false after you press the HOLD-CLEAR
    button.

PRIM Errors

When PRIM detects an error of any type, it sets the status-report variable to
indicate an error, stores the label for the error in the status-arg-out vari-
able, and sends the PAUSE command to the JOINT level. Error reporting over-
rides status reporting. PRIM does not send any commands to JOINT after
detecting an error. One exception to the above rule is if the current input
command is PAUSE and JOINT is reporting a joint-limit error, PRIM does not
report an error. In this case, the CREEP button on the joystick commands
CREEP to JOINT, clearing the error.

PRIM Processing

The three processes for the PRIM level are PRE-PROCESS, COMMAND-PROCESS, and
POST-PROCESS. PRE-PROCESS reads the command, joystick status, and JOINT
status, and prepares for COMMAND-PROCESS. COMMAND-PROCESS, the decision-
processing stage, interprets the command and the command parameters, and sends
joint commands to the command buffer of the JOINT level. POST-PROCESS sends
the PATH level confirmation for each command received and performs the "house-
keeping" required to prepare PRIM for the next command.

PRIM preprocessing

The PRIM routine PRE-PROCESS calls NEW-COMMAND?, JOY-STATUS, and JOINT-STATUS.

NEW-COMMAND?

Input Variables	Output Variables
inc-command-#-in	new-command
old-inc-command-#-in	old-inc-command-#-in
	status
	status-arg

    Sets the new-command flag to true if the value of inc-command-#-in has
    changed since the last cycle. (That is, if inc-command-#-in does not
    equal old-inc-command-#-in.) NEW-COMMAND? also sets the status and
    status-arg variables to noerror.

JOY-STATUS

Input Variables	Output Variables
hold-set	joy-1a
joystick ports	joy-1b
	joy-2a
	joy-2b
	hold-set
	joy-status
	new-command

Reads the joystick ports and stores the binary image of the switches in the variables joy-1a, joy-1b, joy-2a, and joy-2b. (See Appendix F, "Joystick Schematics", for more information.) JOY-STATUS sets the joy-status variable to active if the joystick enable switch is on and a motion switch is active. JOY-STATUS sets the joy-status variable to inactive if the joystick enable switch is off or a no-motion switch is active.

JOY-STATUS sets the new-command variable to true if the hold-clear switch is active and the hold-set variable indicates true. If the hold-set switch is active, JOY-STATUS sets the hold-set variable to true. If the hold-clear switch is active, JOY-STATUS sets the hold-set variable to false.

JOINT-STATUS

Input Variables	Output Variables
status-in	prim-status
inc-command-#-out	feedback-pose
inc-command-#-echo-in	feedback-conf-flag
joint-pose-^	RBT-POSE round-robin
tool movetable	

Sets joint-status to the same value as status-in if inc-command-#-out matches inc-command-#-echo-in. This match indicates that the JOINT level has responded to the current command, and that the status-in variable represents the current JOINT status. If these variables do not match, PRIM sets joint-status to executing.

If the current input command is not RESTART, JOINT-STATUS does two things. First, it adds the specified tool movetable to the joint feedback pose and places this combination in the RBT-POSE round-robin and in the feedback-pose variable. By checking for the RESTART command, PRIM avoids trying to add the tool movetable to a meaningless pose. Second, JOINT-STATUS copies the values of the feedback configuration flags to the RBT-POSE round-robin and the feedback-conf-flag variable.

PRIM decision processing

If the hold-set variable is false and the status-report variable does not
indicate an error, the PATH routine COMMAND-PROCESS uses a case statement to
determine which of the commands in this section to execute. If hold-set is
true and input-command is not RESTART, COMMAND-PROCESS commands JOINT to
pause. If the status-report variable indicates an error, COMMAND-PROCESS
freezes the error state and does not execute any command other than RESTART.

PRIM-RESTART

Input Variables	Output Variables
new-command	joint-command
joint-status	inc-command-#-out
	hold-set
	current-pose
	current-conf-flag
	current-vel
	debug variables

Checks if new-command is true and, if so, sets the value of the
joint-command variable to joint-restart, increments inc-command-#-out,
sets hold-set to false, and resets the debug variables. If new-command
is false, PRIM-RESTART waits for joint-status to indicate done and then
sets current-vel to zero and sets current-pose and current-conf-flag to
the combination of the feedback pose and the tool movetable.

PRIM-PAUSE

Input Variables	Output Variables
new-command	joint-com-pose
joint-status	joint-com-conf-flag
status-arg-in	joint-command
joy-status	inc-command-#-out
joy-1a	current-pose
joy-1b	current-conf-flag
joy-2a	current-vel
joy-2b	

Checks if new-command is true and, if so, sets the value of the
joint-command variable to joint-pause, increments inc-command-#-out, and
sets current-vel to $\emptyset$. If new-command is true and joy-status is active,
PRIM-PAUSE increments the inc-command-#-out variable and calls JOYSTICK
and STRAIGHT-LINE to interpret the joystick command. If new-command is
true and joy-status is inactive, PRIM-PAUSE sets the current velocity and
acceleration to $\emptyset$.

If the value of joint-status is error and the value of status-arg is
joint-error when you press the CREEP button on the joystick console,
PRIM-PAUSE sets the joint-command variable to joint-creep and increments
inc-command-#-out. In response to other error conditions, PRIM-PAUSE
sets joint-command to PAUSE.

TRAJ

Input Variables	Output Variables
last-pose	joint-com-pose
last-vel	joint-com-conf-flag
traj-type-in	joint-command
traj-^-in	inc-command-#-out
goal-pose-^-in	current-pose
	current-vel

Calls CART-TRAJ or JOINT-TRAJ depending on whether the value of the
traj-type-in variable is cart or joint.

CART-TRAJ

Input Variables	Output Variables
last-pose	joint-com-pose
last-vel	joint-com-conf-flag
traj-^-in	joint-command
goal-pose-^-in	inc-command-#-out
	current-pose
	current-conf-flag
	current-vel

Executes the specified Cartesian straight-line trajectory. CART-TRAJ
calls STRAIGHT-LINE to build the trajectory and monitors the joint
status. In response to any error conditions, CART-TRAJ sets joint-
command to PAUSE.

JOINT-TRAJ

Input Variables	Output Variables
traj-^-in	joint-com-pose
goal-pose-^-in	joint-com-conf-flag
status-in	joint-command
	inc-command-#-out
	current-pose
	current-conf-flag
	current-vel

Sends a joint trajectory to the JOINT level and monitors joint status. In response to any error conditions, JOINT-TRAJ sets joint-command to PAUSE.

JOYSTICK

Input Variables	Output Variables
joy-1a	Rg
joy-1b	xg
joy-2a	vmax
joy-2b	amax
last-pose	wmax
	gmax

Adds the motion indicated by the joystick to last-pose and stores the result in Rg and xg for use by STRAIGHT-LINE. JOYSTICK sets vmax to the value resulting from the equation (joy-max-v) * 2**(-vel) and sets wmax to the value resulting from the equation (joy-max-w) * 2**(-vel), where vel represents the setting of the velocity switch on the joystick. JOYSTICK sets variables amax and gmax equal to vmax and wmax, respectively.

STRAIGHT-LINE

Input Variables	Output Variables
Rg	current-pose
xg	current-vel
vmax	
amax	
wmax	
gmax	
last-pose	
last-vel	

Executes the straight-line algorithm.

PRIM postprocessing

The PRIM routine POST-PROCESS sends to the PATH level confirmation for each command received and performs the "housekeeping" required to prepare PRIM for the next command. POST-PROCESS calls CLEAN-UP and, if the current command is not RESTART, calls COMMAND-RR.

CLEAN-UP

    Input Variables   Output Variables

    input-command-var   output-status-var

    Echoes the command and inc-command-# to the PATH level.

COMMAND-RR

    Input Variables   Output Variables

    joint-com-pose   PRIM>JOINT-POSE round-robin
    joint-com-conf-flag   PRIM>JOINT-TRAJ round-robin
    joint-rec

    Adds the inverse tool movetable to the contents of the joint-com-pose
    variable and puts the resulting pose and the joint trajectory parameters
    in the PRIM>JOINT round-robins.

10.7 THE JOINT LEVEL

The JOINT level receives positions expressed in Cartesian coordinates from the
PRIM level, transforms these positions to robot joint coordinates, and con-
trols joint velocities and accelerations.

The design of the JOINT level is modular so that you can replace the existing
robot-dependent modules (the interface routines and transforms) with new mod-
ules designed to control your specific robot.

The two basic modes of motion for JOINT are Cartesian-space motion and joint-
space motion. In the Cartesian-space mode, the PRIM level interpolates
Cartesian paths between the start and end positions by generating and execut-
ing a new point along a Cartesian path each cycle. The JOINT level transforms
each path-point to joint coordinates and, if necessary, scales the move to
meet velocity and acceleration limits.

In the joint-space mode, the PRIM level passes the goal position from the PATH
level to the JOINT level. The JOINT level generates a joint-interpolated tra-
jectory to the goal position.

The routines that the JOINT level executes fall into two categories:
robot-independent and robot-dependent. The functions of the robot-independent
routines do not change if you use a different robot. The functions of the
robot-dependent routines are specific to the Puma 760 robot. You must provide
your own routines to accommodate other robots.

JOINT Commands

The following commands execute at the JOINT level: RESTART, PAUSE, CARTESIAN, JOINT-TRAJ, and CREEP. This section provides the syntax and explains the function of each command.

RESTART command

The syntax of the RESTART command is:

    RESTART

RESTART clears all errors, sets the current joint velocity and acceleration to 0, and resets the debug variables. When the robot interface reports its status as done, RESTART reads the feedback joint values and then sends these values back to the JOINT level on succeeding cycles to maintain the current position. RESTART ignores acceleration limits.

While executing RESTART, the JOINT level reports its status as executing until the robot interface reports done. Then JOINT reports done to PRIM.

PAUSE command

The syntax of the PAUSE command is:

    PAUSE

PAUSE continues sending the most recently commanded joint values to the robot interface. PAUSE ignores acceleration limits. After sending PAUSE, JOINT reports its status as done immediately.

CARTESIAN command

The syntax of the CARTESIAN command is:

    CARTESIAN [pose-^]

where:

• pose-^ points to the position to which the robot is being moved.

CARTESIAN is best used to move through a series of points in a Cartesian motion, where the distances between successive points are small. JOINT transforms each pose it receives from PRIM into a set of goal joint values and moves the robot to the position indicated by pose-^. If necessary, JOINT scales the commanded trajectory to stay within the specified hardware limitations as it interpolates each step along the trajectory.

While executing CARTESIAN, JOINT reports its status as executing if the inter-
polated step size is larger than the system parameter next-point-scale-
threshold. PRIM should not send any new points to JOINT when the JOINT status
is executing.

If the step size is the same or smaller than this system parameter, JOINT
reports its status as next-point. The next-point status indicates that PATH
should send the next Cartesian step on the next cycle.

JOINT reports its status as done when the commanded joint values equal the
goal joint values. The done status indicates that PRIM should send a new goal
point on the next cycle.

JOINT-TRAJ command

The syntax of the JOINT-TRAJ command is:

    JOINT-TRAJ [pose-^] [traj-para-^]

where:

• pose-^ points to the position to which the robot is being moved.

• traj-para-^ points to the trajectory parameters.

JOINT-TRAJ is best used to move through large joint-interpolated path seg-
ments. JOINT transforms each pose it receives from PATH into a set of goal
joint values and moves the robot to the position indicated by pose-^. If
necessary, JOINT scales each step to stay within the limitations specified by
traj-para-^ as it interpolates the trajectory. While executing JOINT-TRAJ,
JOINT reports its status as executing if the commanded joint values are out-
side the range of the goal joint values specified by the j-delta variable.
JOINT reports done after the commanded values are within the j-delta range.

CREEP command

The syntax of the CREEP command is:

    CREEP

CREEP recovers from the joint-limit error state by commanding all joints that
are within the creep-delta distance from a joint limit to move away slowly
from the limit at a speed specified by creep-vel. The creep-delta distance
and the creep-vel velocity are user-defined values.

While executing CREEP, JOINT reports its status as executing until all joint
movements are complete. Then CREEP reports done.

JOINT Input Command Buffer

The JOINT input command buffer consists of the following variables:

inc-command-#-in
> PRIM increments this integer variable each time it sends a new command to JOINT.

input-command
> PRIM sends this integer to JOINT to identify the command. Commands are numbered as follows: Ø-RESTART, 1-PAUSE, 2-CARTESIAN, 3-JOINT-TRAJ, and 4-CREEP.

pose-^-in
> PRIM sends JOINT this pointer to the commanded pose in POSE-FILE.

traj-^-in
> PRIM sends JOINT this pointer to the traj-para in the PRIM>JOINT-TRAJ round-robin.

JOINT Status Information

To provide status feedback to the PRIM level, the JOINT level returns a status report, returns a feedback pose, and returns echoes of the input command and its incremental command number.

JOINT uses the following six variables to return status information to the PRIM level:

cycle-#-status-out
> Returns the cycle count when JOINT returns its status. The changing value of this integer variable verifies that the JOINT level is running.

inc-command-#-echo-out
> Echoes the integer count of new commands received by the JOINT level as indicated by the inc-command-#-in variable. This information enables PRIM to know for which command JOINT is returning status information.

command-echo-out
> Echoes the integer stored in inc-command-#-in. This information enables PRIM to know for which command JOINT is returning status information.

status-report
> Returns the current status of JOINT. The possible values for this integer variable and their meanings are:

Value	Meaning	Description
Ø	executing	The current point is still executing.
1	done	The joint has reached its goal location.
2	error	An error occurred. (See status-arg-out.)
3	next-point	The joint reached an intermediate path-point.

status-arg-out
> Returns the error status. The possible values for this integer variable
> and their meanings are:

Value	Meaning	Description
0	noerror	PRIM detected no errors.
1	lower-level	The servo reported an error to JOINT.
2	command-error	JOINT received an invalid command or parameters.
3	joint-limit	A joint has reached its limit.
4	reach-limit	The goal pose is outside the reach of the robot.
5	configuration	The commanded configuration is invalid.

pose-^-out
> Contains the pointer to the feedback pose, which is the output joint val-
> ues transformed to the wrist pose. During the execution of a RESTART
> command, the feedback pose gives the startup position of the robot. Dur-
> ing the execution of the CARTESIAN and JOINT-TRAJ commands, the feedback
> pose can update the Cartesian trajectory routines with the actual com-
> manded position.

JOINT Errors

When JOINT detects an error of any type, it sets the status variable to indi-
cate an error, stores the label for the error in the status-arg-out variable,
and sends the last valid joint values to the robot. At this point, COMMAND-
PROCESS does not execute any command other than RESTART, with one exception.
If the error is joint-limit, COMMAND-PROCESS allows the CREEP command to cor-
rect the error.

JOINT Processing

The three processes for the JOINT level are PRE-PROCESS, COMMAND-PROCESS, and
POST-PROCESS. PRE-PROCESS reads the command from the PATH level and the
status from the servo. COMMAND-PROCESS, the decision-processing stage, calcu-
lates trajectories for robot motion and scales the motion to meet velocity and
acceleration limits. POST-PROCESS sends the JOINT level confirmation for each
command received and performs the "housekeeping" required to prepare JOINT for
the next cycle.

JOINT preprocessing

The JOINT routine PRE-PROCESS calls NEW-COMMAND? and SERVO-STATUS.

NEW-COMMAND?

    <u>Input Variables</u>   <u>Output Variables</u>

    inc-command-#-in   new-command
    old-inc-command-#-in   old-inc-command-#-in
                                 status
                                 status-arg

Sets the new-command flag to true if the value of inc-command-#-in has
changed since the last cycle (That is, if inc-command-#-in does not
equal old-inc-command-#-in.) NEW-COMMAND? also sets the status and
status-arg variables to noerror.

SERVO-STATUS

    <u>Input Variables</u>   <u>Output Variables</u>

    inc-command-#-out   servo-status
    inc-command-#-echo-in
    status-in

Checks if the values of inc-command-#-out and inc-command-#-echo-in are
equal (indicating that status-in contains the status of the last com-
mand). If these values are equal, SERVO-STATUS sets the value of
servo-status to the value of status-in. If these values are not equal,
SERVO-STATUS sets the value of servo-status to executing.

<u>**JOINT decision processing**</u>

If the status-report variable does not indicate an error, the JOINT routine
COMMAND-PROCESS uses a case statement to determine which of the routines in
this section to execute. If the status-report variable indicates an error
other than joint-limit, COMMAND-PROCESS freezes the error state and does not
execute any command other than RESTART. COMMAND-PROCESS allows CREEP to exe-
cute if the error is joint-limit.

JOINT-RESTART

    <u>Input Variables</u>   <u>Output Variables</u>

    joints-in   output-command
    new-command   inc-command-#-out
    servo-status   servo-com-joint
                                 status-report
                                 v-current
                                 overflow cycle
                                 max-process-time
                                 min-process-time

Checks if new-command is true and, if so, sets the value of the output-command variable to RESTART, increments inc-command-#-out, sets v-current to Ø, and resets the debug variables. If new-command is false, JOINT-RESTART waits for servo-status to indicate done and then calls READ-SERVO-STATUS to set servo-com-joint to the feedback joint values.

JOINT-PAUSE

Input Variables	Output Variables
none	inc-command-#-out
	v-current

Pauses the robot, leaves the current joint values unchanged in the servo-com-joint variable, sets v-current to Ø, and increments inc-command-#-out.

CARTESIAN

Input Variables	Output Variables
pose-^-in	servo-com-joint
v-current	v-current
old-ja	

Retrieves the commanded pose and configuration flags, calls CART>JOINT and CART-CONFIGURE to convert the pose to joint values, calls SCALE to limit the joint velocities and accelerations (using the hardware maximum limits), stores the result in servo-com-joint, and calls JOINT-LIMIT-TEST. If JOINT-LIMIT-TEST does not result in an error, CARTESIAN increments inc-command-#-out. If JOINT-LIMIT-TEST results in an error, CARTESIAN sets the value of servo-com-joint to that of old-ja.

JOINT-TRAJ

Input Variables	Output Variables
pose-^-in	servo-com-joint
traj-^-in	v-current
v-current	
old-ja	

Retrieves the commanded pose, configuration flags, and trajectory parameters; calls CART>JOINT and JOINT-CONFIGURE to convert the pose to joint values; calls SCALE to limit joint velocities and accelerations (using the commanded trajectory parameters), stores the result in servo-com-joint, and calls JOINT-LIMIT-TEST. If JOINT-LIMIT-TEST does not result in an error, JOINT-TRAJ increments inc-command-#-out. If JOINT-LIMIT-TEST results in an error, JOINT-TRAJ sets the value of servo-com-joint to that of old-ja.

SCALE

Input Variables	Output Variables
xg	servo-com-joint
scaling-var	scaling-var

Scales the step from servo-com-joint to xg to meet the velocity and acceleration limits, and ensures that the joint motions are coordinated to reach their goals simultaneously.

JOINT postprocessing

The JOINT routine POST-PROCESS sends to the PRIM level confirmation for each command received, and performs the "housekeeping" required to prepare JOINT for the next command. POST-PROCESS calls CLEAN-UP and, if the input-command-var is not RESTART (or if the command is RESTART and the status-report variable indicates done), calls FEEDBACK-POSE and SET-SERVO-COMMAND.

CLEAN-UP

Input Variables	Output Variables
input-command-var	output-status-var
v-current	v-previous
servo-com-joint	old-ja

Echoes the command and inc-command-# to the PRIM level, sets the value of v-previous to that of v-current, and sets the value of old-ja to that of servo-com-joint.

FEEDBACK-POSE

Input Variable	Output Variable
servo-com-joint	RBT-POSE round-robin

Calls JOINT>CART to transform the value of servo-com-joint to a pose, and stores that pose in the RBT-POSE round-robin.

JOINT Robot-Dependent Routines

The following commands control JOINT operations that are specific to the type of robot the system is controlling. You must edit or replace these routines to accommodate different robots.

READ-SERVO-STATUS

Input Variable	Output Variable
joint-in	servo-com-joint

READ-SERVO-STATUS converts the value of the joint-in variable from the servo format to radians and returns the converted value in servo-com-joint.

SET-SERVO-COMMAND

Input Variable	Output Variable
servo-com-joint	joint-out

SET-SERVO-COMMAND scales the value of the servo-com-joint value from radians to the servo format and returns the converted value in joint-out.

REACH-CHECK

Input Variable	Output Variable
pose	status
	status-arg

REACH-CHECK checks the pose variable to see if the commanded pose is within the work volume of the robot. If the pose is not within the work volume of the robot, REACH-CHECK sets the status variable to error and the status-arg variable to reach-limit.

JOINT-LIMIT-TEST

Input Variable	Output Variable
servo-com-joint	status
	status-arg

JOINT-LIMIT-TEST tests the servo-com-joint variable to see if it exceeds the joint limits. If the servo-com-joint value exceeds the joint limits, JOINT-LIMIT-TEST sets the status variable to error and the status-arg variable to joint-limit.

JOINT>CART

Input Variable	Output Variable
servo-com-joint	pose
	conf-flag

JOINT>CART transforms the value of servo-com-joint to a pose and stores the result in the pose and conf-flag variables.

CART>JOINT

Input Variable	Output Variable
pose	xg (goal joint values)
conf-flags (POSE-FILE local	status
template)	status-arg

CART>JOINT converts the value of the pose and configuration flags to joint values and stores the result in xg, the goal joint values variable. The conf-flag variable contains the configuration flags it reads from the POSE-FILE local template.

In addition to the pose and conf-flag variables, CART>JOINT uses the old-ja variable to determine the new joint values. The variable old-ja stands for old-joint-angle. It holds the commanded joint values from the previous cycle. It is set to servo-com-joint by POST-PROCESS. This process is similar to the way PRIM handles current versus old position and velocity. See the transform documentation for your robot for details on poses and configurations.

Warning: CART>JOINT may generate a floating-point error interrupt that aborts the control process if the pose is outside the work area of the robot. Use REACH-CHECK to test the pose before using CART>JOINT. (See also REACH-CHECK.)

CART-CONFIGURE

Input Variable	Output Variable
xg	xg
old-ja	

CART-CONFIGURE reads xg and old-ja and then modifies xg to minimize joint motion by taking advantage of multiple configurations for the same pose. See the transform documentation for your robot for definitions of configurations.

JOINT-CONFIGURE

Input Variable	Output Variable
xg	xg
conf-flag	

JOINT-CONFIGURE reads xg and conf-flag and modifies the transform output to match the commanded configuration. See the transform documentation for your robot for definitions of configurations.

This chapter discusses how to incorporate user extensions to RSL. It assumes that you have loaded the NBS-supplied system tape as described in Section 5.5, "Software Installation Procedure", and that you have not yet modified the code.

The extensions described in this chapter are extensions made while developing RSL. The code is included as part of RSL on your system tape. To understand the general procedures for making similar extensions to RSL, refer to the blocks mentioned in this chapter.

11.1 UNDERSTANDING THE TYPES OF EXTENSIONS

RSL was developed in the context of the transfer task application and may be inappropriate for other applications, such as tracing an object for a deburring operation. To overcome these potential limitations, you can extend the RSL application by adding new tasks, paths, path-points, and trajectories to the existing RSL control structure.

For example, you need a new trajectory for any type of motion other than Cartesian straight-line or joint interpolated, such as circular motion. You need new path-points whenever you add another sensor to the system. When you develop a new application, both new tasks and new paths are required to provide a hierarchical decomposition of that application.

After you understand the basic procedures, you may want to make more complex extensions to RSL. For example, you can modify RSL to perform a quick change operation that changes the tool movetable while a task is executing, or you can add the ability to download RSL programs from a supervising computer. You can also add new control levels, execute control levels in parallel, or run two robots simultaneously.

11.2 ADDING A TASK TO RSL

You can extend RSL by adding a new task. Adding a task is a complex operation, that usually involves adding additional paths and path-points. This section describes how to add the MOVE-TO task as if it were a new extension to RSL, assuming the move-to path and goto path-point are present.

The syntax for the MOVE-TO task is:

        MOVE-TO [object] [grip#] [destination location type] [destination]
            [sector]

The MOVE-TO task issues a move-to path, using the current location as the starting location. If the destination location type is an array (arr), then the destination is the array sector given by the optional parameter sector. MOVE-TO updates the current location when it completes the path. Refer to the indicated blocks on the system tape for the actual MOVE-TO code.

To add the MOVE-TO task to RSL, you must make four additions. Table 11-1 lists the additions and their associated block numbers. These routines are all on the TASK level on the TASK&PATH board. The block numbers listed assume that you are on the TASK&PATH board with the OFFSET set at 9000. Remember that you have to update the directory/load blocks when you add new routines to RSL.

Table 11-1. Additions for the MOVE-TO Task.

Routine	Addition
MOVE-TO	Add this routine to execute the task, send a move-to path to the PATH level, and wait for the PATH level to report status done. Refer to block 513 for the routine MOVE-TO.
MOVE-TO-PARAM	Add this routine to read the input parameters, looking up record numbers in the object and location files. Refer to blocks 511 and 512 for the routine MOVE-TO-PARAM.
MOVE-TO-SEARCH	Add this routine to search for the proper MOVE-TO-FILE record. Refer to block 402 for the routine MOVE-TO-SEARCH.
COMMAND-PROCESS	Add MOVE-TO to the if-then-else list of legal commands that the RSL routine COMMAND-PROCESS uses to execute tasks on the TASK level. COMMAND-PROCESS is in block 591.

11.3 ADDING A PATH TO RSL

You can extend RSL by adding a new path. This section describes how to add the move-to path type as if it were a new addition to RSL. Note that lower-case move-to is a path type and not the same as the MOVE-TO task described in Section 11.2, "Adding a Task to RSL".

The syntax for the move-to path type is:

        -path- [move-to] [object] [grip#] [start location type] [start location]
             [destination location type] [destination location]

The move-to path type moves the robot quickly from near the start location to near the destination location. The approach and depart path types move the robot when it is near the start location or the destination location. Refer to the indicated blocks on the system tape for the actual move-to code.

Remember that you have to update the directory/load blocks when you add new routines to RSL.

The following steps use the move-to path as an example of the general procedure you follow to add a similar path to RSL. The block numbers listed assume that you are on the RSL board with the OFFSET set at 8000.

1. Define an RSL data structure for the new path type by creating a SMACRO variable owner that lists the parameters for the new path type. The variable owner defines the record format for the move-to data structure file, described in Section 9.2, "RSL Overview".

   Insert the new file declaration in an empty block between blocks 141 and 149, the blocks reserved for RSL path-type file declarations. List block 141 to see the move-to path parameter file MOVE-TO-FILE.

2. Add the new path type to the list of legal path types. Block 195 contains the sequential variable owner path-type-list that defines the legal RSL path types. List block 195 to see the addition of the move-to sequential variable to the path-type-list owner.

3. Add a routine that compiles the path parameters and starts the path-point (ppt) list. The routine reads the new command and all its parameters, looks up the record numbers for the locations and object, and creates a path-point list in the RSL PATH-POINT-FILE. The routine should store the results of reading the command in the file created in Step 1. List blocks 411 and 412 to see the routine MOVE-TO.

   List blocks 413 and 414 to see the optional routine ?MOVE-TO that displays information about all currently defined move-to paths. You can create a similar routine for other path types.

4. Add the new path type to the case statement in the RSL routine -path- that starts compiling an RSL path. List block 491 to see the move-to path type in the case statement.

5. Initialize the new path file created in Step 1, by using the SMACRO file operator ~re-init-file. List block 993 to see the initialization of the MOVE-TO-FILE.

11.4 ADDING A PATH-POINT TO RSL

You can extend RSL by adding a new path-point. This section describes how to add a range path-point that positions the tool point at a given distance from a surface, using a sonar range finder. Although the range path-point is included with RSL, you cannot use this path-point without a sonar and additional hardware circuitry to enable RCS to read the range.

The syntax for the range path-point is:

       -ppt- range [sonar#] [range] [threshold] [{X, Y, Z}] [loc-phrase]
           [traj-phrase]

The range path-point translates the tool point along the axis of the loc-phrase frame, until the range read by the specified sonar is within the threshold of the range. Refer to the indicated blocks on the system tape for the actual range code.

Remember that you have to update the directory/load blocks when you add new routines to RSL. To add the range path-point, you have to add code on the RSL board and the TASK&PATH board.

Adding Code on the RSL Board

The following steps describe the additions you need to make on the RSL board to add the range path-point or a similar path-point to RSL. The block numbers listed assume that you are on the RSL board with the OFFSET set at 8000.

1. Define an RSL data structure for the new path-point by creating a SMACRO variable owner that lists the parameters for the new path-point. The variable owner defines the record format for a new data structure file, similar to the data structures defined in Section 9.2, "RSL Overview".

   Insert the new file declaration in an empty block between blocks 161 and 169, the blocks reserved for RSL path-point command parameters file declarations. List block 162 to see the range path-point parameter file RANGE-FILE.

2. Add the new path-point to the list of legal path-points. Block 192 contains the sequential variable owner ppt-command-list that defines the legal RSL path-points. List block 192 to see the addition of the range path-point to the ppt-command-list owner.

3. Add a routine to compile the new ppt, read ppt syntax fields, look up the record numbers for the location, and add records to the trajectory, range, and path-point files. The routines must read and check all of the ppt syntax fields before storing any records. You must leave the files in a clean state in case any errors occur in the ppt syntax fields. List block 343 to see the routine RANGE.

4. Add a garbage collection routine to remove records added by the routine in Step 3. The routine should remove the records when a path containing a range ppt is redefined. List block 344 to see the routine RANGE-REMOVE.

5. Add the new path-point to the case statement in the RSL routine -ppt- that defines path-points. List block 391 to see the addition of the range path-point to the case statement.

6. Add the garbage collection routine in Step 4 to the case statement in the RSL routine PPT-REMOVE. List block 395 to see the addition of the routine RANGE-REMOVE to the case statement.

7. Initialize the new path-point file created in Step 1, by using the SMACRO file operator ~re-init-file. List block 993 to see the initialization of the RANGE-FILE.

Adding Code on the TASK&PATH Board

The following steps describe the additions you need to make on the TASK&PATH board to add the range path-point or a similar path-point to RSL. All the additions on the TASK&PATH board are to the PATH level. The block numbers listed assume that you are on the TASK&PATH board in the PATH vocabulary with the OFFSET set at 10000.

1. Add the variables needed to execute routines for the new path-point. The variables you need to add depend heavily on the type of path-point you are adding to RSL. List block 141 to see the variables needed for the range path-point. List block 142 to see the additional variables that give addresses of the ports for the sonar interface, and some constants used in the interface protocol.

2. Add any routines needed to process information from a sensor. These routines depend heavily on the path-point and sensor you are adding to RSL. List block 251 to see the addition of the range path-point routine SONAR-PORT-INIT that initializes the sonar interface port. List block 252 to see the addition of the routine SONAR-READ that reads the sonar range, converts the range to inches, and stores the result in sonar-range.

3. Add any read routines specified in Step 2 to the RSL routine PRE-PROCESS. List block 299 for the addition of SONAR-READ to the PRE-PROCESS routine for the PATH level. This addition enables you to read the sonar every cycle, making data available as soon as needed. (The SONAR-READ routine is currently commented out.)

4. Add the command routines needed to execute the new path-point in empty blocks between blocks 300 and 399. For the range path-point, list block 331 to see the routine TRANSLATE, which translates the current tool pose by a specified delta along the specified axis. TRANSLATE stores the result in prim-com-pose.

   List block 332 to see the routine HALT, which sets prim-com-pose to the current tool pose and sets the neighborhood fields of the current trajectory template to 0. HALT commands the robot to halt at the current tool pose.

   List block 411 to see the routine R-NEW-PPT, which retrieves the range path-point parameters and initializes the range path-point variables.

   List blocks 412 and 413 to see the routine RANGE, which executes the range path-point.

5. Initialize the new path-point routines and variables. List blocks 982 and 983 to see the initialization of these variables and routines for the range path-point.

11.5 ADDING A TRAJECTORY TYPE TO RSL

You can extend RSL by adding a new trajectory type. This section describes
how to add a servo trajectory type to RSL. The code that implements this
trajectory type is included on the system tape and is loaded when you load
RSL.

The syntax for the servo trajectory phrase is:

        servo [sensor-mtb] [inv-sensor-mtb] [goal-mtb] [trn-max-acc]
            [trn-max-vel] [trn-min-vel] [max-range] [trn-nbrhd] [rot-max-acc]
            [rot-max-vel] [rot-min-vel] [max-angle] [rot-nbrhd]

The servo trajectory type moves the sensor toward the goal (target pose plus
goal-mtb). The servo trajectory reports done when the robot is within the
neighborhood you specify in trn-nbrhd and rot-nbrhd. Servo decreases the
translation velocity linearly from trn-max-vel (for ranges greater than or
equal to the max-range) to trn-min-vel at the goal (range=Ø). Servo decreases
the rotation velocity linearly from rot-max-vel (for angles greater than or
equal to max-angle) to rot-min-vel at the goal (angle=Ø). Refer to the indi-
cated blocks on the system tape for the actual servo code.

Remember that you have to update the directory/load blocks when you add new
routines to RSL.

To add the servo trajectory type, you have to add code on the RSL board, the
TASK&PATH board, and the PRIM board.

Adding Code on the RSL Board

The following steps describe the additions you need to make on the RSL board
to add the servo trajectory type or a similar trajectory to RSL. The block
numbers listed assume that you are on the RSL board with the OFFSET set at
8ØØØ.

1. Define an RSL data structure for the new trajectory type by creating a
    SMACRO variable owner that lists the parameters for the new trajectory
    type. The variable owner defines the record format for a new data struc-
    ture file, similar to the data structures defined in Section 9.2, "RSL
    Overview".

    Insert the new routine in an empty block between blocks 121 and 129, the
    blocks reserved for RSL trajectory file declarations. List block 123 to
    see the servo trajectory-parameter file SERVO-FILE.

2. Add the new trajectory type to the list of legal trajectory types. Block
    194 contains the sequential variable owner traj-list that defines the
    legal RSL trajectory types. List block 194 to see the addition of the
    servo sequential variable to the traj-list owner.

3. Add a routine to read the new command and all its parameters. The routine should store the results of reading the command in the local template of the file created in Step 1. List block 322 to see the routine READ-SERVO-TRAJ.

4. Add the routine created in Step 3 to the case statement in the RSL routine READ-TRAJ-PHRASE. List block 337 to see the addition of READ-SERVO-TRAJ to the case statement.

5. Add the routine created in Step 1 to the case statement in the RSL routine STORE-TRAJ-PHRASE. List block 338 to see the addition of SERVO-FILE to the case statement.

6. Add the routine created in Step 1 to the case statement in the RSL routine REMOVE-TRAJ-PHRASE. List block 339 to see the addition of SERVO-FILE to the case statement.

7. Add a round-robin to pass the new trajectory type parameters from the PATH level to the PRIM level. Add the round-robin in an empty block between blocks 511 and 519, the blocks reserved for RSL round-robins. The round-robin enables the PATH level to change parameters every cycle, if necessary. List block 511 to see the servo round-robin PATH>PRIM-SRV.

8. Initialize the new trajectory file created in Step 1, by using the SMACRO file operator ˜re-init-file. List block 993 to see the initialization of the SERVO-FILE.

Adding Code on the TASK&PATH Board

The following steps describe the additions you need to make on the TASK&PATH board to add the servo trajectory type or a similar trajectory type to RSL. All the additions on the TASK&PATH board are to the PATH level. The block numbers listed assume that you are on the TASK&PATH board in the PATH vocabulary with the OFFSET set at 10000.

1. Add an integer variable to the SMACRO variable owner reserved-record# to access the round-robin created in Step 7 of the previous section. List block 173 to see the addition of the servo variable path-srv-ˆ to the reserved-record# owner.

2. Add the new trajectory type file to the case statement in the RSL routine TRAJ-PHRASE. This addition enables you to retrieve the appropriate record from the data structure file, and also makes the new trajectory type legal for the PATH level. List block 322 to see the addition of SERVO-FILE to the case statement.

3. Add the new trajectory type to the case statement in the RSL routine HALT block 332.

4. Add the new trajectory type and file to the case statement in the RSL routine TRAJ-ROUND. TRAJ-ROUND sends the trajectory parameters to the trajectory round-robin. List block 804 to see the addition of the servo trajectory type and SERVO-FILE for the PATH>PRIM-SRV round-robin.

5. Initialize the new trajectory variable created in Step 1. The variable
    identifies the round-robin record for the RSL routine TRAJ-ROUND. List
    block 981 to see the initialization of path-srv-^.

Adding Code on the PRIM Board

The following steps describe the additions you need to make on the PRIM board
to add the servo trajectory type or a similar trajectory type to RSL. The
block numbers listed assume that you are on the PRIM board with the OFFSET set
at 11000.

1. Add the variables and routines for the new trajectory type. The variables
    you need to add depend heavily on the type of trajectory you are adding to
    RSL. Refer to blocks 730 through 739 for the servo trajectory variables
    and routines.

    The Cartesian straight-line trajectory type is the basis for the servo
    trajectory. The routines transform the velocity of the tool point to the
    sensor frame, command the goal pose as the goal of both the rotation and
    translation parts of the trajectory, compute the maximum velocity as a
    function of the range to the goal, and transform the result back into a
    motion of the tool point.

2. Add the new trajectory type to the case statement in the RSL routine TRAJ.
    This addition makes the new trajectory type legal for the PRIM level.
    List block 791 to see the addition of the servo trajectory type to the
    case statement.

This chapter describes two example applications of RCS. NBS developed each application for a different project. The first application describes a machining workstation that is part of a totally automated factory project. The second application describes a field materiel-handling robot that is part of an Army-sponsored research project.

12.1 A MACHINING STATION IN THE AUTOMATED MANUFACTURING RESEARCH FACILITY

The National Bureau of Standards is developing an experimental factory called the Automated Manufacturing Research Facility (AMRF). The AMRF will operate as a small, totally automated, batch machine shop.

Currently the AMRF consists of five workstations: three machining stations, a cleaning and deburring station, and an inspection station. The AMRF maintains a central database that provides information for the five workstations. Each workstation uses robotic material handling for tasks such as machine-tool loading and unloading, deburring parts, and loading a collet into a lathe. The horizontal machining station and the cleaning and deburring station use RCS to maintain real-time control over the robot.

The following sections discuss the horizontal machining workstation in more detail and give an example of unloading an incoming parts tray.

For more information, read the IEEE Computer Society reprint entitled, "A Hierarchically Controlled, Sensory Interactive Robot in the Automated Manufacturing Research Facility". This paper is a reprint from the IEEE International Conference on Robotics and Automation, St. Louis, Missouri, March 25 to 28, 1985.

The Horizontal Machining Workstation

This example discusses the horizontal machining workstation. This workstation contains a horizontal-machining center and a materiel-handling robot, the Cincinnati Milacron T3 hydraulic, six-degree-of-freedom manipulator. The function of the T3 robot is to load part blanks into the horizontal-machining center fixtures and then unload the machined parts. The T3 robot also loads and unloads the parts from the part trays and buffers of the workstation.

To meet the requirements of the AMRF, NBS equipped the T3 with a hierarchical real-time control system (RCS), a 3-D vision system, a watchdog safety system, an active pedestal, a quick-change device, and an instrumented servo-controlled gripper.

Figure 12-1 shows the major robot-related components of this workstation and
the workstation control system, which sends commands to the T3 RCS.
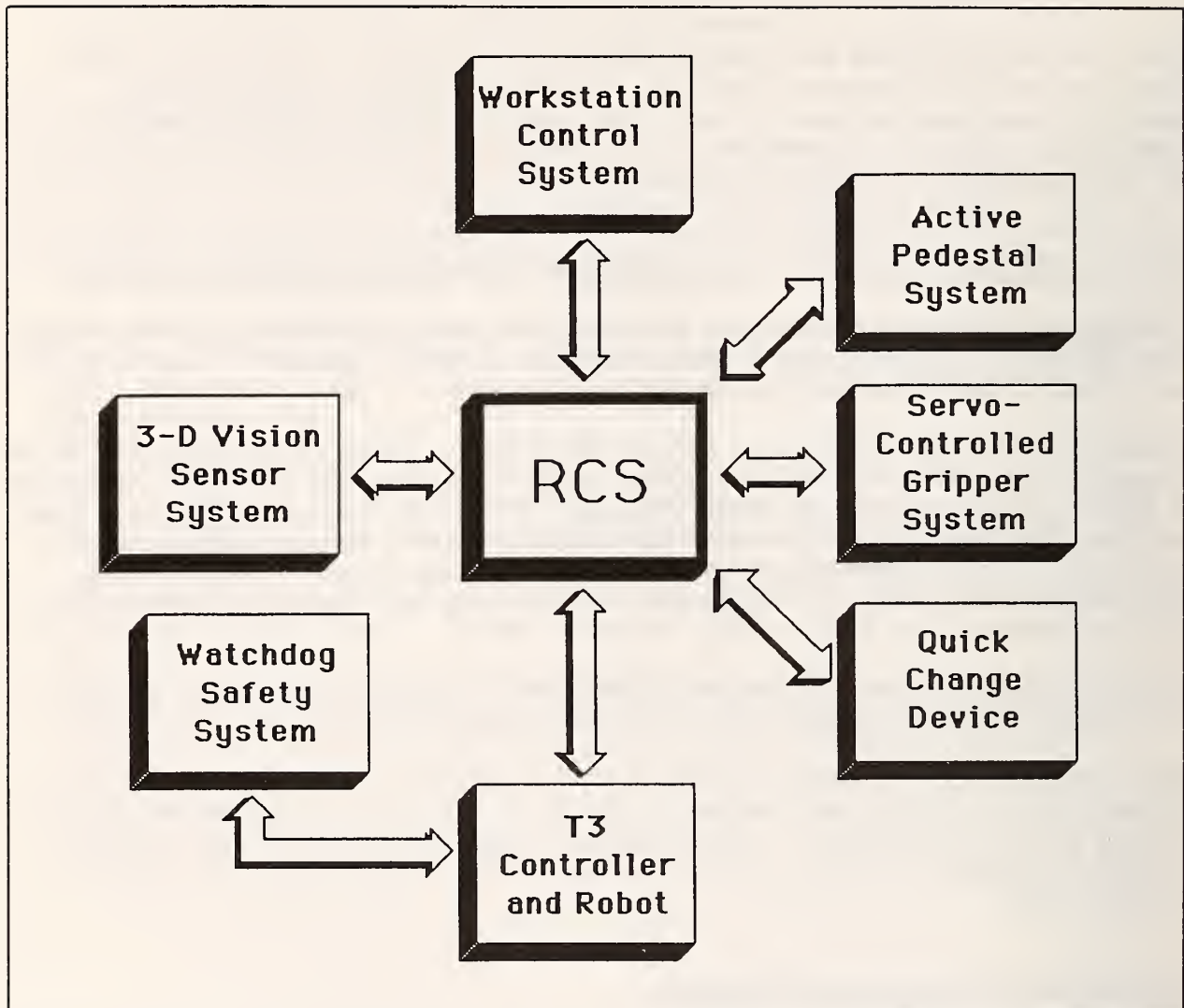
Figure 12-1. Major robot-related components of the horizontal
machining workstation.

Table 12-1 lists the functions of the major robot-related components of the horizontal machining workstation.

Table 12-1. Functions of the Major Robot-Related Components of
the Horizontal Machining Workstation.

Component	Function
RCS	Controls the operation of the T3 robot, the active pedestal system, and the quick change device.
3-D Vision Sensor System	Locates and identifies objects.
Watchdog Safety System	Monitors individual joint and tool-point motions of the robot to prevent the robot from damaging itself or other equipment.
Active Pedestal System	Regrips parts.
Quick Change	Changes end effectors.
Servo-Controlled Gripper System	Enables the T3 to open a gripper to a specified width or close a gripper with a specified force.

The hardware and software configuration of the T3 RCS is more complex than the RSL configuration described in earlier chapters, because the T3 RCS supports additional devices.

Hardware configuration of the T3 RCS

The hardware configuration of RCS for the horizontal machining workstation consists of six Intel 86/30 processor boards communicating via a MULTIBUS. Three of the 86/30 boards contain the task decomposition levels: TASK, SUBTASK, E-MOVE (elemental move), PRIM (primitive), PARTS GRIPPER, VALVE GRIPPER, and QUICK CHANGE.

The final robot-dependent level, T3, is on a separate 86/30 board. Of the other two remaining 86/30 boards, one contains a diagnostics system and the communications process (COMM), and the other controls the graphics display monitor.

The 86/30 boards have parallel I/O and A/D ports for communicating with sensors and actuators. For example, the board containing the E-MOVE and PRIM control levels has access to proximity sensors and gripper beam-break sensors through the parallel I/O ports of the board.

This implementation of RCS also includes six other boards: two memory boards for the common memory, which contains user files, communications buffers, and the system dictionary; a DMA (Direct Memory Access) board that provides communications with the vision system; two 68000 processor boards that provide access to other workstations on the network; and the board for controlling the hard disk and tape drive.

Figure 12-2 shows the T3 RCS hardware configuration.
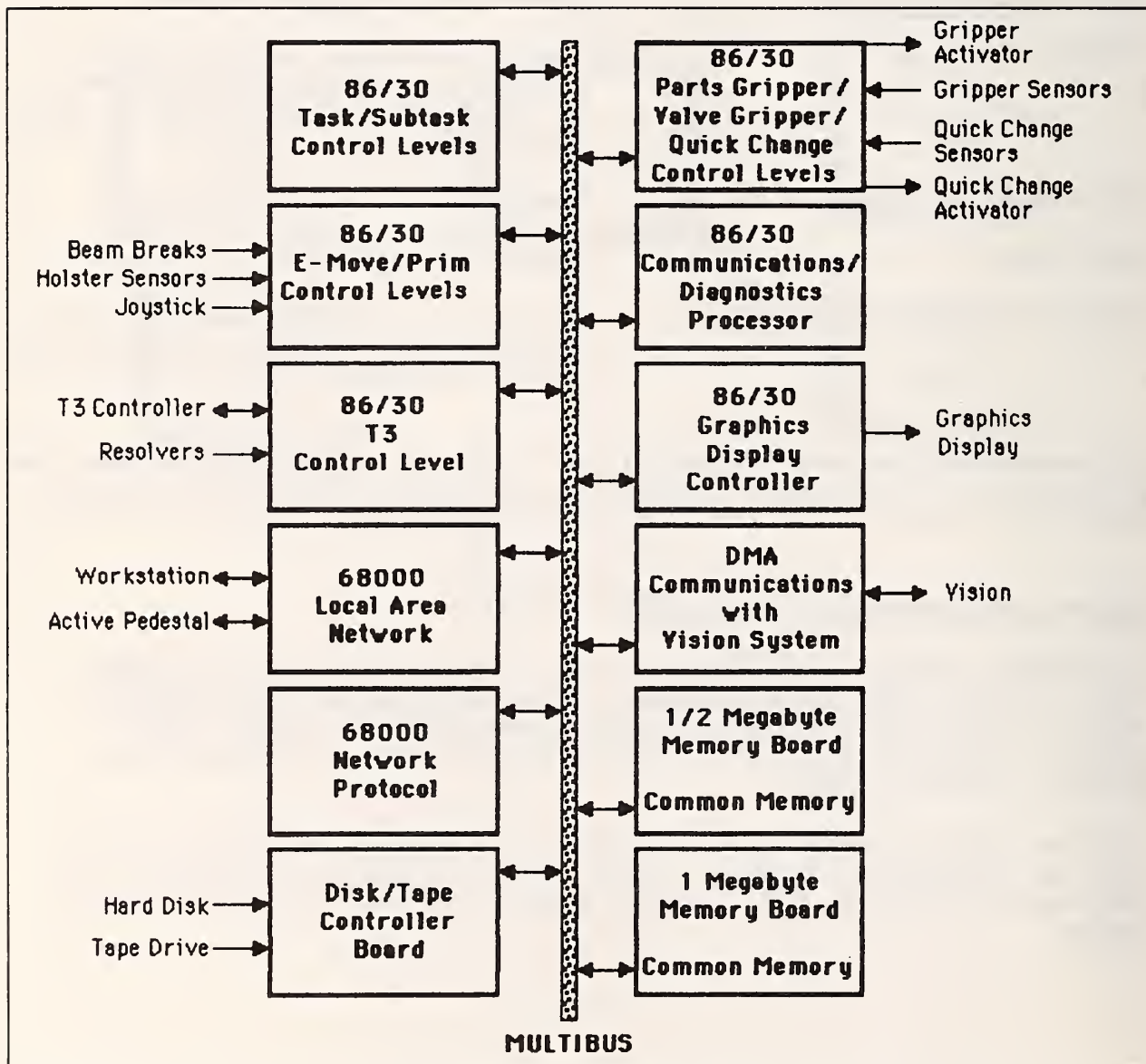
Figure 12-2. T3 RCS hardware configuration.

12.1 A MACHINING STATION IN THE AUTOMATED MANUFACTURING RESEARCH FACILITY

Software configuration of the T3 RCS

The RCS software configuration for the horizontal machining workstation consists of task decomposition control levels similar to the RSL application control levels. This application of RCS decomposes tasks using the control levels: TASK, SUBTASK, E-MOVE, PRIM, and T3. The T3 level is robot dependent, transmitting the appropriate commands to the T3 controller.

In addition, the control levels PARTS GRIPPER, VALVE GRIPPER, and QUICK CHANGE execute in parallel with the PRIM level, enabling the gripper system to position the gripper independently of the T3 robot motion. The control levels PARTS GRIPPER, VALVE GRIPPER, and QUICK CHANGE transmit commands to the two grippers and to the quick change actuator, respectively. Figure 12-3 shows the control-level hierarchy.
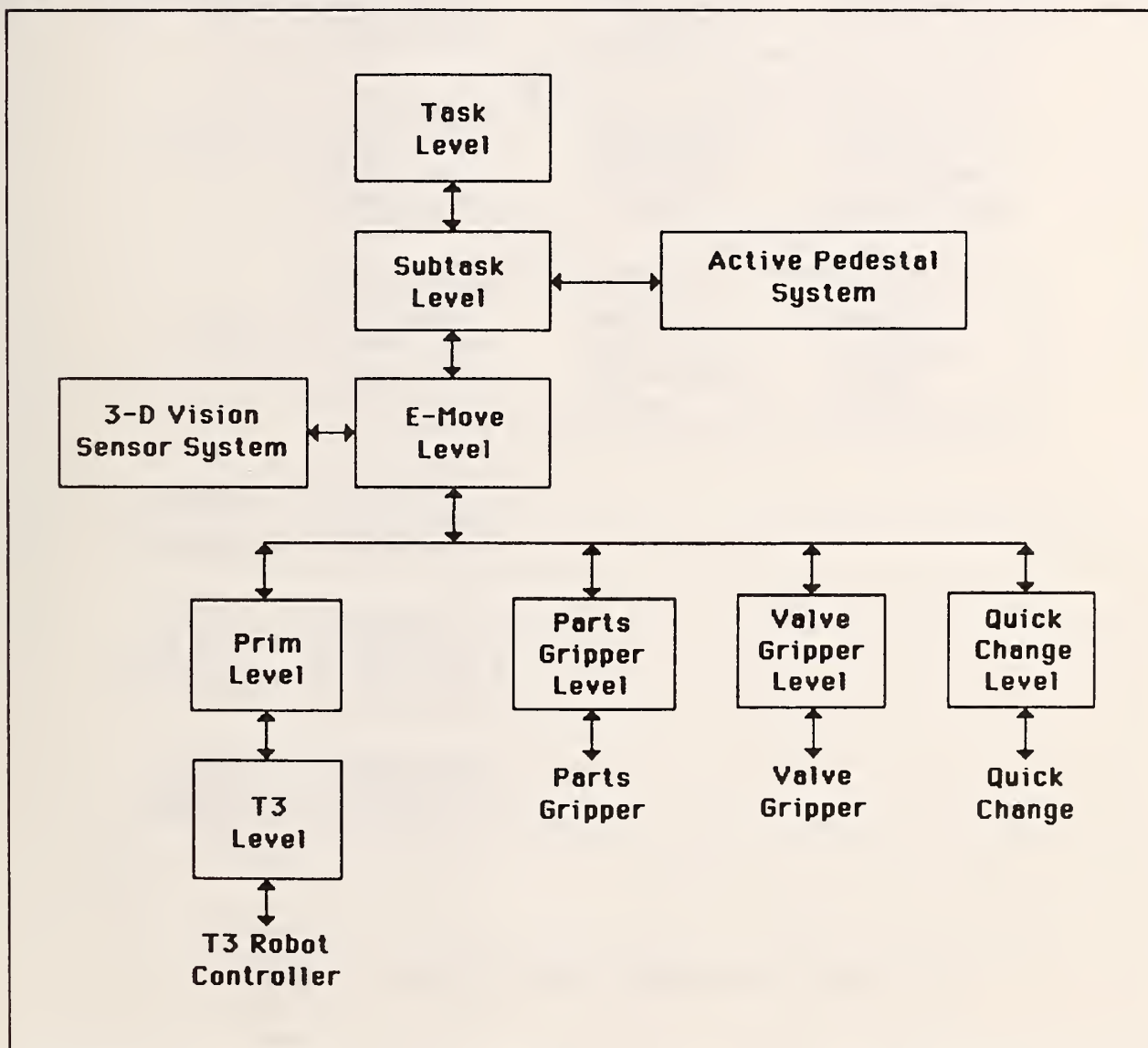
Figure 12-3. T3 RCS control-level hierarchy.

12.1 A MACHINING STATION IN THE AUTOMATED MANUFACTURING RESEARCH FACILITY

The COMMUNICATIONS/DIAGNOSTICS processor manages communications between levels. This processor transfers the command and status buffers between levels every 40 milliseconds, as set by the fixed cycle time of the T3 RCS.

Each control level processes a set of commands of decreasing complexity. A typical command at the TASK level decomposes into several robot movements, while a command at the PRIM level typically becomes one simple robot movement.

For example, a TRANSFER command consists of the following sequence of steps: moving to the specified object at the specified location, identifying the object orientation using the vision system, grasping the object, moving the object to the destination point, and releasing the object. The other control levels decompose these steps into simpler and simpler actions. For example, the command DELTA-MOVE at the PRIM level moves the robot a short distance from its current position.

Figure 12-4 shows the commands that each control level can process.

Task	TRANSFER UNLOAD MOVE POSITION	REFIXTURE ACQUIRE PAUSE	

Subtask	GET-ENDEFF FIX-GRIP GET-OBJECT PLACE-OBJ	GOTO-ENDPT GOTO-DEST MOVE-OBJ>D S-PAUSE	>POSITION RELEASE MOVE-SAFE

E-Move	MOV-TO-LOC MOV-TO-OBJ MOV-OBJ-TO MOV-TO-VU	LOCATE-OBJ QC-DETACH QC-ATTACH E-PAUSE	GRASP-OBJ RELEASE WITHDRAW MOV-TO-HOL

Prim	DPART-THRU GO-THRU APPR-THRU STOP-AT-PT GOTO-PT	GO-UNTIL CONTACT SEAT DELTA-MOVE EXTRACT	CONNECT UNSEAT REMOVE PAUSE ROBOT-INIT

Parts Gripper	POSITION OPEN-GRIP CLOSE-GRIP

Valve Gripper	POSITION OPEN-GRIP CLOSE-GRIP

Quick Change	UNLOCK-QC LOCK-QC

Figure 12-4. Control level commands for the T3 RCS.

12.1 A MACHINING STATION IN THE AUTOMATED MANUFACTURING RESEARCH FACILITY

Whenever possible, this RCS application uses the SMACRO state table statement to decompose tasks. Figure 12-5 shows an example state table routine, QC-DETACH, which decomposes a quick change operation, disengaging the current end effector on the robot.

```
routine QC-DETACH-ST                                            EDEF
    state-table    ref-action         "qc-status-in"
        state:     new-command        XX             EXECUTING
                                                     GET-HOLSTER-D CONTACT
        state:     XX                 "executing"    EXECUTING
        state:     contact-made       "locked"       EXECUTING  QC-UNLOCK
        state:     contact-made       "unlocked"     EXECUTING  SEAT
        state:  ⌐  seated             "unlocked      EXECUTING  EXTRACT
        state:     extracted          "unlocked"     EXECUTING  VERIFY-
                                                                DETACH
        state:     detached           XX             EXECUTING  DEPART-
                                                                HOLSTER
        state:     executing          XX             EXECUTING
        state:     delta-move-done    XX             DONE

        default-state:  STATE-ERR-MSG

    end-state-table

end-routine
```

Figure 12-5. The QC-DETACH routine.

In the QC-DETACH routine, RCS first gets the correct holster position information and moves the robot into contact with the holster. The application uses proximity sensors on the holster to determine when the robot contacts the holster. After the contact, QC-DETACH commands the quick change device to unlock, disconnecting the end effector and dropping it into the holster. The robot then slides the end effector to the seat position and moves away slightly. RCS checks the sensors in the robot wrist to verify the detach. After the robot detaches the end effector, it departs from the holster.

Each control level uses similar routines to decompose the commands at that level. Each control level consists of an executing routine that calls the routines PRE-PROCESS, STATE-TABLE, and POST-PROCESS. These routines perform the RCS functions of preprocessing, decision processing, and postprocessing, respectively.

T3 UNLOAD Tray Example

One function of the T3 robot is to unload incoming parts from a tray and store them in a buffer area. When the workstation sensors detect an incoming parts tray, the workstation controller sends an UNLOAD command to the TASK level. The workstation controller also sends the tray location point and the unload buffer area as UNLOAD command parameters. RCS must obtain information about the contents of the parts tray from the AMRF central database.

For this example, suppose the tray contains two rectangular part blanks and a valve body, as shown in Figure 12-6.
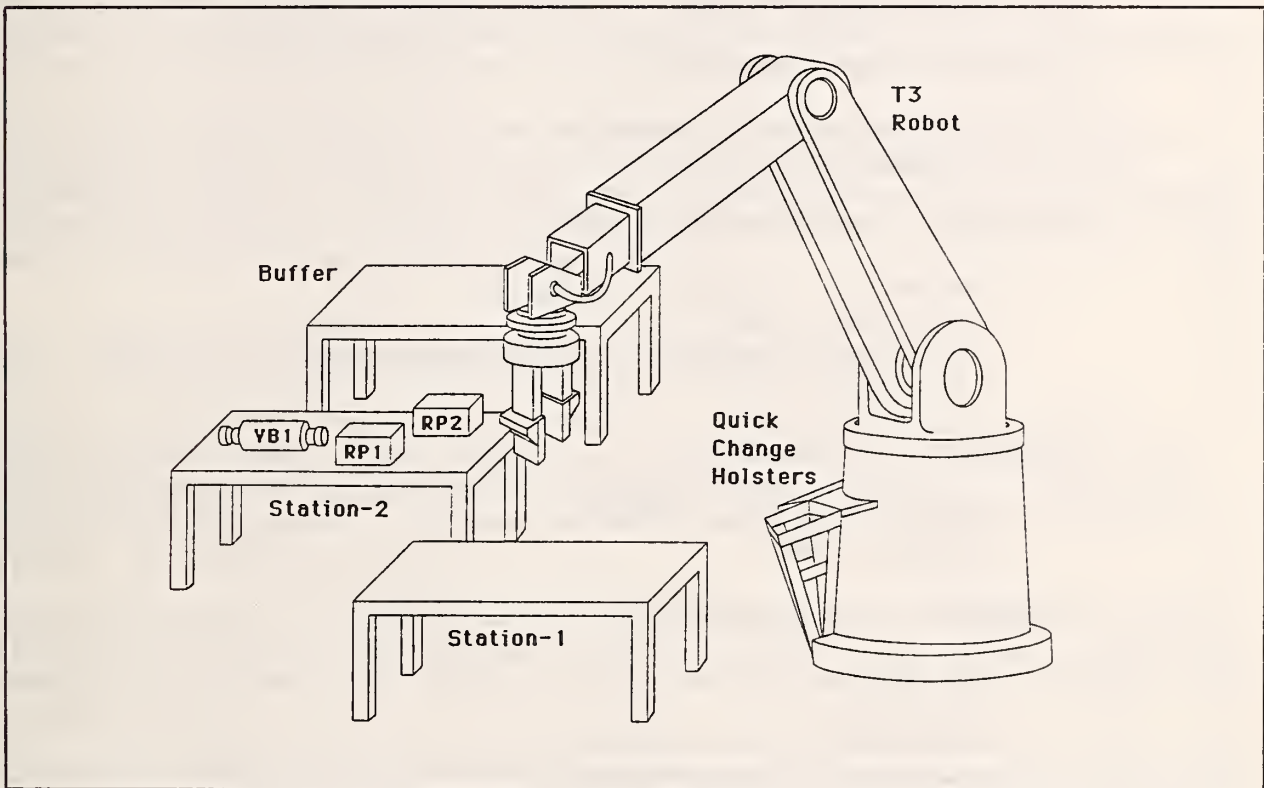
Figure 12-6. Example UNLOAD situation for the T3 robot.

The rectangular parts, RP1 and RP2, require the T3 to use a parts gripper, and the valve body, VB1, requires the T3 to use a valve gripper. Assume that the rectangular parts gripper is attached to the robot. Figure 12-7 gives a pseudocode example of the sequence of control statements generated by the UNLOAD command.

12.1 A MACHINING STATION IN THE AUTOMATED MANUFACTURING RESEARCH FACILITY

Figure 12-7 lists statements down to the E-MOVE control level. Each indentation indicates statements at the next lower control level.

```
UNLOAD ( STATION-2, BUFFER, SAFE )

     GET-OBJECT ( RP1, STATION-2, SECTOR-3 )

          MOV-TO-VU ( STATION-2, SECTOR-3 )
          LOCATE-OBJ ( RP1 )
          MOV-TO-OBJ ( RP1 )
          GRASP-OBJ ( RP1 )

     PLACE-OBJ ( RP1, BUFFER )

          MOV-OBJ-TO ( RP1, BUFFER )
          RELEASE ( RP1 )

     GET-OBJECT ( RP2, STATION-2, SECTOR-4 )

          MOV-TO-VU ( STATION-2, SECTOR-4 )
          LOCATE-OBJ ( RP2 )
          MOV-TO-OBJ ( RP2 )
          GRASP-OBJ ( RP2 )

     PLACE-OBJ ( RP2 BUFFER )

          MOV-OBJ-TO ( RP2, BUFFER )
          RELEASE ( RP2 )

     GET-ENDEFF ( VALVE-GRIPPER )

          MOV-TO-HOL ( )
          QC-DETACH ( )
          MOV-TO-HOL ( VALVE-GRIPPER )
          QC-ATTACH ( VALVE-GRIPPER )

     GET-OBJECT ( VB1, STATION-2, SECTOR-2 )

          MOV-TO-VU ( STATION-2, SECTOR-2 )
          LOCATE-OBJ ( VB1 )
          MOV-TO-OBJ ( VB1 )
          GRASP-OBJ ( VB1 )

     PLACE-OBJ ( VB1, BUFFER )

          MOV-OBJ-TO ( VB1, BUFFER )
          RELEASE ( VB1 )

     GOTO-ENDPT ( SAFE )
```

Figure 12-7. Pseudocode example of a T3 UNLOAD command.

12.1 A MACHINING STATION IN THE AUTOMATED MANUFACTURING RESEARCH FACILITY

STATION-2 and BUFFER are location-point arrays and SAFE is a location point. The SECTOR parameter indicates which array position contains the specified part. The TASK level obtains the value of SECTOR from the AMRF database before the first SUBTASK command, GET-OBJECT.

The objects RP1, RP2, and VB1 have associated grip and vision information. The control-level routines obtain much of the information needed to execute the UNLOAD task from the files in common memory. For example, when the T3 must move from the BUFFER to the holsters for a quick change operation, the system searches the trajectory file for a trajectory between the array BUFFER and the fixed holster location point HOL-SAFE. If the system finds a trajectory, it uses the path-points and velocity parameters to move the robot; otherwise, it uses the end points and default parameters.

The UNLOAD example includes three sequences of GET-OBJECT/PLACE-OBJ operations--one sequence for each object. The example includes an additional GET-ENDEFF operation after the first two objects, because the T3 must change grippers to pick up the valve body part. After the T3 unloads the valve body part, it moves to the location labeled SAFE.

12.2 THE FIELD MATERIEL-HANDLING ROBOT CONTROL SYSTEM

The U.S. Army Human Engineering Laboratory is developing a Field Materiel-Handling Robot (FMR). When completed, the FMR project will include a specially developed robot designed to automate materiel handling. The Human Engineering Laboratory is sponsoring NBS to develop an RCS-based robot controller for the FMR project.

One proposed task for the FMR is to locate, acquire, and transfer a randomly oriented pallet load from a truck bed to a conveyor. The following sections describe the hardware and software configurations required to accomplish the transfer task.

The FMR application uses an extended version of RSL. The extensions add path-points to use the sensors mounted on the FMR end effector. The discussion of this example assumes that you are familiar with the information on RSL in Chapter 9, "Robot Sensor Language (RSL)", and Chapter 10, "RSL Control Levels".

Hardware Configuration for the FMR

The specifications for the FMR robot include a reach of 25 feet with the ability to move a 4,000-pound load at speeds of up to 150 inches per second. Commercially available robots cannot meet these specifications. NBS uses the Unimate 4000 robot to test software and sensor development.

NBS developed a forklift-like end effector for the Unimate 4000 robot. The fork enables the robot to insert tines into a pallet to transport the materiel securely on the pallet. The fork also provides a structure on which to place

the sensors needed to position the fork for picking up a randomly oriented pallet. Figure 12-8 shows the fork and sensor hardware and the associated coordinate frame.
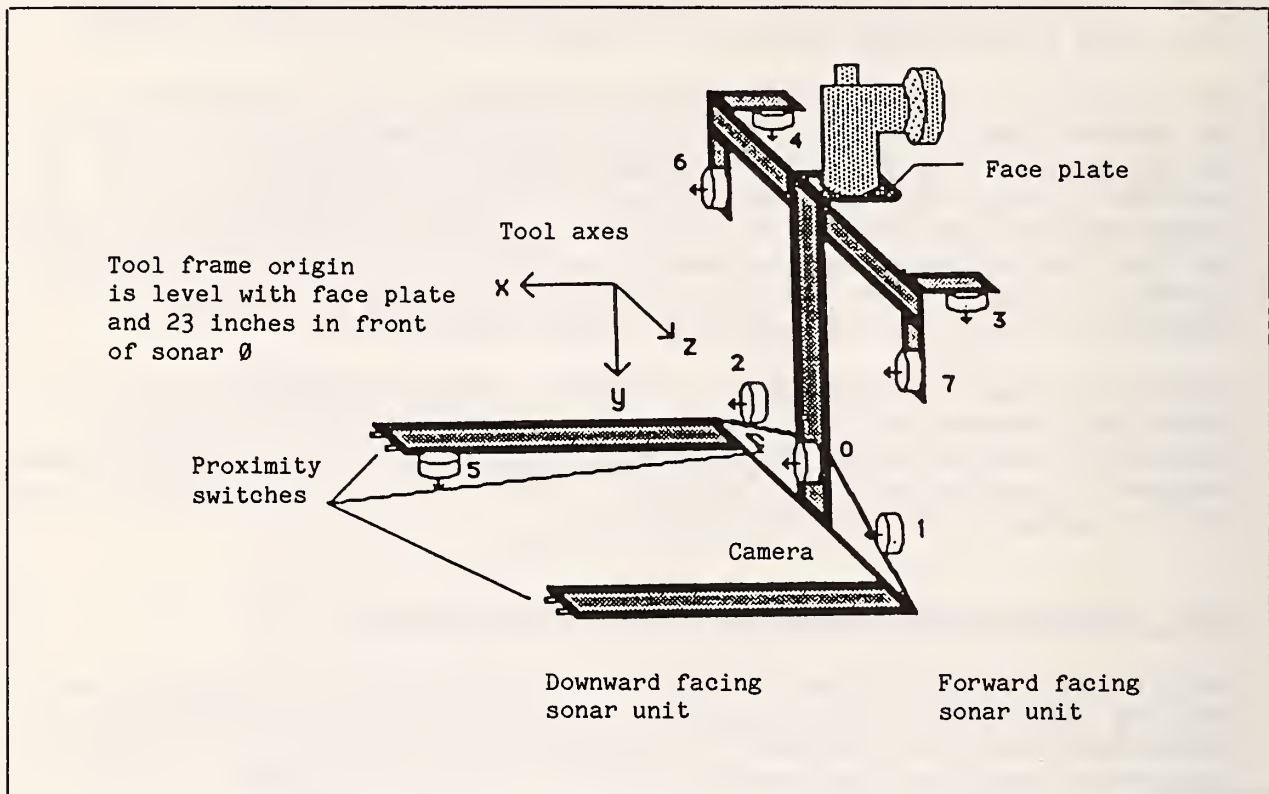
Figure 12-8. Fork and sensor hardware for the FMR.

The sensor hardware enables the robot to orient the fork with the truck bed, to align the fork with the desired entry side of the pallet, and to guide the fork under the pallet. The sensors are Polaroid ultrasonic ranging devices or sonars, and optical proximity switches. Routines can control robot motions, such as translations along and rotations about the tool axes, using the sonar sensors shown in Figure 12-8. For example, routines can control a roll motion about the X-axis using sonars 3 and 4.

The FMR application uses the same RCS hardware configuration as RSL. The FMR contains four 86/30 processor boards containing the four RSL control levels TASK, PATH, PRIM, and JOINT; a 512K memory board for common memory; and the tape and disk controller board. The boards communicate through a MULTIBUS.

Figure 12-9 shows the hardware configuration for the FMR example.
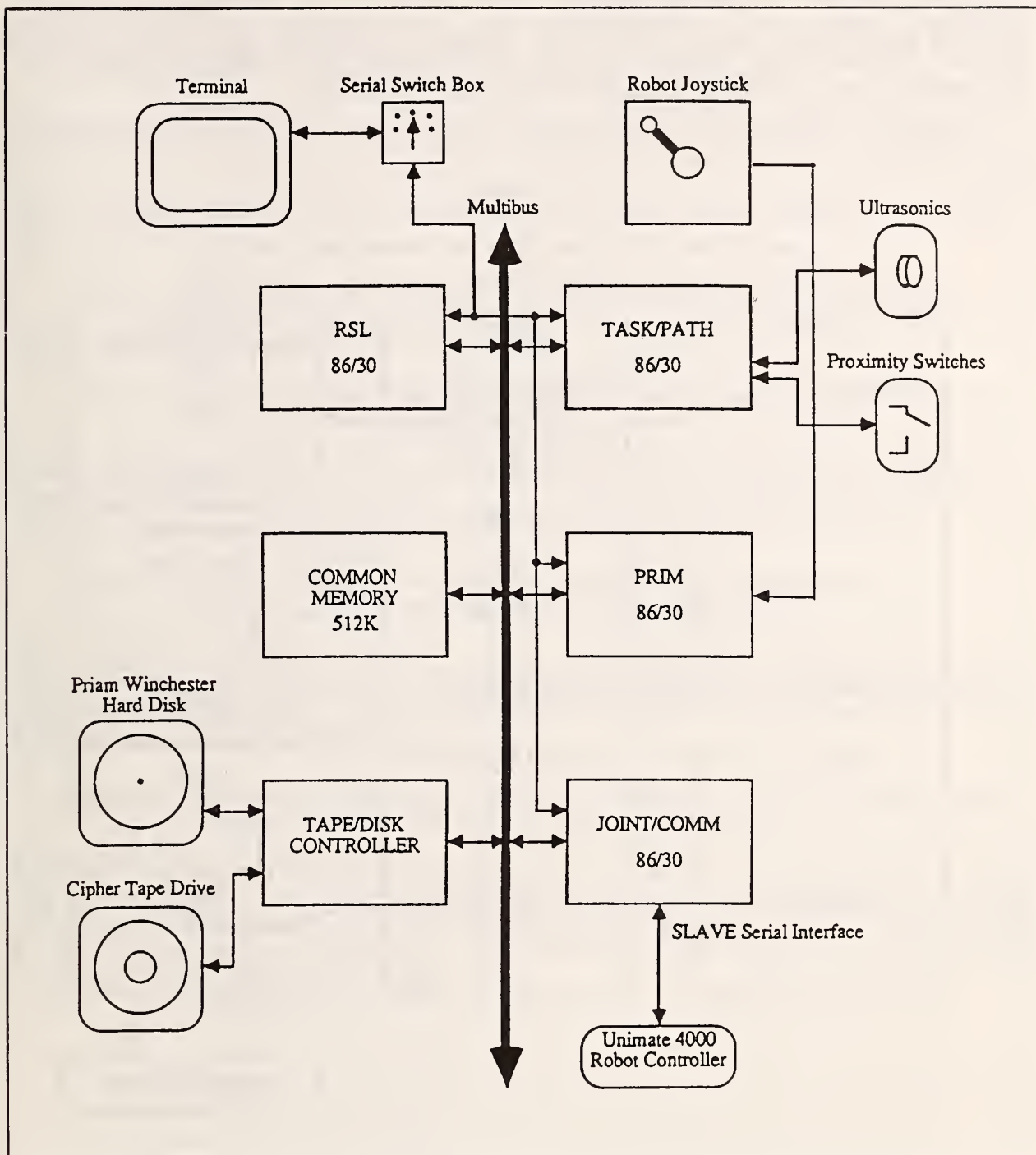
Figure 12-9.   RCS hardware configuration for the FMR.

Software Configuration for the FMR

The FMR application uses the same RCS software configuration as the RSL application. Figure 12-10 reviews the RSL control-level hierarchy and shows the RSL data types and common memory data structure files.
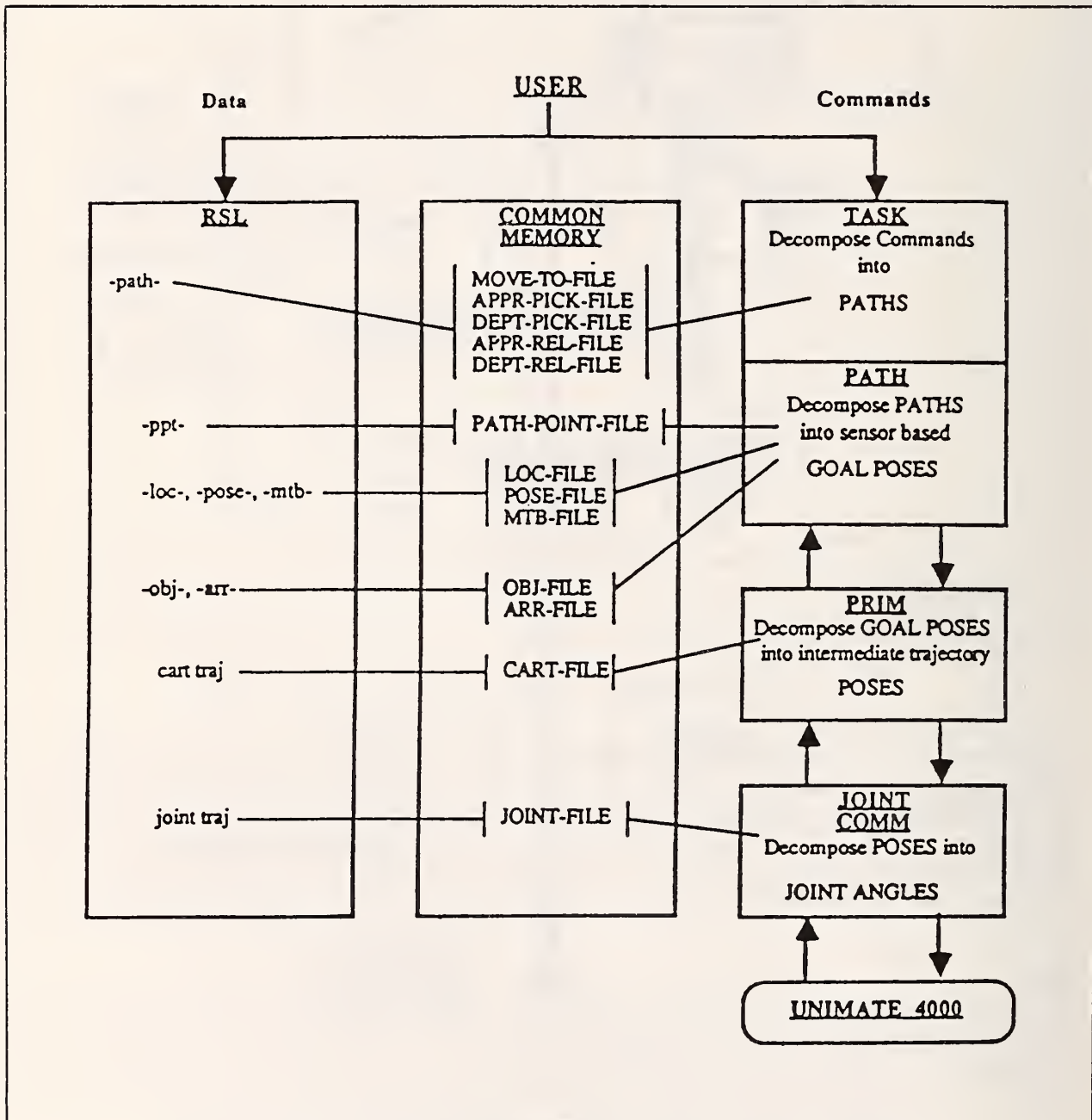
Figure 12-10.   RCS software configuration for the FMR.

To locate a randomly oriented pallet, the FMR application extended RSL by add-
ing path-points that use the sonar and proximity sensors. The new path-points
control individual sensor motion, scan the work volume and analyze the orien-
tation of a pallet, and combine sequences of lower-level path-points so that
you can execute these sequences of path-points in parallel.

The new path-points are edge, range, equate, scan, align-grip, approach-
pallet, and pickup-pallet. The application also uses the RSL goto path-point.

The following list provides the syntax and a brief description of each FMR
path-point.

        goto   [location type] [location name] [traj type] [traj parameters]

Moves the robot directly to the location.

        edge   [sonar#] [range] [delta] [location type] [location name]
               [traj type] [traj parameters]

Moves the robot toward the location name looking for an edge. The delta
parameter describes how large the edge is, and range specifies at what
distance to start looking for the edge.

        range [sonar#] [range] [threshold] [axis] [location type]
               [location name] [traj type] [traj parameters]

Moves the robot along the specified axis of the Cartesian frame specified by
the location type and location name. The robot moves to the range measured by
sonar (within threshold). The commanded translation is positive if the range
minus the sonar is greater than 0.

        equate [sonar#1] [sonar#2] [threshold] [offset] [axis] [location type]
               [location name] [traj type] [traj parameters]

Rotates about the axis of the Cartesian frame specified by the location type
and location name until the two selected sonars take the same reading (within
threshold). The rotation is positive if sonar#1 minus sonar#2 is greater than
0. If two sonars are on different but parallel planes, you can specify the
difference between them in offset.

scan   [sonar#] [skip readings] [max object range] [min range delta]
               [extra] [pose name] [location type] [location name] [traj type]
               [traj parameters]

Determines the nominal location of a rectangular object. The robot scans an
area taking range readings starting from the current position and ending at
the location name. When the sonars take readings, the routines associated
with scan link the readings to the position of the robot and store the posi-
tions in a file. The scan path-point returns the nominal pose of the object
in pose name.

        align-grip   [perm-edge-val] [perm-equal-val] [s1s2-offset] [extra]
                     [long-integer] [min-total-long] [max-short-side]
                     [side-equate-thresh] [location type] [location name]
                     [goto-traj-type] [traj parameters] [edge traj type]
                     [traj parameters] [equate traj type] [traj parameters]

Uses information from the scan path-point and the current sonar data to deter-
mine if the long side of the pallet faces the fork. By calling the edge,
equate, and goto commands, the align-grip path-point uses the trajectory
parameters to align the fork with the long side of the pallet.

Figure 12-11 shows a sequence of path-points similar to the path-points that align-grip might execute. However, the figure makes some assumptions that cannot be made until after sonar data processing, such as which direction to move when looking for the edge.
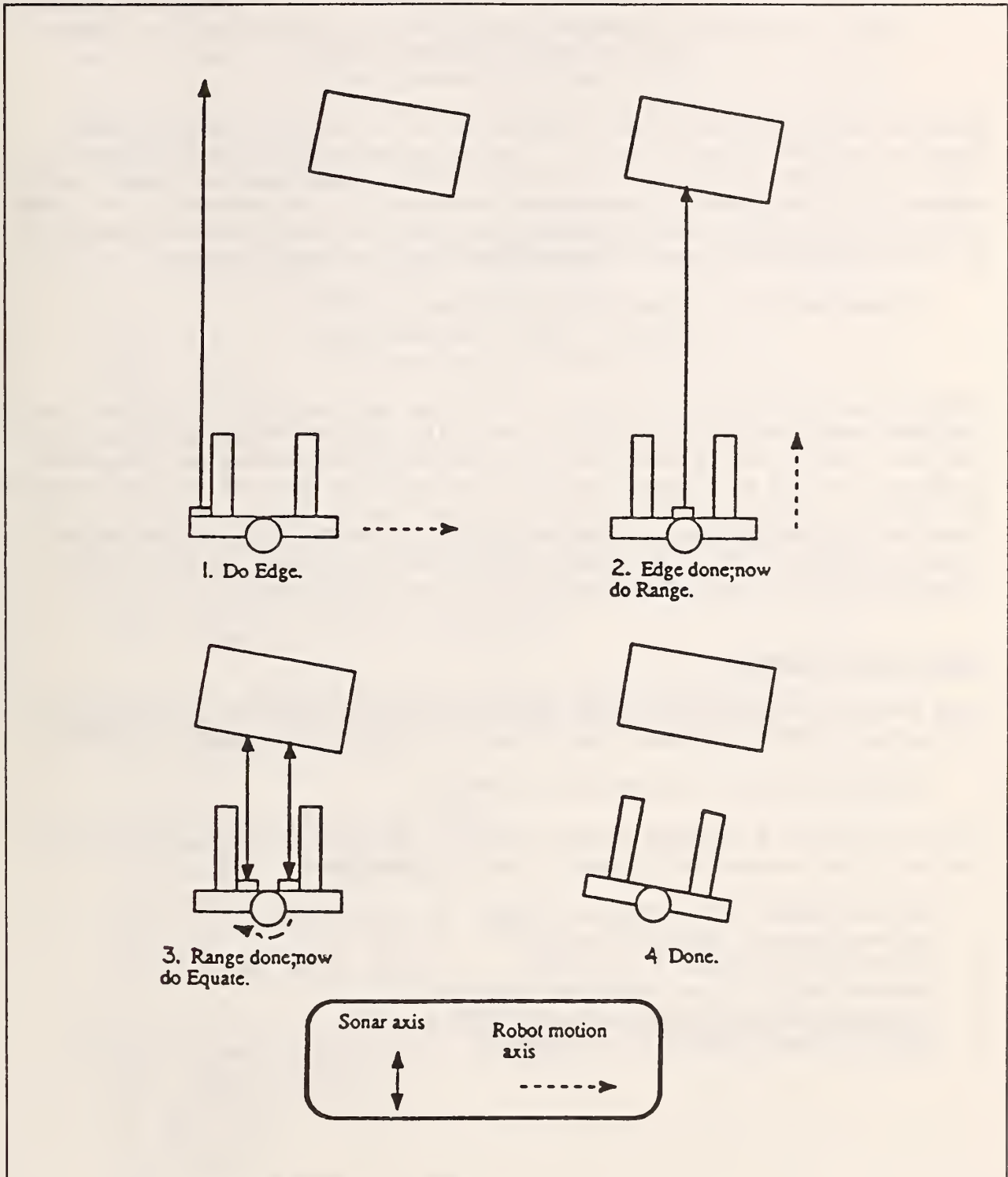
Figure 12-11. FMR path-point examples.

```
approach-pallet  [t-x-sonar#] [t-x-range] [t-x-threshold]
                 [t-y-sonar#] [t-y-range] [t-y-threshold]
                 [r-x-sonar#1] [r-x-sonar#2] [r-x-offset] [r-x-threshold]
                 [r-y-sonar#1] [r-y-sonar#2] [r-y-offset] [r-y-threshold]
                 [location type] [location name]
                 [traj type] [traj parameters]
```

Achieves the proper height and orientation of the fork before the robot
inserts the fork under the pallet. The approach-pallet path-point calculates
four tool motions similar to the calculations for the range and equate path-
points. The t-x- and t-y- parameters correspond to the parameters for range
path-points along the x and y axes. The r-x- and r-y- parameters correspond
to the parameters for equate path-points about the x and y axes.

```
pickup-pallet    [sonar#] [z-correction] [extra]
                 [location type] [location name]
                 [traj type] [traj parameters]
```

Ensures that the fork tines do not hit the pallet feet while the robot inserts
the fork under the pallet. Optical proximity sensors detect when the tines
are too close to the pallet feet. The specified sonar# obtains the nominal
distance the fork must travel before a switch at the rear of the fork engages
the pallet. When a proximity sensor senses a pallet foot, the robot trans-
lates in the appropriate z direction until the sensor is no longer active.
Because of the narrow beam of the sensors, the robot also travels an addi-
tional z-correction after the sensor has cleared the foot.

FMR Transfer Example

This example provides the source code for the paths required to execute the
following TRANSFER command, which transfers PALLET 1 from TRUCK to CONVEYOR.

    TRANSFER PALLET 1 loc TRUCK loc CONVEYOR

The six steps of a TRANSFER command specify the paths for the robot to pick
up, move, and release the pallet. The six steps are:

1. move-to PALLET 1 loc HOME loc TRUCK
2. approach-pickup PALLET 1 loc TRUCK
3. depart-pickup PALLET 1 loc TRUCK
4. move-to PALLET 1 loc TRUCK loc CONVEYOR
5. approach-release PALLET 1 loc CONVEYOR
6. depart-release PALLET 1 loc CONVEYOR

To execute the TRANSFER command, you must define and compile all six path steps from the RSL board. The RSL code for the paths and path-points needed to accomplish the TRANSFER command follow. The % character indicates a comment line.

```
% Move to a starting position (from home) before scanning the truck.
   -path-   move-to PALLET 1 loc HOME loc TRUCK

   % Move to the predefined scan start location using a fast joint
   % trajectory motion.
     -ppt-   goto loc SCAN-START
        joint 30.0 30.0 5.0

% Scan the truck from left to right searching for a pallet, align
% with long side of pallet, and engage fork.
   -path-   approach-pickup PALLET 1 loc TRUCK

   % Orient fork with the truck bed
   % adjust roll.
     -ppt-   equate 4 3 .5 .0 X tool nul
        cart .2 .15 .25 .3 .2 .25
   % adjust pitch.
     -ppt-   equate 4 5 .5 20.0 Z tool nul
        cart .2 .15 .25 .3 .2 .25

   % Fork is now parallel with truck bed.  Scan for pallet, return
   % position in PALLET-POSE.  SCAN-MTB causes the fork to travel in a
   % base rotation motion.
     -ppt-   scan 0 0 50.0 .5 0 PALLET-POSE
        tool SCAN-MTB joint 25.0 25.0 5.0

   % Move to loc PALLET-LOC which consists of PALLET-POSE and a
   % movetable to position the fork in front of the pallet.
     -ppt-   goto loc PALLET-LOC
        joint 25.0 25.0 1.0

   % Find the long side of the pallet.
     -ppt-   align-grip
        4.0 8.0 0.0 .75 15.0 14.0 5
        tool nul
        cart .3 .15 .25 .3 .15 .25
        cart .3 .15 .25 .3 .15 .25
        cart .3 .15 .25 .3 .15 .25

   % Lower the fork to the truck bed.  Ensure that the fork is parallel
   % with the face of pallet and truck bed.
     -ppt-   approach-pallet
        0   17.75 .5
        4   28.5  .25
        4 3 .0 .25
        7 4 .0 .5
        cart .3 .07 .25 .3 .07 .25
```

```
% Guide fork under the pallet until the rear switch signals engagement.
  -ppt-  pickup-pallet 7 .5 1.0
     cart .3 .3 .25 .3 .15 .25

% Depart by picking up the pallet and tilting it back.
  -path-  depart-pickup PALLET 1 loc TRUCK

    % PALLET-UP1 is an offset up from the current position under the
    % pallet.
      -ppt-  goto tool PALLET-UP1
         cart .3 .3 .25 .3 .3 .25

    % PALLET-UP2 tilts the pallet back.
      -ppt-  goto tool PALLET-UP2
         cart .3 .3 .25 .3 .3 .25

% Move to an intermediate safe position.
  -path-  move-to PALLET 1 loc TRUCK loc CONVEYOR

    % CONV-SAVE is a predefined safe position near the conveyor, which
    % can be approached using a high-joint velocity.
      -ppt-  goto loc CONV-SAFE
         joint 10.0 30.0 5.0

% Approach conveyor, a predefined location, and release pallet.
  -path-  approach-release PALLET 1 loc CONVEYOR

    % CONV-UP1 is an offset up from CONVEYOR goal.  Goal type
    % takes the movetable (CONV-UP1) and adds it to the path goal
    % (CONVEYOR).
      -ppt-  goto goal CONV-UP1
         cart .3 .3 .25 .3 .3 .25

    % Place pallet at the goal CONVEYOR.
      -ppt-  goto goal nul
         cart .3 .3 .25 .3 .3 .25

% Extract fork tines.
  -path-  depart-release PALLET 1 loc CONVEYOR

    % CONV-BACK is an offset up from the CONVEYOR goal.
      -ppt-  goto goal CONV-BACK
         cart .3 .25 .25 .3 .25 .2

      -ppt- goto loc CONV-SAFE
         joint 10.0 30.0 5.0
```

This chapter describes several RCS debugging techniques, including debugging interactively using Show mode, single-stepping through a routine, single-stepping control levels, isolating problems, creating debugging routines, and using other debugging techniques.

13.1 DEBUGGING INTERACTIVELY USING SHOW MODE

In most high-level languages (when an interactive debugging system is unavailable), you debug routines, or procedures, by inserting write or print statements within the code, recompiling the code, and executing the code again. SMACRO is interactive. You can perform the following functions at the terminal: execute individual routines, assign values to variables, and display the contents of variables.

Show mode is a useful debugging tool, enabling you to display information at the terminal. In Show mode, when you enter the name of an owner, RCS displays the name of the owner and the contents of all the members. When you enter the name of a variable, RCS displays the value of the variable.

For example, if you are using the RSL application, move to the TASK&PATH board and change to Show mode by entering :S. Enter TDEF to ensure that you are in the TASK vocabulary and then enter input-command, the variable that contains the command that the user passes to the TASK level. RCS displays the contents of the input-command, for example, PAUSE.

To see the values of all members in the output status buffer for the TASK level, enter the name of the owner, output-status-var. RCS displays the name of the owner and the contents of the members of the owner:

```
output-status-var
(iv) cycle-#-status-out = 15
(iv) inc-command-#-echo-out = 1
(strv) command-echo-out = PAUSE

(iv) status-report = Ø
(iv) status-arg-out = Ø
```

For example, to test the robot transforms, set up block 21 on the JOINT/COMM
board as follows:

```
:S  joint/comm>21 LIST
21
   Ø                                            $DEF
   1  :R
   2  1Ø.deg   2Ø.deg   3Ø.deg
   3  4Ø.deg   5Ø.deg   6Ø.deg ==> servo-com-joint
   4  TIME-P JOINT>CART
   5  TIME-P CART>JOINT
   6  :S
   7  CR JS servo-com-joint
   8  CR JS xg
   9  CR PMS pose
  1Ø  CR conf-flag
  11
  12
  13
  14
  15
```

Line 2 sets servo-com-joint to the desired joint values. Line 4 executes
JOINT>CART and displays the execution time. The input to JOINT>CART is in
servo-com-joint, the output is in pose and conf-flags. Line 5 executes
CART>JOINT and displays the execution time. The input to CART>JOINT is in
pose and conf-flags, the output is in xg. Lines 7 through 1Ø display the
inputs and outputs. Load block 21 by entering 21 LOAD. RCS yields the fol-
lowing output:

```
JOINT>CART 975Ø usec
CART>JOINT 83ØØ usec
servo-com-joint
1Ø.           2Ø.          3Ø.          4Ø.          5Ø.          6Ø.
xg
1Ø.           2Ø.          3Ø.          4Ø.          5Ø.          6Ø.
pose as matrix
              x^           y^           z^           xyz
              -Ø.6366      Ø.Ø2272      Ø.77Ø9       25.66
              Ø.7712       Ø.Ø296       Ø.6359       9.Ø82
              -Ø.ØØ8369    Ø.9993       -Ø.Ø3636     39.23
(1:fa) conf-flag =
-1.           1.           1.
:S  joint/comm>
```

Because xg has the same values as servo-com-joint, the two transforms are
inverses of each other, as required. Block 21 displays the pose as a matrix
for easier interpretation. You can set the joint angles to simple values (for
example, Ø or 9Ø degrees) to check the pose and conf-flag computation. To

check the computation, return to the master board, edit line 2 of block 12021, move to the JOINT board, and reload block 21 (using ELOAD). Edit block 21 to contain the simple joint angles in the following listing:

```
 0                                              $DEF
 1  :R
 2  0.deg  0.deg  90.deg
 3  0.deg  0.deg  0.deg ==> servo-com-joint
 4  TIME-P JOINT>CART
 5  TIME-P CART>JOINT
 6  :S
 7  CR JS servo-comm-joint
 8  CR JS XG
 9  CR PMS pose
10  CR conf-flag
11
12
13
14
15
:S rsl
```

Now load the block by entering <u>21 ELOAD</u>. The output is:

```
JOINT>CART 7920 usec
CART>JOINT 6750 usec
servo-com-joint
0.0         0.0         90.         0.0         0.0         0.0
xg
0.0         0.0         90.         0.0         0.0         0.0
pose as matrix
                x^          y^          z^          xyz
                0.0         0.0         1.          23.62
                0.0         1.          0.0         4.488
                -1.         0.0         0.0         25.59
(1:fa) conf-flag =
-1.         1.          1.
:S  joint/comm>
```

These particular values correspond to the pose for the PUMA 760 with the elbow at 90 degrees.

13.2 SINGLE-STEPPING THROUGH A ROUTINE

To locate an error within a routine, single-step through the routine one line at a time. You can execute routines line by line in two ways: by making the entire routine a comment and then restoring the routine one line at a time, or by executing the FORTH equivalent of the code in the routine line by line at the terminal (if possible).

To make an entire routine into a comment, you should first copy the routine to an empty block. Then use the screen editor to enclose the routine, except for the first line of SMACRO code, in parentheses. Leave the screen editor, load the block, and execute the routine. If you do not get an error, go back into the screen editor and move the first parenthesis to include another line of code. Continue this procedure until you find the problem.

Executing the code at the terminal works best for routines that manipulate SMACRO files, because you can execute many of the SMACRO file operators directly at the terminal. These file operators are:

add-list	retrieve-l&r
add-record	store
clear-list	store-l&r
~re-init-file	store-source
remove	update-header
retrieve	

Many other SMACRO operators have equivalents in FORTH that you can use to execute lines of code at the terminal. For example, the FORTH equivalent for the SMACRO assignment operator (=>) is the FORTH store command (~!).

13.3 SINGLE-STEPPING THROUGH THE RSL CONTROL LEVELS

Often the best way to isolate an error is to single-step through the control levels. In single-step, each step executes one communications cycle. To single-step through the control levels, follow this procedure:

1. On the RSL board, enter 923 LIST.

2. Use the screen editor to select between dummy and real execution. Making line 6 a comment selects single-step without the robot. Making line 5 a comment selects single-step with the robot.

3. Enter Task/path REMOTE to move to the TASK&PATH board.

4. Issue a command by loading a block that contains an RSL command. On the NBS system tape, the directory block 910 lists the blocks containing RSL commands. Enter 913 LOAD to issue a transfer task.

5. Enter ^X to return to the master board.

6. Enter HALT whenever you return to the master board from a slave board. Entering HALT makes the single-step output easier to read.

7. Enter PAGE TT to execute one communications cycle.

Figure 13-1 shows sample output that RCS displays when you enter TT.

```
        task:   2 transfer nul Ø1 arr ARRAY ØØ Ø8 ;; loc CONVEYOR
        path:   13 2 1 Ø Ø 1
        133Ø usec
        237Ø usec
        :S task&path>
        prim:   22 2 1 Ø Ø
         (fv) |xs| = Ø.Ø
         (fv) angRs = Ø.Ø
        1Ø94Ø usec
        :S prim>
        joint: 533 2 1 Ø 1. 1.
        servo-com-joint
        53.3 -26.38 -79.Ø8 -174.4 55.98 161.4
        3188Ø usec
```

Figure 13-1. Single-step output.

TT commands each board to load block 919 in its offset. (TASK&PATH loads
TASK's 919, and not PATH's 919.) Block 919 on each level contains the words
that execute that level, and any debug or display words you may have added.
Here is block 919 on the TASK&PATH board:

```
Ø                                       TASK DEFINITIONS
1   :R 1 remote-active !
2       BOARD-PROCESS
3   :S
4       PDEF
5   % CR ppt-started
6   % CR new-command
7   % CR inc-command-#-out
8
9   CR :R TDEF process-time ~@ PRINT-TIME :S
10  CR :R PDEF process-time ~@ PRINT-TIME :S
11
12
13
14
15
```

Here is block 919 on the PRIM board:

```
 0                                    PRIM DEFINITIONS
 1  :R 1 remote-active !
 2      BOARD-PROCESS
 3  :S
 4    CR |xs|
 5    CR angRs
 6  % CR current-vel
 7    CR :R process-time ~@  PRINT-TIME :S
 8  % CR PMS joint-com-pose
 9
10
11
12
13
14
15
```

Here is block 919 on the JOINT/COMM board:

```
 0  % single step dummy mode          JOINT DEFINITIONS
 1  :R
 2         1 remove-active !
 3         COMM-PROCESS JOINT-LEVEL
 4         done ~@ ==> status-in joint-out joint-in   12 ~MOVE
 5         inc-command-#-out ~@ ==> inc-command-#-echo-in
 6    CR JS servo-com-joint
 7  % CR JS xg
 8  % CR JS v-current
 9  :S
10  % CR PMS pose
11  % CR conf-flag
12
13  CR :R process-time ~@ PRINT-TIME :S
14
15
```

Note: The TASK&PATH and PRIM boards simply run BOARD-PROCESS, but the
       JOINT/COMM board is more complex. The difference is because the
       JOINT/COMM board must run without the robot communications, which are
       usually included in BOARD-PROCESS for that board.

The following example shows output from TT taken from the middle of a TRANSFER task execution. The times shown are for 5 MHz boards.

```
task: 9 TRANSFER nul Ø1 arr ARRAY ØØ Ø8 ;; loc CONVEYOR
      Ø Ø 2 Ø
path: 8 2 Ø Ø Ø Ø
117Ø usec
254Ø usec
:S task&path>
prim: 1Ø 2 Ø Ø Ø
(fv) |xs| = 5.263
(fv) angRs = Ø.Ø
1445Ø usec
:S prim>
joint: 78 2 1 Ø 1. 1.
servo-com-joint
13.45      Ø53.7      -54.Ø4      -Ø.ØØ3327      -72.47      18.45
32Ø3Ø usec
:S joint/comm>
:S rsl>
```

The Display routine on each level generates the lines labeled with the level name. (For example, the PRIM level Display routine generates the line prim: 1Ø 2 Ø Ø Ø. TT sets the print-f of each level to true.) Other words in the 919 blocks on each level generate the additional output lines. The rest of this section describes the output in detail, line by line.


```
task: 9 TRANSFER nul Ø1 arr ARRAY ØØ Ø8 ;; loc CONVEYOR
      Ø Ø 2 Ø
```

These lines are from the TASK Display routine. It shows the values of inc-command-#-in (9), input-command (TRANSFER nul Ø1 arr ARRAY ØØ Ø8 ;; loc CONVEYOR), status-report (Ø is executing), status-arg-out (Ø is noerror), state-label (2), and sector-count (Ø).


```
path: 8 2 Ø Ø Ø Ø
```

This line is from the PATH Display routine. It shows the values of inc-command-#-in (8), input-command (2 - PATH), status-report (Ø - executing), status-arg-out (Ø - noerror), ppt-command (Ø - goto), and ppt-done (Ø - false).


```
117Ø usec
```

This line is generated from the line "CR :R TDEF process-time ~@ PRINT-TIME :S" in TASK block 919. It displays the execution time for the TASK level.

```
2540 usec
```

This line is generated by the line "CR :R PDEF process-time ~@ PRINT-TIME :S" in TASK block 919. It displays the execution time for the PATH level.

```
:S task&path>
```

This line is the prompt for the TASK&PATH board.

```
prim:  10 2 0 0 0
```

This line is from the PRIM Display routine. It shows the values of inc-command-#-in (10), input-command (2 - TRAJ), status-report (0 - executing), status-arg-out (0 - noerror), and traj-type-in (0 - cart).

```
(fv) |xs| = 5.263
```

This line is generated by the line "CR |xs|" in PRIM block 919. It displays the translational distance from the goal.

```
(fv) angRs = 0.0
```

This line is from the line "CR angRs" in PRIM block 919. It displays the rotational distance from the goal.

```
14450 usec
```

This line is generated by the line "CR :R process-time ~@ PRINT-TIME :S" in PRIM block 919. It displays the execution time for the PRIM level.

```
:S prim>
```

This line is the PRIM board prompt.

```
joint: 78 2 1 0 1. 1.
```

This line is from the JOINT Display routine. It shows the values of inc-command-#-in (78), input-command (2 - CARTESIAN), status-report (1 - done), status-arg-out (0 - noerror), v-scale-min (1.), and a-scale-min (1.).

```
servo-com-joint
13.45      053.7      -54.04      -0.003327      -72.47      18.45
```

This line is generated by the line "CR JS servo-com-joint" in JOINT block 919. It displays the output joint angles in degrees.

32030 usec

This line is generated by the line "CR :R process-time ~@ PRINT-TIME :S" in JOINT block 919. It displays the execution time for the JOINT level.

    :S joint/comm>
    :S rsl>

These lines are the prompts for the JOINT/COMM and RSL boards.

The word Display on each control level, and any variables executed in Show mode in block 919 on each control level, generate this output. You can execute a number of cycles and watch the single-step display change by entering [#cycles] TTT. Single-stepping through the control levels is often helpful in locating errors.

13.4 ISOLATING PROBLEMS

When the system aborts a robot task or does not complete a task, debug the problem first by determining where the problem occurred. If you can see that the robot is not performing a task correctly, finding the cause of the problem is usually easy. For example, if the robot starts a transfer task and hits an object while moving directly to the first sector of an array, you have to add a path-point to the transfer routine that first moves the robot to a safe location.

If the error is in the software, you have to determine where the problem occurred and correct it. To illustrate this procedure, the following example introduces an error onto the system tape, isolates the problem by single-stepping the control levels and tracing the execution of the task, and restores RCS to its previous condition.

  1. Start the system in background mode by entering the following commands:

        Ø CBOOT Ø MBOOT init-cm 2 D>M
        922 LOAD

  2. Load block 928 to show the contents of the status-report and status-arg-out variables on each level by entering the command:

        928 LOAD

3. Edit block 981 on the PRIM level, as follows:

       3981 ED

    Introduce an error by editing block 981 to make line 9 a comment and to
    include a new line 8 that sets tool-mtb-^ to Ø. The block should now
    look as follows:

    CHARACTER OPS   LINE OPS   BLOCK OPS   SPECIAL OPS
    ^A Insert On/Off   ^C Copy Line   ^F Forward Block   PF1 Home   PF2 Clear
    ^E Erase Char   ^D Delete Line   ^P Previous Block   ^U Undo Block
    ^K Mark to Keep   ^O Open Line   ^G Goto Block   ^W Want string
    ^Z Input Keep   ^T Transfer   ^N Next Want
                                           ^R Retire(quit)   ^X Cancel

      BLOCK   3981   11981

     Ø   PRIM DEFINITIONS |
     1 :R |
     2 |
     3 RR-^ PRIM>JOINT-POSE retrieve   rr-^ ~@ ==> prim>joint-pose-rr-^ |
     4 RR-^ PRIM>JOINT-TRAJ retrieve   rr-^ ~@ ==> prim>joint-traj-rr-^ |
     5 |
     6 RR-^ RBT-POSE   retrieve   rr-^ ~@ ==> rbt-pose-rr-^ |
     7 |
     8 Ø ==> tool-mtb-^ |
     9 % MTB-^ TOOL-MTB   retrieve record# ~@ ==> tool-mtb-^ |
    1Ø MTB-^ INV-TOOL-MTB retrieve record# ~@ ==> inv-tool-mtb-^ |
    11 |
    12 |
    13 |
    14 |
    15 |

4. Load the edited block containing the error by halting RCS execution and
    moving to the PRIM board, as follows:

       HALT
       Prim REMOTE
       981 ELOAD

5. Now single-step through the control levels until the error occurs.
    Enter:

       ^X
       HALT
       PAGE TT

    The error message **BOARD-PROCESS ABORTED** appears after the first cycle of
    single-step. Because the message appears before the prompt for the PRIM
    board, the error occurred on the PRIM level.

Note: Some errors do not occur until RCS has single-stepped through many cycles. Single-stepping through the control levels is often a useful debugging tool.

6. Move to the PRIM board and re-execute the word that caused the error. The error occurs again, enabling you to locate the block that aborted. Enter:

       Prim REMOTE
       LOC BOARD-PROCESS

7. As you can see on the display, the routine BOARD-PROCESS executes several other routines. Because PRIM-LEVEL is the only routine an RCS user is likely to have changed, locate that routine by entering:

       LOC PRIM-LEVEL

8. The routine PRIM-LEVEL also executes several routines, but an RCS user is likely to have changed only the routines PRE-PROCESS, COMMAND-PROCESS, POST-PROCESS, and Display. Execute these routines in the same order as PRIM-LEVEL executes them, stopping when an error occurs. Enter:

       PRE-PROCESS
       COMMAND-PROCESS

   Executing COMMAND-PROCESS should cause the error to occur again.

9. Enter the following commands to display the last word executed and to locate that word:

       \N
       \L

10. Trace the execution of the routine COMMAND-PROCESS by displaying variables in Show mode to isolate the problem further. Enter:

        :S
        status-report
        error
        hold-set
        false
        input-command
        prim-restart

11. At this point, COMMAND-PROCESS executes the routine PRIM-RESTART. Enter:

        PRIM-RESTART

    The error should occur again. Now locate PRIM-RESTART by entering:

        \L

12. Trace the execution of the routine PRIM-RESTART by displaying variables in SHOW mode to isolate the problem further, as follows (the command N L displays the rest of the routine):

```
:S
new-command
true
joint-status
error
N L
joint-status
done
```

13. At this point, PRIM-RESTART executes the routine FEEDBACK-POSE. Execute FEEDBACK-POSE, as follows:

```
FEEDBACK-POSE
```

The error should occur again. Now locate FEEDBACK-POSE by entering:

```
\L
```

14. Because the original error message said RCS aborted because of a Ø record#, look for statements in FEEDBACK-POSE that assign values to record# and display those variables. Enter:

```
:S
joint-pose-^
tool-mtb-^
```

Note: You cannot execute retrieve-from-field from the terminal.

15. Because tool-mtb-^ equals Ø, you need to find where the variable tool-mtb-^ is initialized. Use the directory block structure to determine where PRIM level round-robin variables are initialized by entering:

```
Ø LIST
9ØØ LIST
98Ø LIST
981 LIST
```

16. Return block 981 to its original state by entering:

```
^X
RED
```

Edit the block to contain the following code:

CHARACTER OPS	LINE OPS	BLOCK OPS	SPECIAL OPS
^A Insert On/Off	^C Copy Line	^F Forward Block	PF1 Home PF2 Clear
^E Erase Char	^D Delete Line	^P Previous Block	^U Undo Block
^K Mark to Keep	^O Open Line	^G Goto Block	^W Want string
^Z Input Keep		^T Transfer	^N Next Want
		^R Retire(quit)	^X Cancel

```
     BLOCK    3981    11981

 Ø                                                      PRIM DEFINITIONS |
 1 :R                                                                    |
 2                                                                       |
 3 RR-^ PRIM>JOINT-POSE retrieve  rr-^ ~@ ==> prim>joint-pose-rr-^       |
 4 RR-^ PRIM>JOINT-TRAJ retrieve  rr-^ ~@ ==> prim>joint-traj-rr-^       |
 5                                                                       |
 6 RR-^ RBT-POSE        retrieve  rr-^ ~@ ==> rbt-pose-rr-^              |
 7                                                                       |
 8                                                                       |
 9 MTB-^ TOOL-MTB       retrieve record# ~@ ==> tool-mtb-^              |
10 MTB-^ INV-TOOL-MTB retrieve record# ~@ ==> inv-tool-mtb-^            |
11                                                                       |
12                                                                       |
13                                                                       |
14                                                                       |
15                                                                       |
```

When you extend RSL, use this procedure to debug errors.

13.5 CREATING DEBUGGING ROUTINES

You can create your own routines to help debug problems. RSL contains several debugging routines that display variables. Each control level contains a routine called Display and a list owner called List-display. Figure 13-2 lists the routines Display and List-display for the PATH level. You can write similar routines to display other variables.

```
1909         10909 ABS
                                                              PATH DEFINITIONS
   routine Display
      if print-f (EQ) true
      then
         ~F CR
         ~PRINT" path: "
         ~PRINT inc-command-#-in
         ~PRINT input-command
         ~PRINT status-report
         ~PRINT status-arg-out
         ~PRINT ppt-command
         ~PRINT ppt-done
      endif
   end-routine

   1908         10908 ABS
                                                              PATH DEFINITIONS
      LIST-O  List-display
      m new-command
      m ppt-done
      m new-ppt
      m path-done
      m prim-status
      m output-command
      m inc-command-#-out
```

Figure 13-2. Display routine and List-display list owner
for the PATH level.

Note: In debugging routines when RSL is running in the background, you cannot
see the intermediate results of calculations. To show the intermediate
results, you can run RSL in the foreground and include ~PRINT state-
ments. However, ~PRINT statements slow RCS operation.

13.6 USING OTHER DEBUGGING TECHNIQUES

You can also use other techniques to debug RCS hardware, RCS software, and RSL
software.

RCS Hardware Debugging Techniques

You can add the following optional RCS hardware to make some debugging operations easier:

- A hardware switch box enables you to use the hardware switch to communicate directly with the other boards in the system. When only one board in the system malfunctions, use the switch box to reset that board without rebooting the entire system.

- An oscilloscope on the bus busy enables you to see the signal on the MULTIBUS. The signal goes down when the bus is busy.

RCS Software Debugging Techniques

Some techniques for debugging RCS software problems include:

- Check your spelling. Remember, reserved words in the FORTH dictionary have three significant characters. SMACRO words have 31 significant characters.

- If the vocabulary of a control level is full, increase the size allocated in block 9 of that control level.

- If the system dictionary for a board is full, edit the system vocabulary declaration for that board to increase the size of the dictionary. These declarations are located in absolute blocks 1406 to 1412. You must reload the base system for this to be effective.

- If you cannot access a slave board, try entering [board name] Board-sem-initialize.

- Make sure you did not put a vocabulary identifier in routines that are more than one block long.

RSL Software Debugging Techniques

Some techniques for debugging RSL software problems include:

- To check the current status of all control levels, enter 8928 ØLOAD to display the status and status-arg-out information from all control levels.

- Check that all RSL source code blocks contain :R. The RSL compiler does not work in other modes.

- If you are not sure what RSL code is loaded, enter HALT to halt the system and then enter 8990 ØLOAD to reload the code.

- If the robot continues to reach a wrist joint-limit when moving to a pose, try changing the wrist configuration by editing the wrist configuration flag in the pose definition. Note that you cannot change the wrist configuration when using the joystick.

- Write debugging routines to display variables.

This appendix lists the error messages that RCS displays to indicate error conditions. The error messages include RCS, 8087, and disk and tape error messages. RCS error messages consist of explanatory text. 8087 error messages consist of a display of the 8087 register contents. Disk and tape error messages consist of an error code described in the Rimfire manual.

A.1 RCS ERROR MESSAGES

RCS error messages describe fatal and nonfatal errors. Fatal errors are the result of problems in allocating memory space for an application. A fatal error requires you to execute at least a RESTORE and a D>M, rather than simply reload a single block, to recover from the error. RESTORE and D>M return the system to the "clean" state that existed before you encountered the error. The fatal error messages include BUFFER OVERFLOW, DICTIONARY FULL, FILE FULL, FILE SPACE FULL, SYSDICT FILE FULL, SYSDICT SPACE FULL, and vocab redefined larger. The remaining error messages indicate nonfatal errors.

The following list describes the RCS error messages.

~var only
      RCS detected something other than a SMACRO variable following ==>.
      (Nonfatal)

[name] ?
      The specified name is undefined. (Nonfatal)

6 msec time-out interrupt
      An application program attempted to access an I/O port or a RAM address
      that is not physically present in the system. (Nonfatal)

ALREADY ASSIGNED HERE
      RCS found more than one occurrence of the same variable in a list owner
      (LIST-O). (Nonfatal)

base<>10
      RCS detected that you were trying to load a block with DBG-ON without
      first setting BASE to decimal. The block is not loaded. (Nonfatal)

buffer length mismatch
      RCS detected that two buffers specified for a COMM transfer have differ-
      ent lengths. (Nonfatal)

[name] BUFFER OVERFLOW
     The current variable owner does not have room for the name to be defined.
     BUFFER OVERFLOW is the most common fatal error. This error results from
     the user specifying an insufficient number of bytes during the variable
     owner declaration. The error actually occurs when the SMACRO compiler
     assigns the members of that variable owner to the allocated space, which
     is too small to hold the members. (Fatal)

comm table full
     RCS cannot accept more than 60 COMM transfer definitions. (Nonfatal)

DICTIONARY FULL
     The FORTH dictionary space is full. This condition results from defining
     too many FORTH words or encountering too many errors while compiling
     SMACRO routines. If the condition results from defining too many FORTH
     words, you may be able to circumvent the condition by reloading the base
     system with LOCATE-OFF. (RCS loads RSL with LOCATE-OFF automatically.)

     RCS compiles SMACRO routines in FORTH space before moving them to SMACRO
     space. If an error occurs during the compilation, RCS does not move the
     part of the SMACRO routine already compiled to SMACRO space, thus using
     up FORTH space. (Fatal)

[name] F-EXISTS
     The specified name is a previously defined FORTH word. This error mes-
     sage is a warning only; RCS defines the SMACRO word. (Nonfatal)

FILE FULL
     The current SMACRO file is full. This error can occur when you load the
     RSL code. To correct this condition, delete some of the RSL code for
     that file or increase the size of the file.

     Deleting some RSL code and reloading the current set (enter 990 LOAD for
     RSL) may solve the problem if the file does not use garbage collection
     (such as the POSE-FILE or the LOCATION-FILE).

     If you choose to increase the file size, you must use RESTORE and D>M to
     return the system to a "clean" state before the file was declared on any
     level. Then declare the file with the new size and reload the system.
     Examine block 4 on each level to determine if the level declares the
     file. (Fatal)

FILE SPACE FULL
     The SMACRO file being declared is too large for the remaining space in
     the common memory area allocated for user files. You can check the cur-
     rent size of the file space by entering F-MEM. To correct this condi-
     tion, you must redefine the values of the fpage, ftop, and fbottom
     variables in block 1402, and reload the base system. (Fatal)

floating point only
     RCS detected something other than a floating-point number in the input
     for the #.READ word. (Nonfatal)

ILLEGAL

    RCS detected an illegal value following <=. (Nonfatal)

illegal type

    RCS detected something other than a string, array, byte variable, integer
    variable, floating-point variable, or a segment variable following ==>.
    (Nonfatal)

invalid preserve#

    The preserve (or preserve-file) number is outside the range 1 through 9.
    (Nonfatal)

invalid image#

    The D>M image number is outside the range 1 through 5. (Nonfatal)

[name] Pre-locate

    The indicated name cannot be found using LOC. (Nonfatal)

record# = 0

    The variable record# was 0 when the program tried to manipulate a file.
    (Nonfatal)

remove record not on list

    The SMACRO file-manipulation word, remove, could not find the specified
    record number on the current list. This error indicates that remove did
    not remove any records. (Nonfatal)

STACK EMPTY

    Program operation caused the FORTH stack to underflow. Syntax errors in
    SMACRO statements may cause this error. (Nonfatal)

SYSDICT FILE FULL

    RCS detected an attempt to add a word to a vocabulary that is already
    full. Enter V-SIZE to determine the size of the current vocabulary. To
    increase the size of a vocabulary, you must first use RESTORE and D>M to
    return the system to a "clean" state where that vocabulary is not
    defined. Then define the larger vocabulary. (Fatal)

SYSDICT SPACE FULL

    The vocabulary being declared is too large for the remaining space in the
    common memory area allocated for the system dictionary. You can check
    the current size of the system dictionary by entering F-MEM. To correct
    this condition, you must redefine the values of the dpage, dtop, and
    dbottom variables in block 1402, and reload the base system. (Fatal)

u-STACK-underflow

    A stack used in compiling SMACRO routines has underflowed. This message
    indicates a syntax error, such as if you spelled "endif" as "end-if".
    (Nonfatal)

vocab already exists

    RCS detected an attempt to define more than one vocabulary with the same
    name. Each vocabulary name must be unique throughout the entire system.
    (Nonfatal)

vocab redefined larger
>   RCS detected an attempt to increase the size of a vocabulary when you
     redefined it. (Fatal)

var-owner only
     RCS detected something other than a variable owner in a COMM transfer
     definition. (Nonfatal)

A.2 8087 ERROR MESSAGES

If the 8087 detects an error, it aborts the current operation and displays the
control, status, and tag registers (in binary). It also displays the instruc-
tion address (in either the FORTH or SMACRO segment), the opcode, and the
operand address (in either the FORTH or SMACRO segment). You can enter
0.0 0.0 F/ for an example of this display.

A.3 RIMFIRE DISK AND TAPE ERROR MESSAGES

Disk and tape errors have the following format:

     tape error [error code] block [block#] [word]

The error code gives the two Rimfire status bytes. The lower 6 bits of the
high order byte give the error code. See the Rimfire manual listed under
"Disk and Tape Controller Board" in the bibliography for a description of the
error codes. The block# gives the block where the error occurred, and word is
the error encountered.

This appendix describes the RCS and RSL user words. The word descriptions are grouped according to function and labelled with headings (See the Appendix B portion of the table of contents at the beginning of this manual for a list of the headings.) Within each group, the words are listed in ASCII order. The descriptions include the required syntax showing the word and its parameters in the order in which you should enter them.

Table B-1 lists the abbreviations and Table B-2 lists the phrases used to describe the syntax of the words. Table B-3 helps you find the description of a specific word in this appendix. This table lists all RCS and RSL user words in ASCII order. The table consists of the word followed by its group heading, the page number on which it is found in this appendix, and the page number where it is discussed in the manual. The bottom of each page of the table lists the ASCII character sequence to help you locate specific words. Because of the length of this table, horizontal lines separate every five words.

Table B-1. List of Abbreviations Used in the Syntax Descriptions

Abbreviation	Meaning
var	Any variable, including subscripted arrays.
ivar	An integer or byte variable.
iexp	An integer expression, composed of integer variables and operators. Note that integer expressions do not contain parentheses.
fvar	A scalar floating-point variable, including subscripted floating-point arrays.
fexp	A scalar floating-point expression.
vvar	A vector variable.
vexp	A vector expression.
qvar	A quaternion variable.
qexp	A quaternion expression.
pvar	A pose variable.
pexp	A pose expression.
mvar	A matrix variable.
mexp	A matrix expression.

Table B-2. List of Phrases Used in the Syntax Descriptions.

<u>Phrase</u>	<u>Meaning</u>
local template	The variable owner that serves as a template for records in the file. The members define the fields in the record.
current file	The last file made current by executing its name. All file operations refer to this file.
current record	The record in the current file pointed to by the variable record#. If record# is 0, no current record exists.
current list	The linked list in the current file starting at the current record. If record# is 0, no current list exists.
free list	The linked list of available records in the current file. The variable avail-record points to the free l.

Table B-3.   Complete List of RCS and RSL User Words in ASCII Order.

```
==============================================================================
                                                        APPENDIX    MANUAL
WORD                        GROUP HEADING               PAGE #      PAGE #
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!                           FORTH words                 B-46        6-5
"                           Miscellaneous RCS words      B-35        6-9
""                          SMACRO operator words        B-59
#.READ                      SMACRO operator words        B-60        10-16
#LLIST                      Editing words                B-29
------------------------------------------------------------------------------
#READ                       SMACRO operator words        B-60
$DEF                        RSL operating system words   B-94        6-5
%                           Miscellaneous RCS words      B-35        6-14
%%                          Miscellaneous RCS words      B-35        5-12
' '                         Miscellaneous RCS words      B-35        6-9
------------------------------------------------------------------------------
(                           Miscellaneous RCS words      B-36        6-8
(( ))                       SMACRO operator words        B-60
()                          SMACRO operator words        B-60
(*)                         SMACRO operator words        B-60        7-9
(*/)                        SMACRO operator words        B-61
------------------------------------------------------------------------------
(+)                         SMACRO operator words        B-61        7-9
(-)                         SMACRO operator words        B-61        7-9
(/)                         SMACRO operator words        B-61        7-9
(ABS)                       SMACRO operator words        B-61
(AND)                       SMACRO Boolean-operator words B-74       7-11
------------------------------------------------------------------------------
(COM)                       SMACRO operator words        B-61
(EQ)                        SMACRO Boolean-operator words B-74       6-17
(GE)                        SMACRO Boolean-operator words B-74       7-11
(GT)                        SMACRO Boolean-operator words B-74       7-11
(LE)                        SMACRO Boolean-operator words B-74       7-11
------------------------------------------------------------------------------
(LT)                        SMACRO Boolean-operator words B-74       7-11
(MAX)                       SMACRO operator words        B-61
(MIN)                       SMACRO operator words        B-62
(MOD)                       SMACRO operator words        B-62
(NE)                        SMACRO Boolean-operator words B-75       7-11
------------------------------------------------------------------------------
*                           FORTH words                  B-46        10-46
+                           FORTH words                  B-46
-                           FORTH words                  B-46
---                         Language words               B-98        9-4
-1#                         Predefined SMACRO variable words  B-57
------------------------------------------------------------------------------
```

ASCII Sequence:

! " # $ % & ' ( ) * + , - . / Ø...9 : ; < = > ? @ Aa...Zz [\ ] ^ _   { | } ~

```
===============================================================================
                                                      APPENDIX    MANUAL
WORD                        GROUP HEADING             PAGE #      PAGE #
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-arr-                    Language words                  B-98        9-4
-imtb-                   Language words                  B-98        9-4
-loc-                    Language words                  B-99        9-4
-mtb-                    Language words                  B-99        9-4
-mtb-end-                Language words                  B-100       9-4

-obj-                    Language words                  B-100       9-4
-path-                   Language words                  B-100       9-5
-pose-                   Language words                  B-101       9-3
-ppt-                    Language words                  B-101       9-5
-rr-                     Language words                  B-101      10-14

.                        FORTH words                     B-46        7-17
.( ).                    SMACRO operator words           B-62        7-9
.*.                      SMACRO operator words           B-62        7-9
.*2**.                   SMACRO operator words           B-62
.+.                      SMACRO operator words           B-62        7-9

.-.                      SMACRO operator words           B-62        7-9
./.                      SMACRO operator words           B-63        7-9
.=>.                     SMACRO operator words           B-63        6-17
.ABS.                    SMACRO operator words           B-63
.ATAN,SIN,COS.           SMACRO operator words           B-63

.ATAN.                   SMACRO operator words           B-63
.AXIS,ANGLE>Q.           SMACRO quaternion-operator words  B-70
.AXIS,SIN,COS>Q.         SMACRO quaternion-operator words  B-70
.CROSS.                  SMACRO vector-operator words    B-68
.D                       FORTH words                     B-47

.DOT.                    SMACRO vector-operator words    B-68
.EQ.                     SMACRO Boolean-operator words   B-75        7-11
.EQZ.                    SMACRO Boolean-operator words   B-75        7-11
.Esc                     Miscellaneous RCS words         B-36
.FRAC.                   SMACRO operator words           B-63

.GE.                     SMACRO Boolean-operator words   B-75        7-11
.GEZ.                    SMACRO Boolean-operator words   B-75        7-11
.GT.                     SMACRO Boolean-operator words   B-75        7-11
.GTZ.                    SMACRO Boolean-operator words   B-75        7-11
.INT.                    SMACRO operator words           B-63
```

ASCII Sequence:

! " # $ % & ' ( ) * + , - . / Ø...9 : ; < = > ? @ Aa...Zz [\ ] ^ _   { | } ~

WORD	GROUP HEADING	APPENDIX PAGE #	MANUAL PAGE #
.LE.	SMACRO Boolean-operator words	B-75	7-11
.LEZ.	SMACRO Boolean-operator words	B-76	7-11
.LT.	SMACRO Boolean-operator words	B-76	7-11
.LTZ.	SMACRO Boolean-operator words	B-76	7-11
.M=>.	SMACRO matrix-operator words	B-71	7-10
.M>Q.	SMACRO matrix-operator words	B-71	
.MAX.	SMACRO operator words	B-64	
.MIN.	SMACRO operator words	B-64	
.MINUS.	SMACRO operator words	B-64	
.MOD+-18Ø.	SMACRO operator words	B-64	
.NE.	SMACRO Boolean-operator	B-76	7-11
.NEZ.	SMACRO Boolean-operator words	B-76	7-11
.P=>.	SMACRO pose-operator words	B-72	7-10
.PINV.	SMACRO pose-operator words	B-72	
.PP*.	SMACRO pose-operator words	B-72	
.PQ*.	SMACRO pose-operator words	B-72	
.PV+.	SMACRO pose-operator words	B-72	
.Q=>.	SMACRO quaternion-operator words	B-70	7-10
.Q>AXIS,ANGLE,SIN,COS.	SMACRO quaternion-operator words	B-70	
.Q>AXIS,SIN,COS.	SMACRO quaternion-operator words	B-71	
.Q>M.	SMACRO matrix-operator words	B-72	
.QINV.	SMACRO quaternion-operator words	B-71	
.QP*.	SMACRO pose-operator words	B-73	
.QQ*.	SMACRO quaternion-operator words	B-71	
.QV*.	SMACRO quaternion-operator words	B-71	
.ROT,SIN,COS.	SMACRO pose-operator words	B-73	
.ROT.	SMACRO pose-operator words	B-73	
.SIGN.	SMACRO operator words	B-64	
.SIN,COS.	SMACRO operator words	B-64	
.SQ.	SMACRO operator words	B-64	
.SQRT.	SMACRO operator words	B-65	
.TRN.	SMACRO pose-operator words	B-73	
.UNIT.	SMACRO vector-operator words	B-69	
.V*S.	SMACRO vector-operator words	B-69	
.V+.	SMACRO vector-operator words	B-69	7-16

ASCII Sequence:

! " # $ % & ' ( ) * + , - . / Ø...9 : ; < = > ? @ Aa...Zz [\ ] ^ _   { | } ~

```
===============================================================================
                                                        APPENDIX    MANUAL
WORD                       GROUP HEADING                PAGE #      PAGE #
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ASCII Sequence:

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ASCII Sequence:

! " # $ % & ' ( ) * + , - . / 0...9 : ; < = > ? @ Aa...Zz [\ ] ^ _   { | } ~

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ASCII Sequence:

! " # $ % & ' ( ) * + , - . / Ø...9 : ; < = > ? @ Aa...Zz [\ ] ^ _   { | } ~

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! " # $ % & ' ( ) * + , - . / Ø...9 : ; < = > ? @ Aa...Zz [\ ] ^ _   { | } ~

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! " # $ % & ' ( ) * + , - . / 0...9 : ; < = > ? @ Aa...Zz [\ ] ^ _   { | } ~

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ASCII Sequence:

! " # $ % & ' ( ) * + , - . / Ø...9 : ; < = > ? @ Aa...Zz [\ ] ^ _   { | } ~

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ASCII Sequence:

! " # $ % & ' ( ) * + , - . / Ø...9 : ; < = > ? @ Aa...Zz [\ ] ^ _   { | } ~

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ASCII Sequence:

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! " # $ % & ' ( ) * + , - . / 0...9 : ; < = > ? @ Aa...Zz [ \ ] ^ _    { | } ~
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ASCII Sequence:

! " # $ % & ' ( ) * + , - . / 0...9 : ; < = > ? @ Aa...Zz [\ ] ^ _   { | } ~

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! " # $ % & ' ( ) * + , - . / 0...9 : ; < = > ? @ Aa...Zz [\ ] ^ _   { | } ~

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_____
```

ASCII Sequence:

```
! " # $ % & ' ( ) * + , - . / Ø...9 : ; < = > ? @ Aa...Zz [ \ ] ^ _     { | } ‾
```

```
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 ─────────────────────────────────────────────────────────────────────────────
```

ASCII Sequence:

```
! " # $ % & ' ( ) * + , - . / 0...9 : ; < = > ? @ Aa...Zz [ \ ] ^ _    { | } ~
```

B.1 RCS WORDS

This section describes user words defined in RCS, including SMACRO and COMM.
The RCS words include:

- Operating system words
- FORTH words
- SMACRO words
- COMM words

All block references are absolute, unless otherwise indicated.

Operating System Words

The operating system words include:

- MBOOT/CUSTOM words
- Terminal words
- Printing words
- Tape words
- Editing words
- Remote-slave words
- Miscellaneous words

MBOOT/CUSTOM words

AUTO?

>   [d>m#] AUTO?
>
>   Lists the auto-load block for the specified D>M# on the current board.

Basic

>   Basic
>
>   Loads the second half of the basic FORTH system. Use this word after
>   MBOOT and before other load words.

BOOT-BASE-SYSTEM

>   BOOT-BASE-SYSTEM
>
>   Loads absolute block 1490 to boot the base system (1 D>M) on each board.

BOOT-SYSTEM

    BOOT-SYSTEM

    Loads block 1460 to boot the slave boards in the system. You may edit
    blocks 1460 through 1469 to configure the boot process.

CBOOT

    [board#] CBOOT

    Boots the Winchester disk from the board that you specify using board#.
    Use CBOOT at power-up only.

CUSTOM

    [custom#] CUSTOM

    Loads a block (block 1370 + custom#) that loads a custom set of utilities
    on the current board for an application. You must set up and maintain
    this custom# block.

CUSTOM?

    [custom#] CUSTOM?

    Lists the custom block if the argument is present; lists the custom map
    block if the argument is not present.

D>M

    [d>m#] D>M

    Loads a specified D>M image from disk to memory and loads the auto-load
    block.

dbottom

    dbottom

    Specifies the bottom 20-bit address used by the system dictionary. The
    pointer value in this FORTH variable consists of a segment and an offset
    within the megabyte page specified by the dpage variable. You must set
    the value above 1FFFF because a processor board interprets any lower
    address as an on-board address instead of a common memory address. You
    set dbottom in block 1402. (See also dpage and dtop)

Disk-fix

    Disk-fix

    Loads the disk-patching utility.

DM?

    [board#] DM?

    Lists the D>M map block. If the argument is present, this word lists the
    D>M map for the specified board. If the argument is not present, this
    word lists the D>M map for the current board.

dpage

    dpage

    Specifies which megabyte page (using a pagecode) in common memory con-
    tains the system dictionary. You can use >PAGE to store a pagecode value
    in this FORTH variable. You set the dpage variable in block 1402. (See
    also >PAGE, under "Miscellaneous RCS words", dtop, and dbottom)

dtop

    dtop

    Specifies the top 20-bit address used by the system dictionary. The
    pointer value in this FORTH variable consists of a segment and an offset
    within the megabyte page specified by the dpage variable. You set the
    dtop variable in block 1402. (See also dpage and dbottom)

fbottom

    fbottom

    Specifies the bottom 20-bit address used by the SMACRO files. The
    pointer value in this FORTH variable consists of a segment and an offset
    within the megabyte page specified by the fpage variable. You must set
    the value above 1FFFF because a processor board interprets any lower
    address as an on-board address instead of a common memory address. You
    set the fbottom in block 1402. (See also fpage and ftop)

fpage

    fpage

    Specifies which megabyte page (using a pagecode) in common memory con-
    tains the SMACRO files. You can use >PAGE to store a pagecode value in
    this FORTH variable. You set the fpage variable in block 1402. (See
    also >PAGE, under "Miscellaneous RCS words", ftop, and fbottom)

ftop

    ftop

    Specifies the top 20-bit address used by the SMACRO files. The pointer
    value in this FORTH variable consists of a segment and an offset within
    the megabyte page specified by the fpage variable. You set the ftop
    variable in block 1402. (See also fpage and fbottom)

init-cm

    init-cm

    Initializes the common memory space by filling it with zeros. Block 1405
    defines the area to be initialized. (When editing block 1405, you should
    also edit block 1402, which sets the common memory pointer variables)

MAP

    MAP

    Lists the first map block.

MBOOT

    [board#] MBOOT

    Loads the first half of the basic FORTH system by loading block 9 from
    1000 OFFSET. Use MBOOT at power-up and following a reset, and follow it
    with Basic to load the second half of the basic FORTH system, or D>M to
    boot a finished system.

MEM>DISK

    [d>m#] MEM>DISK

    Writes a D>M image of memory to disk and assigns a number to the image.

PMAP

> PMAP

Lists the preserve map block.

PRESERVE

> [preserve#] PRESERVE

Writes an image (identified by preserve#) of the current system diction-
ary to disk. (See also RESTORE)

PRESERVE-FILE

> [preserve-file#] PRESERVE-FILE

Writes the current user files to disk. (See also RESTORE-FILE)

RCS

> RCS

Loads RCS. Note that the system ignores any words typed after this word
on the same line.

RESTORE

> [preserve#] RESTORE

Restores the specified system dictionary image from disk. (See also
PRESERVE)

RESTORE-FILE

> [preserve-file#] RESTORE-FILE

Restores a specified set of user files from disk. (See also
PRESERVE-FILE)

WFIX

[block#] WFIX

Reformats the portion of the disk containing the specified block. This
word displays the range of blocks that would be affected by the refor-
matting and asks you to confirm that the reformatting is to take place.
This reformatting process usually repairs blocks that generate disk
errors.

WUNLOAD

WUNLOAD

Unloads the heads and powers down the drive motor of the Winchester disk
drive. You must use this command before you turn off the system.

Terminal words

Datamedia

Datamedia

Loads the control words required to use a Datamedia Elite 1521A terminal
as the system console. (See also EDIT under "Editing words")

DC

[row] [column] DC

Positions the cursor at the specified row and column.

Fastbaud

Fastbaud

Sets the communication rate of the board to 19,200 baud. After issuing
this word, you must also set the terminal communication rate to 19,200
baud. For the TeleVideo 950, Fastbaud sets the rate to 19,200 automat-
ically. For the VT100, you must set the baud rate manually. Fastbaud is
inappropriate for the Datamedia because the Datamedia does not operate at
19,200 baud.

Function-keys

Function-keys

Programs the function keys by loading block 1405. You may edit block
1405 to customize the operations of the function keys.

Opaq

>   Opaq

Stops sending output to the printer. This word cancels the action of
Opaq. This word operates only when used with a TeleVideo 950 terminal.
(See also Tran)

Poff

>   Poff

Disables the printer port on the terminal so that output sent to the ter-
minal is not also sent to the printer. (See also Pon)

Pon

>   Pon

Enables the printer port on the terminal so that output sent to the ter-
minal is also sent to the printer. (See also Poff)

Televideo

>   Televideo

Loads the control words required to use a TeleVideo 950 terminal as the
system console. (See also EDIT under "Editing words")

Thru-tv

>   Thru-tv [words]

Executes Tran to send output to the printer, executes the words you enter
at the keyboard, then executes Opaq to stop sending the output to the
printer. This word operates only when used with a TeleVideo 950 terminal
or a VT100 terminal.

Tran

>   Tran

Sends all output to the system printer, including all control sequences
that the terminal normally intercepts and interprets. This word operates
only when used with a TeleVideo 950 terminal. (See also Opaq)

VT100

VT100

Loads the control words required to use a DEC VT100 or compatible ter-
minal as the system console. (See also EDIT under "Editing words")

Printing words

CPRINT

[start block#] [end block#] CPRINT

Prints the specified range of blocks at a density of 10 blocks per page.

Dec-writer

Dec-writer

Loads the control words required to use a Digital Equipment Corporation
DECwriter III as the system printer. (See also Printing)

Image-writer

Image-writer

Loads the control words required to use an Apple Imagewriter as the sys-
tem printer. (See also Printing)

List-directory

List-directory

Places RCS in the list-directory mode, which is similar to the list-
programs mode except that list-directory mode prints the comments (lines
3 through 11) in the load blocks instead of listing the program blocks.
These lines should provide a directory to the code contained in each
block.

List-programs

List-programs

Places RCS in the list-programs mode. In this mode, RCS prints at least
10 blocks per page (more if the blocks contain blank lines). The actual
number of blocks printed per page depends on the format of the 10-block
load block structure.

The best way to use this utility is to set up a block that lists an entire level as follows:

        List-programs
        Small
        100 LOAD
        200 LOAD
        301 load 380 load
        Restore

The word List-programs redefines "load" to be the listing word at the beginning of the block, and the word Restore puts back the FORTH definition at the end of the block. The word Small instructs the printer to use condensed type. 100 LOAD prints the blocks normally loaded by 100; this block is assumed to use "load" (and not "LOAD") to load 10-block segments.

RCS prints only the nonblank lines from each block actually loaded. RCS enhances the printing of the first line of each 10-block load block to serve as a label for the load block. (It does not print the rest of the 10-block load block)

RCS does not print the first line of each program block because it assumes that the first line contains a vocabulary identifier. RCS prints the block number on the line above the block and, if the current page does not have enough room to print a complete 10-block load block, RCS begins a new page.

Paper-tiger

        Paper-tiger

        Loads the control words required to use an Integral Data Systems Paper Tiger as the system printer. (See also Printing)

Print

        [start block#] [end block#] Print

        Prints the specified range of blocks at a density of three blocks per page.

Printing

        Printing

        Loads the printing utilities. Use this word after you select a specific printer. (See also Dec-writer, Image-writer, and Paper-tiger)

Pset-tab

    [column#] Pset-tab

    Sets a printer tab stop at the specified column. (The first column is
    column 1)

Restore

    Restore

    Returns you to the mode you were using before you entered the
    List-programs word or the List-directory word.

Small

    Small

    Selects condensed printing for the printers.

Tape words

ADD-TO-TAPE

    [absolute start block#] [absolute end block#] ADD-TO-TAPE

    Begins at the current tape position and writes the specified range of
    blocks to tape.

BACKUP

    BACKUP

    Lists the backup block. You can edit this block to specify customized
    tape backup procedures.

BAD-TAPE

    [absolute start block#] [absolute end block#] BAD-TAPE

    Extends the previous file (while preserving file numbers) on the tape to
    cover a bad section detected by an attempted ADD-TO-TAPE. BAD-TAPE can-
    not work if the first file on the tape is bad.

FROM-TAPE

>   [absolute start block#] [absolute end block#] FROM-TAPE

>   Begins at the current tape position and loads the specified range of
>   blocks into memory.

TAPE

>   TAPE

>   Loads the tape utility.

TDOC

>   [absolute start block#] [absolute end block#] [file#] TDOC

>   Moves the tape to the start of the specified file and then displays the
>   start and end blocks. TDOC also leaves the start block# and end block#
>   on the stack.

TGOTO

>   [file#] TGOTO

>   Moves the tape to the beginning of the specified file.

TREWIND

>   TREWIND

>   Rewinds the tape to the beginning.

TUNLOAD

>   TUNLOAD

>   Unloads the tape. RCS does not wait for the tape to finish unloading
>   before executing the next word you enter.

Editing words

#LLIST

>   [block#] #LLIST

>   Lists a block (specified by its relative block number) with relative and
>   absolute block numbers, but without line numbers.

ØED

    [absolute block#] ØED or [absolute block#] Øed

    Makes a block (specified by its absolute block number) the current block
    and then enters the screen editor. (Loaded by EDIT)

Øed

    (see ØED)

ØLIST

    [absolute block#] ØLIST

    Lists a block (specified by its absolute block number) with relative and
    absolute block numbers and with line numbers.

ØLLIST

    [absolute block#] ØLLIST

    Lists a block (specified by its absolute block number), but without line
    numbers.

B

    B

    Decrements the current block number for listing or editing nearby blocks.

BLOCKS

    [source block#] [destination block#] [#blocks] BLOCKS

    Copies a number of blocks (specified by #blocks) from the source block
    number to the destination block number. The source and destination block
    ranges can overlap. (Loaded by Ed-extend)

CLEAR

    [start block#] [end block#] CLEAR

    Clears the specified range of blocks by filling the blocks with spaces.
    (Loaded by Ed-extend)

Datamedia-terminal

> Datamedia-terminal
>
> Customizes the screen editor for the Datamedia terminal. (Loaded by
> EDIT)

ED

> [block#] ED or [block#] ed
>
> Makes a block (specified by its relative block number) the current block
> and then enters the screen editor. If no block number is entered, the
> screen editor is entered at the current block. (Loaded by EDIT)

ed

> (See ED)

EDIT

> EDIT
>
> Loads the screen editor. One of the following terminal customization
> words must follow the word EDIT: TeleVideo-terminal, Datamedia-terminal,
> or VT100-terminal. EDIT also loads the following screen editor words:
> TeleVideo-terminal, Datamedia-terminal, VT100-terminal, ED, ed, 0ED, 0ed,
> RED, and red.

Ed-extend

> Ed-extend
>
> Loads the following command extensions to the line editor: BLOCKS,
> CLEAR, FIND, FIND-R, and R-WITH.

FIND

> [start block#] [end block#] FIND [string^]
>
> Locates and displays each line within the specified block range contain-
> ing the specified string. (Loaded by Ed-extend)

FIND-R

    [start block#] [end block#] FIND-R [string^]

    Locates and replaces all occurrences of the specified string within the
    specified block range. You must precede FIND-R with R-WITH to specify
    the replacement string. (Loaded by Ed-extend) (See also R-WITH)

L

    L

    Lists the current block with line numbers.

LIST

    [block#] LIST

    Lists a block (specified by its relative block number) with line numbers.

N

    N

    Increments the current block number for listing or editing nearby blocks.

QR

    [start block#] [end block#] QR

    Prompts you for the search and replace strings, then searches through the
    specified range of blocks for the first occurrence of the search string.
    After matching the search string, QR waits for you to enter a space, Y,
    or y, before replacing the string and then continuing to search for the
    next occurrence.

    You can enter a question mark (?) to receive help information. Entering
    any other character causes QR to leave the matched string unchanged and
    search for the next occurrence. (Loaded by Query-replace)

Query-replace

    Query-replace

    Loads the QR utility. (See also QR)

R-WITH

    R-WITH [string^]

    Places the specified string into the insert buffer. FIND-R uses the
    string in the insert buffer as the replacement text for its search and
    replace operation. (Loaded by Ed-extend) (See also FIND-R)

RED

    RED or red

    Makes current for editing the most recently accessed block on the most
    recently accessed slave board. You must load RED by using 1124 ØLOAD in
    CUSTOM after you load the words Master and EDIT.

red

    (See RED)

Televideo-terminal

    Televideo-terminal

    Customizes the screen editor for the TeleVideo 95Ø terminal. (Loaded by
    EDIT)

VT1ØØ-terminal

    VT1ØØ-terminal

    Customizes the screen editor for the VT1ØØ terminal. (Loaded by EDIT)

Remote-slave words

Board-sem-initialize

    [board segment] Board-sem-initialize

    Initializes the semaphore used to control remote/slave operation. This
    semaphore must be initialized by the master board for each slave board at
    power-up.

ELOAD

    [block#] ELOAD

    Empties the local block buffers, then executes LOAD. You must use ELOAD
    to reload a block onto a slave board after you have edited it from the
    master board.

Master

    Master

    Loads the master utility.

MONITOR

    [board segment] MONITOR

    Displays all output from the specified board and then returns to the
    master board when the slave becomes idle (waiting for input).

REMOTE

    [board segment] REMOTE [string\]

    Places the master board into remote mode to communicate with the speci-
    fied slave board, and then sends the slave board the specified string.

REMOTE-SLAVE

    REMOTE-SLAVE

    Places the current board into slave mode.

Slave

    Slave

    Loads the slave utility.

SYNC

    [board segment] SYNC

    Waits for the specified board to become idle (waiting for input).

TALK

[board segment] TALK\ [string]

Sends the specified string to the specified board.

^x

^x (This word is control-x, not caret-x)

Terminates slave mode on the current board and returns to the master
board, or returns from the master board to the most recently accessed
slave board.

Miscellaneous RCS words

"

" [string"] (This word consists of one double quotation mark character)

Displays the specified string. You can use this word in load blocks to
display comments during loading.

%

%

Indicates that the rest of the line is a comment.

%%

%%

Indicates that the rest of the block is a comment.

''

'' [string"] (This word consists of two single quotation mark
                characters)

Reads a string of up to 256 characters from the keyboard or block. RCS
stores the string in a temporary area so you can use ==> to initialize a
string variable.

(

    ([string])

    Enters a comment that terminates with a closing parenthesis. You cannot
    nest this kind of comment.

.Esc

    .Esc [string]

    Sends to the terminal an ASCII ESC code followed by the specified string.
    You can use this word to program terminal options, such as function keys.
    This word may be used only in FORTH words, and cannot be used in load
    blocks. (See also Esc)

.^

    .^ [string]   (This word consists of a period and a caret)

    Converts the ASCII string into the corresponding control characters and
    sends the control-character string to the terminal. You can use this
    word to program terminal options, such as function keys. This word may
    be used only in FORTH words, and cannot be used in a load block.

ØLOAD

    [absolute block#] ØLOAD

    Loads the specified block from Ø OFFSET, then restores the previous
    OFFSET.

87INIT

    87INIT

    Initializes the 8087. All boards must execute 87INIT after booting RCS
    at power-up.

:L

    :L or :l

    Places RCS in Locate mode.

:l

    (See :L)

:OK

      :OK [string"]

    Sets the system prompt to the specified string.

:R

      :R

    Places RCS in Run mode.

:r

    See :R

:S

      :S

    Places RCS in Show mode.

:s

    See :S

<PAGE

    [pagecode] <PAGE

    Converts a pagecode to a page number and leaves this page number on the
    stack. (See also >PAGE)

==>

    [values] ==> [variable]

    Moves information from the stack to the specified variable in the current
    vocabulary. RCS assumes that the information on the stack is correct for
    the type of variable you specify.

>PAGE

    [page#] >PAGE

    Converts a page number to a pagecode and leaves the pagecode on the
    stack. (See also <PAGE)

AA>Q

    [vector] [angle] AA>Q

    Normalizes the specified vector and converts the vector and the access
    angle (specified in radians) into a quaternion. This word leaves the
    quaternion on the stack so that you can use ==> to initialize quaternion
    variables.

BASE

    BASE

    Contains the current number base. The value of this variable affects all
    input and output numbers. (See also BI, DECIMAL, and HEX)

BI

    BI

    Specifies base 2 operation. The action of this word affects all input
    and output numbers. (See also BASE, DECIMAL, and HEX)

CR

    CR

    Sends to the terminal an ASCII carriage-return code followed by an ASCII
    line-feed code.

DBG-OFF

    DBG-OFF

    Turns off debug load. (See also DBG-ON)

DBG-ON

    DBG-ON

    Turns on debug load. Debug load performs three tasks: displays each
    block number before it is loaded, aborts the load if BASE is not decimal,
    and displays any numbers still on the stack after each block is loaded.
    Some of these numbers appear while loading SMACRO code, but any numbers
    remaining on the stack when loading is complete indicate one or more
    errors. (See also DBG-OFF)

DECIMAL

DECIMAL

Specifies base 10 operation. The action of this word affects all input
and output numbers. (See also BASE, BI, and HEX)

deg

[angle in degrees] deg

Converts floating-point angle measurements from degrees to radians and
leaves the converted value on the stack.

Esc

Esc [string]

Sends to the terminal an ASCII ESC code, followed by the specified
string. You can use this word to program terminal options, such as func-
tion keys. This word may be used only in a load block, and cannot be
used in a FORTH word. (See also .Esc)

F-MEM

F-MEM

Displays the current, minimum, and maximum highest address for the system
dictionary and user files.

GET-FROM-DISK

[page] [segment] [page address] [start block#] [#blocks] GET-FROM-DISK

Moves #blocks * 1024 bytes of data from the disk beginning at the start
block# (specified by its absolute block number) to the specified RAM page
address. (See also SAVE-ON-DISK)

HEX

HEX

Specifies base 16 operation. The action of this word affects all input
and output numbers. (See also BASE, BI, and DECIMAL)

LOAD

[block#] LOAD

Loads the specified block.

load

[block#] load

Loads the specified block relative to the current ref-blk. (See also ref-blk)

LOC

LOC [word]

Lists the source block for the specified word. The error message, **Pre-locate,** indicates that you cannot list the specified word.

MS

MS [matrix variable]

Displays the name of the specified matrix variable and then displays its contents.

NQUIT

NQUIT

Corrects a problem (indicated by the loss of :R in the prompt) that occurs in rare situations.

nz

nz

Contains the specification for the maximum number of zeros FORTH displays following the decimal point and before the most significant digit of a floating-point number. You can set this FORTH variable to display up to 32 characters in a floating-point number.

OFFSET

OFFSET

Contains the value of the current offset. RCS adds the value of this
FORTH variable to relative block numbers to generate the absolute block
numbers.

OLOAD

[offset] [block#] OLOAD   (Oh-LOAD, not ØLOAD)

Changes the current OFFSET to the specified offset, loads the specified
block, and then restores the previous OFFSET.

PAGE

PAGE

Sends a PAGE character to the terminal. This PAGE (also called a form
feed) character may be different for different types of terminals.

PAGE-MOVE

[source seg] [address] [dest seg] [address] [#bytes] [pagecode] PAGE-MOVE

Moves #bytes from the specified address in the source segment to the
specified address in the destination segment. Either the source or the
destination segment must be in the current board. The other segment must
be in the page specified by the pagecode.

PAGE-SEG-ERASE

[page] [segment] PAGE-SEG-ERASE

Fills with zeros the 64-kilobyte segment beginning at the specified page
and segment address.

PDUMP

[page] [segment] [address] [#bytes] PDUMP

Displays #bytes (in hex) beginning at the specified page address.

PMS

    PMS [pose variable]

    Displays the name of the pose variable and shows it as a rotation matrix
    with a translation vector.

PRINT-TIME

    [#tics] PRINT-TIME

    Displays the result (in microseconds) of TIMER-READ execution. (See also
    TIMER READ and TIMER-START)

QMS

    QMS [quaternion variable]

    Displays the name of the specified quaternion matrix variable and shows
    the quaternion as a matrix.

QS

    QS [quaternion variable]

    Displays the name of the specified quaternion variable and shows the
    quaternion value as an axis and an angle.

rad

    [angle in radians] rad

    Converts floating-point angle measurements from radians to degrees and
    leaves the converted value on the stack.

ref-blk

    [block#] ref-blk

    Updates the current ref-blk by making it the sum of the specified block
    number and the current block number. (See also load)

SAVE-ON-DISK

[page] [segment] [page address] [start block#] [#blocks] SAVE-ON-DISK

Moves #blocks * 1024 bytes of data from the specified RAM page address to
the disk, beginning at start block# (specified by its absolute block num-
ber). (See also GET-FROM-DISK)

sd

sd

Contains the specification for the number of significant digits FORTH
displays in floating-point numbers and leaves this value on the stack.
You can set this FORTH variable to display up to 8 significant digits in
a floating-point number.

SEG-DUMP

[segment] [address] [#bytes] SEG-DUMP

Displays #bytes (specified in hex) beginning at the specified segment
address.

SEG-MOVE

[source address] [dest address] [#bytes] [source seg] [dest seg] SEG-MOVE

Moves #bytes from the source segment address to the destination segment
address.

TAB

TAB

Sends an ASCII TAB character to the terminal.

THRU

[start block#] [end block#] THRU

Loads the specified range of blocks.

TIME-OUT-INIT

TIME-OUT-INIT

Enables the 6-millisecond time-out interrupt, which aborts access to a
memory location or I/O port if the hardware does not respond within 6
milliseconds of the request. This interrupt generates the message **6 msec
time-out interrupt.** To enable this interrupt, the system must execute
TIME-OUT-INIT at power-up.

TIME-P

TIME-P [routine]

Displays the name of the specified routine, executes the routine, and
displays the time of execution. TIME-P subtracts the appropriate over-
head time required to call the routine from the terminal task to provide
an accurate measurement of the time required to execute the routine.
TIME-P uses the same timer (timer 1) as TIMER-READ and TIME-START.

The overhead factor is correct for 8-MHz operation. You should enter the
following lines in the D>M auto-load block for each board running at
5-MHz:

        16 fnul-word-time !
        81 snul-word-time !

TIMER-READ

TIMER-READ

Reads the timer and returns on the stack the number of ticks from the
153-KHz clock. TIMER-READ uses the same timer (timer 1) as TIME-P and
TIMER-START. (See also PRINT-TIME and TIMER-START)

TIMER-START

TIMER-START

Starts the timer. TIMER-START uses the same timer (timer 1) as TIME-P
and TIMER-READ. (See also PRINT-TIME and TIMER-READ)

V-SIZE

V-SIZE

Displays the current vocabulary, the number of words defined in it, and
the maximum number of words the vocabulary can hold.

\L

    Re-executes the last SMACRO word executed, this time in Locate mode.

\l

    (See \L)

\N

    Displays the name of the last SMACRO word executed.

\n

    (See \N)

\R

    Re-executes the last SMACRO word executed, this time in Run mode.

\r

    (See \R)

\S

    Re-executes the last SMACRO word executed, this time in Show mode.

\s

    (See \S)

\^

    ^ [string] (This word consists of a caret)

    Converts the ASCII string into the corresponding control characters and
    sends this control-character string to the terminal. You can use this
    word to program terminal options, such as function keys. This word may
    be used only in a load block, and may not be used in a FORTH word. (See
    also .^)

~DUMP

    [address] [#bytes] ~DUMP

    Displays #bytes (in hex) from the specified SMACRO segment address.

~MEM

~MEM

Displays the number of bytes remaining in the SMACRO segment.

~MOVE

[source] [destination] [#bytes] ~MOVE

Moves #bytes (specified in hex) from the SMACRO segment source to the
SMACRO segment destination.

FORTH Words

!

[value] [FORTH address] !

Stores the specified 16-bit integer value in the specified FORTH address.

*

[value1] [value2] *

Calculates the product of two 16-bit integer values and leaves the result
on the stack.

+

[value1] [value2] +

Calculates the sum of two 16-bit integer values and leaves the result on
the stack.

-

[value1] [value2] -

Calculates the difference between two 16-bit integer values by subtract-
ing value2 from value1 and leaves the result on the stack.

.

[value] .

Displays the specified 16-bit integer value.

.D

    [value] .D

    Displays the specified 16-bit decimal integer value, but does not change
    the current base.

/

    [value1] [value2] /

    Calculates the quotient of two 16-bit integer values by dividing value1
    by value2 and leaves the result on the stack.

2!

    [address] [value] 2!

    Stores a 32-bit integer in a FORTH variable.

2@

    [address] [value] 2@

    Retrieves a 32-bit integer from a FORTH variable.

2IN

    [port address] 2IN

    Reads the 8-bit port twice and leaves the resulting 16-bit value on the
    stack. This word reads the low-order byte of this 16-bit value before
    the high-order byte.

2OUT

    [value] [port address] 2OUT

    Sends the specified 16-bit value to the specified output port as 2 bytes.
    This word sends the low-order byte of this 16-bit value before it sends
    the high-order byte.

:

    :[name]

    Creates a FORTH word and causes the system to enter the FORTH Compile
    mode.

:C~EXEC

    :C~EXEC [SMACRO word]

    Sets the mode temporarily to Compile, compiles a call to the specified
    SMACRO word, and restores the previous mode after the SMACRO word exe-
    cutes. This word may be used only in FORTH words, not in a load block.

:L~EXEC

    :L~EXEC [SMACRO word]

    Sets the mode temporarily to Locate, compiles a call to the specified
    SMACRO word, and restores the previous mode after the SMACRO word exe-
    cutes. This word may be used only in FORTH words, not in a load block.

:S~EXEC

    :S~EXEC [SMACRO word]

    Sets the mode temporarily to Show, compiles a call to the specified
    SMACRO word, and restores the previous mode after the SMACRO word exe-
    cutes. This word may be used only in FORTH words, not in a load block.

;

    ;

    Causes the system to exit from the FORTH Compile mode.

?

    [FORTH address] ?

    Displays the 16-bit integer value contained in the specified FORTH
    address.

@

    [FORTH address] @

    Retrieves a 16-bit integer value from the specified FORTH address and
    leaves it on the stack.

B.

[value] B.

Displays the specified 16-bit integer value in binary, but does not change the current base.

BACKGROUND

[stack size] [return stack size] [# user variables] BACKGROUND

Allots space for a background task by creating an entry in the FORTH dictionary with the parameter fields providing (in the following order) the background task address, stack origin, and the user area size (expressed as an 8-bit value). FORTH adjusts the task address upwards to fall on a 16-byte boundary to simplify segment register manipulations. (See also BUILD)

BUILD

[task address] BUILD

Inserts the background task from the specified task address into the FORTH round-robin. BUILD places the new background task immediately after the current task in the round-robin, copies the user variables declared for the background task from the operator task, and sets the background stack pointer to its origin. (See also BACKGROUND)

CLR-BIT

[bit#] [port address] CLR-BIT

Clears the specified bit in the specified port to 0. Other bits remain unaffected. You can use this word to clear interrupt masks with PIC. (See also SET-BIT)

DUMP

[FORTH address] [#bytes] DUMP

Displays #bytes beginning at the specified FORTH address.

F*

[value1] [value2] F*

Calculates the product of two 32-bit floating-point values and leaves the result on the stack.

F+

　　[value1] [value2] F+

　　Calculates the sum of two 32-bit floating-point numbers and leaves the
　　result on the stack.

F-

　　[value1] [value2] F-

　　Calculates the difference of two 32-bit floating-point values by sub-
　　tracting value2 from value1 and leaves the result on the stack.

F-ABS

　　[value] F-ABS

　　Calculates the absolute 32-bit floating-point value of the specified
　　value and leaves the result on the stack.

F.

　　[value] F.

　　Displays the specified 32-bit floating-point value.

F/

　　[value1] [value2] F/

　　Calculates the quotient of two 32-bit floating-point values by dividing
　　value1 by value2 and leaves the result on the stack.

FLOAT

　　[integer] FLOAT

　　Converts a 16-bit integer value to a 32-bit floating-point value and
　　leaves the converted value on the stack. (See also ROUND)

H.

　　[value] H.

　　Displays the specified 16-bit integer value in hex, but does not change
　　the current base.

INPUT

    [port address] INPUT

    Reads the 8-bit value from the specified input port and leaves the value
    on the stack.

IRR

    IRR

    Returns on the stack the port address for the Interrupt Request Register
    in the Programmable Interrupt Controller. This FORTH constant is useful
    for determining if interrupts are connected correctly.

LOCATE-OFF

    LOCATE-OFF

    Turns off locate for FORTH words.

LOCATE-ON

    LOCATE-ON

    Turns on locate for FORTH words. You cannot locate words defined with
    locate off. Turning off locate saves 2 bytes of FORTH space per word.
    (Locate is always on for SMACRO words)

MOVE

    [source FORTH address] [destination FORTH address] [#bytes] MOVE

    Moves #bytes from the source FORTH address to the destination FORTH
    address.

OUTPUT

    [value] [port address] OUTPUT

    Sends the specified 8-bit value to the specified output port.

PI

    PI

    Leaves the 32-bit floating-point value of pi on the stack.

PIC

PIC

Returns on the stack the port address for the Programmable Interrupt Controller. You use this port to mask and unmask interrupts.

ROUND

[float] ROUND

Converts a 32-bit floating-point value to a 16-bit integer value through rounding and leaves the converted value on the stack. (See also FLOAT)

SET-BIT

[bit#] [port address] SET-BIT

Sets the specified bit in the specified port to 1. Other bits remain unaffected. You can use this word to set interrupt masks with PIC. (See also CLR-BIT)

SQRT

[value] SQRT

Calculates the square root of the specified 32-bit floating-point value and leaves the result on the stack.

~!

[value] [SMACRO address] ~!

Stores the specified 16-bit integer value in the specified SMACRO address.

~?

[SMACRO address] ~?

Displays the 16-bit integer value contained in the specified SMACRO address.

~@

    [SMACRO address] ~@

    Retrieves the 16-bit integer value contained in the specified SMACRO
    address and leaves the value on the stack.

~C!

    [value] [address] ~C!

    Stores data in a SMACRO byte variable.

~C@

    [address] [value] ~C@

    Retrieves data from a SMACRO byte variable.

~F!

    [value] [SMACRO address] ~F!

    Stores the specified 32-bit floating-point value in the specified SMACRO
    address.

~F?

    [SMACRO address] ~F?

    Displays the 32-bit floating-point value contained in the specified
    SMACRO address.

~F@

    [SMACRO address] ~F@

    Retrieves the 32-bit floating-point value contained in the specified
    SMACRO address.

~FR?

    [address] ~FR?

    Reads a 32-bit floating-point value from the specified address, converts
    it from radians to degrees, and then displays the converted value.

SMACRO Words

The SMACRO words include the following types:

- SMACRO declaration words
- SMACRO predefined SMACRO variable words
- SMACRO operator words
- SMACRO vector-operator words
- SMACRO quaternion-operator words
- SMACRO matrix-operator words
- SMACRO pose-operator words
- SMACRO boolean-operator words
- SMACRO file-operation variable words
- SMACRO file-operation header variable words
- SMACRO file-operation words
- SMACRO boolean file-operation words
- SMACRO statement words
- Miscellaneous SMACRO words

SMACRO declaration words

1:a

    [#elements] 1:a [name]

    Creates a one-dimensional integer array, which belongs to the most
    recently declared variable owner. The parameter #elements must be less
    than 256.

1:fa

    [#elements] 1:fa [name]

    Creates a one-dimensional floating-point array, which belongs to the most
    recently declared variable owner. The parameter #elements must be less
    than 256.

2:a

    [#rows] [#columns] 2:a [name]

    Creates a two-dimensional integer array, which belongs to the most
    recently declared variable owner. SMACRO stores the array by rows. The
    product of the #rows and the #columns must be less than 256.

2:fa

[#rows] [#columns] 2:fa [name]

Creates a two-dimensional floating-point array, which belongs to the most
recently declared variable owner. SMACRO stores the array by rows. The
product of the #rows and the #columns must be less than 256.

<=

<= [values]

Stores the specified values in the most recently declared variable. The
values are assumed to be of the correct type and number for the variable
type. This declaration word works only for string, byte, and integer
variables. (See ==> for other variable types) The parameter <= is used
to initialize variables as they are declared, not in routines.

bv

bv [name]

Creates an 8-bit byte variable, which belongs to the most recently
declared variable owner.

bytes

bytes

Performs no function. You can use this nul word to make source code more
readable (for example, 2 bytes VAR-O).

end-routine

end-routine

Terminates the Compile mode. (See also routine)

FILE

[max #records] FILE [file name]

Creates a file with the specified name, using the most recently declared
variable owner as a template. Include this statement in the source block
that declares the variable owner. The max #records parameter specifies
the size of the new file.

fv

    fv [name]

    Creates a 32-bit floating-point variable, which belongs to the most
    recently declared variable owner.

iv

    iv [name]

    Creates a 16-bit integer variable, which belongs to the most recently
    declared variable owner.

mem

    mem

    Performs no function. You can use this nul word, which is an abbrevia-
    tion for members, to make source code more readable (for example, 10 mem
    S-VAR-O).

rec

    rec

    Performs no function. You can use this nul word, which is an abbrevia-
    tion for records, to make source code more readable (for example, 10 rec
    FILE).

routine

    routine [name]

    Creates a routine with the specified name and enters the Compile mode.
    (See also end-routine)

S-VAR-O

    [#members] S-VAR-O [name]

    Creates a sequential variable owner with the specified name. The sequen-
    tial variable can accept a maximum of #members.

segv

    [segment] [address] [#bytes] segv [name]

    Creates a segment variable, which belongs to the most recently declared
    variable owner.

seqv

    seqv [name]

    Creates a sequential variable, which belongs to the most recently
    declared sequential variable owner. The first sequential variable
    receives a value of Ø, the second variable receives a value of 1, and
    each successive variable receives the next sequential integer value.

strv

    [#bytes] strv [name]

    Creates a string variable #bytes long with the specified name, which
    belongs to the most recently declared variable owner.

VAR-O

    [#bytes] VAR-O [name]

    Creates a variable owner with the specified name and allots to this vari-
    able owner #bytes of space in the SMACRO segment for variable storage.

VOCABULARY

    [assembler voc#] [SMACRO voc#] [#entries] VOCABULARY [name]

    Creates a vocabulary. Enter the vocabulary numbers (voc#s) in hexadeci-
    mal. Both voc#s are four-digit numbers. The first three digits for the
    assembler vocabulary must be 513. The first three digits for the SMACRO
    vocabulary must be 531. The fourth digit of each number must be the
    same; must be 7, 9, B, D, or F; and must be different from any other
    vocabulary declared on the same board. The vocabulary name must be
    unique in the system, because RCS does not check for duplicate vocabulary
    names. The system may contain up to 2Ø vocabularies.

Predefined SMACRO variable words

-1# 1# 2# 3# 4# 5# 6# 7# 8# 9# 1Ø# 11# 12# 13# 14# 15# 16# 17# 18# 19# 32767#

    Each of these predefined integer variables contains the indicated value
    (for example, -1# contains the value -1).

0.# 1.# 2.#

Each of these predefined floating-point variables contains the indicated value (for example, 2.# contains the floating-point value 2.0).

cos{angle}

Predefined floating point variable used as output for certain quaternion operators.

cycle-count

A segment variable that provides the current cycle count. The communications process updates the cycle count.

false

Predefined sequential variable with integer value 0. You use the predefined sequential variables false, true, set, reset, ready, and not ready for logic tests. Their integer values are 0, 1, 2, 3, 4, and 5, respectively.

identity-pose

This predefined pose variable contains the identity pose, 1.0 0.0 0.0 0.0 0.0 0.0 0.0.

not-ready

Predefined sequential variable with integer value 5. (See also false)

ready

Predefined sequential variable with integer value 4. (See also false)

reset

Predefined sequential variable with integer value 3. (See also false)

rot-angle

Predefined floating-point variable used as output for certain quaternion operators.

rot-axis

>   Predefined floating-point variable used as output for certain quaternion
>   operators.

set

>   Predefined sequential variable with integer value 2. (See also false)

sin{angle}

>   Predefined floating-point variables used as outputs of certain quaternion
>   operators.

true

>   Predefined sequential variable with integer value 1. (See also false)

X Y Z

>   These predefined integer variables contain Ø, 1, and 2, respectively.
>   You can use these predefined variables with pose operators to identify
>   frame axes.

SMACRO operator words

The general spelling convention for SMACRO operators is as follows: operators
surrounded by () are integer, operators surrounded by .. are floating point,
and operators ending in _B are byte. (There may be exceptions to this conven-
tion) See Table B-1 earlier in this appendix for definitions of the abbrevia-
tions used in syntax descriptions.

" "

>   " "

>   Returns the result of the most recent integer expression. This word may
>   operate incorrectly if you place other code between the most recent inte-
>   ger expression and the pair of double quotation mark characters.

#.READ

#.READ

Reads a word (bounded by ASCII spaces) from the current input and tries
to find the word in the current vocabulary. If #.READ finds the word in
the current vocabulary, it assumes that the word is a floating-point var-
iable and returns the value of the variable. Otherwise, #.READ assumes
that the word is a floating-point number and returns this value. You can
use the #.READ word in place of a floating-point variable except as the
destination of the .=>. SMACRO word.

#READ

#READ

Reads a word (bounded by ASCII spaces) from the current input and tries
to find the word in the current vocabulary. If #READ finds the word in
the current vocabulary, it assumes that the word is an integer variable
and returns the value of the variable. Otherwise, #READ assumes that the
word is an integer number and returns this value. You can use #READ in
place of an integer variable except as an array index or as the destina-
tion of the => SMACRO word.

(( ))

(([ivar]))

Causes SMACRO to treat the integer variable, ivar, as a pointer.

()

[var] ()

Specifies an address by adding the current value of the index register to
the value of var. There is no space between the parentheses. (See also
Index-on)

(*)

[iexp] (*) [ivar]

Returns the product of iexp and ivar (iexp * ivar).

(*/)

    [iexp] (*/) [ivar1] [ivar2]

    Returns the result of iexp * ivar1/ivar2. The intermediate results of
    this expression can occupy up to 32 bits to maintain accuracy.

(+)

    [iexp] (+) [ivar]

    Returns the sum of iexp and ivar (iexp + ivar).

(-)

    [iexp] (-) [ivar]

    Returns the difference of ivar subtracted from iexp (iexp - ivar).

(/)

    [iexp] (/) [ivar]

    Returns the quotient of iexp divided by ivar (iexp/ivar).

(ABS)

    (ABS) [iexp]

    Returns the absolute value of iexp.

(COM)

    (COM) [iexp]

    Returns the one's complement of iexp.

(MAX)

    [iexp1] (MAX) [iexp2]

    Returns the signed maximum integer of iexp1 and iexp2.

(MIN)

      [iexp1] (MIN) [iexp2]

      Returns the signed minimum integer of iexp1 and iexp2.

(MOD)

      [iexp1] (MOD) [iexp2]
      Performs a modulo operation (iexp1 modulo iexp2) and returns the result
      using the same sign as iexp1.

.( ).

      .( ).

      Specifies the processing order for floating-point operations within an
      expression. Scalar operations can support up to eight levels of nesting,
      vector operations can support up to one level of nesting, and pose and
      quaternion operations can support any number of levels of nesting.

.*.

      [fexp1] .*. [fexp2]

      Returns the floating-point product of fexp1 and fexp2.

.*2**.

      [fexp1] .*2**. [fexp2]

      Rounds fexp2 to an integer value and then returns a value computed
      according to the following expression:

$$fexp1 * 2^{fexp2}$$

.+.

      [fexp1] .+. [fexp2]

      Returns the floating-point sum of fexp1 and fexp2.

.-.

      [fexp1] .-. [fexp2]

      Returns the floating-point difference of fexp1 minus fexp2.

./.

    [fexp1] ./. [fexp2]

    Returns the floating-point quotient of fexp1 divided by fexp2.

.=>.

    [fexp] .=>. [fvar]

    Stores fexp into fvar.

.ABS.

    .ABS. [fexp]

    Returns the absolute value of fexp.

.ATAN,SIN,COS.

    .ATAN,SIN,COS. [fexp1] [fexp2]

    Returns the arctangent, in radians of the quotient resulting from divid-
    ing fexp1 by fexp2 (fexp1/fexp2). This word also returns the SIN and
    COS values of the quotient in the predefined variables sin{angle} and
    cos{angle}, respectively.

.ATAN.

    .ATAN. [fexp1] [fexp2]

    Returns the arctangent in radians of the quotient resulting from dividing
    fexp1 by fexp2 (fexp1/fexp2).

.FRAC.

    .FRAC. [fexp]

    Returns the fraction portion of fexp as a floating-point value.

.INT.

    .INT. [fexp]

    Returns the integer portion of fexp as a floating-point value.

.MAX.

   [fexp1] .MAX. [fexp2]

   Returns the signed maximum floating-point value of fexp1 and fexp2.

.MIN.

   [fexp1] .MIN. [fexp2]

   Returns the signed minimum floating-point value of fexp1 and fexp2.

.MINUS.

   .MINUS. [fexp]

   Multiplies fexp by -1.Ø and returns the result.

.MOD+-18Ø.

   .MOD+-18Ø. [fexpr]

   Forces the result of fexpr into the range ± Pi radians (+18Ø degrees).

.SIGN.

   .SIGN. [fexp]

   Returns the floating-point sign of fexp as +1.Ø, -1.Ø, or Ø.Ø if the
   value of fexp is greater than Ø, less than Ø, or equal to Ø,
   respectively.

.SIN,COS.

   .SIN,COS. [fexp]

   Returns the sine and cosine of fexp in radians in the predefined SMACRO
   variables sin{angle} and cos{angle}. This word is a statement in itself
   and cannot be used as part of another expression.

.SQ.

   .SQ. [fexp]

   Returns the square of fexp.

.SQRT.

.SQRT. [fexp]

Returns the square root of fexp. This word generates an 8087 error if fexp has a negative value.

2pi

2pi

Returns the indicated floating-point value.

=>

[iexp] => [ivar]

Stores iexp into ivar.

=>SEG

[var] [#bytes] =>SEG [segvar]

Moves #bytes from var to the segment address identified in pointer variable, segvar.

a#

a# [var]

Returns the address, not the value, of var.

B*

[iexp] B* [ivar]

Returns the byte product of iexp and ivar.

B+

[iexp] B+ [ivar]

Returns the byte sum of iexp and ivar.

B-

    [iexp] B- [ivar]

    Returns the byte difference of iexp minus ivar.

B-to-stack

    [iexp] B-to-stack

    Converts iexp to a byte value and then pushes it onto the 8086 stack.

B/

    [iexp] B/ [ivar]

    Returns the byte quotient of iexp divided by ivar.

B=>

    [iexp] B=> [bvar]

    Converts iexp to a byte value and stores the resulting value in bvar.

F>I

    F>I [fexp]

    Returns the integer value obtained by rounding the floating-point value
    of fexp.

from-stack

    from-stack

    Pops the 8086 stack and returns the resulting integer value. (See also
    to-stack)

I>F

    I>F [iexp]

    Converts the integer value of iexp to a floating-point value.

in-port

   [ivar] in-port

   Returns the byte value read from the 8-bit I/O port specified by the
   address value in ivar.

index-on

   index-on [ivar]

   Loads ivar into the indexing register for use with the () operator.

mask-with

   [iexp] mask-with [ivar]

   Returns the result of a bitwise AND using iexp and ivar (iexp AND ivar).

out-port

   [iexp] out-port [ivar]

   Truncates iexp to an 8-bit value and sends it to the 8-bit output port
   whose address is contained in ivar.

pi

   pi

   Returns the indicated floating-point value.

pi/2

   pi/2

   Returns the indicated floating-point value.

READ"

   READ"

   Reads a string terminated by an ASCII double quotation mark character (")
   from the current input. You must follow READ" with S=> to store the
   string in a variable.

SEG=>

    [segvar] [#bytes] SEG=> [var]

    Moves #bytes to var from the segment address identified in pointer vari-
    able, segvar.

to-stack

    [iexp] to-stack

    Pushes iexp onto the 8086 stack. (See also from-stack)

WREAD

    WREAD

    Reads a string terminated by an ASCII space character. WREAD must be
    followed by S=> to store the string in a variable. If the input string
    is to contain spaces, use READ" instead of WREAD.

{ }

    array-var {[ivar1] [ivar2]}

    Provides a means of indexing arrays. In the case of one-dimensional
    arrays, ivar1 specifies the element number (beginning at 0) and the
    second variable, ivar2, is not included. In the case of two-dimensional
    arrays, ivar1 specifies the row number and ivar2 specifies the column
    number.

SMACRO vector-operator words

.CROSS.

    [vexp1] .CROSS. [vexp2]

    Returns the cross-product of vexp1 and vexp2.

.DOT.

    [vexp1] .DOT. [vexp2]

    Returns the dot-product of vexp1 and vexp2.

.UNIT.

.UNIT. [vexp]

Returns a unit vector parallel to vexp.

.V*S.

[vexp] .V*S. [fexp]

Returns the vector obtained by multiplying each element of vexp by fexp.

.V+.

[vexp1] .V+. [vexp2]

Returns the vector obtained by adding vexp1 to vexp2, element by element.

.V-.

[vexp1] .V-. [vexp2]

Returns the vector obtained by subtracting vexp2 from vexp1, element by element.

.V/S.

[vexp] .V/S. [fexp]

Returns the vector obtained by dividing the elements of vexp by fexp.

.V=>.

[vexp] .V=>. [vvar]

Stores vexp into vvar.

.VINV.

.VINV. [vexp]

Returns the generalized inverse of vexp (that is, $vexp/|vexp|^2$).

.VMAG.

   .VMAG. [vexp]

   Returns the magnitude of vexp.

.VMINUS.

   .VMINUS. [vexp]

   Returns the negative of vexp.

SMACRO quaternion-operator words

.AXIS,ANGLE>Q.

   .AXIS,ANGLE>Q. [vexp] [fexp]

   Treats vexp as an axis and fexp as an angle in radians, and returns the
   equivalent quaternion. The vector vexp must be a unit vector. (See also
   .UNIT. in the section "SMACRO vector-operator words")

.AXIS,SIN,COS>Q.

   .AXIS,SIN,COS>Q. [vexp] [fexp1] [fexp2]

   Treats vexp as an axis, fexp1 as sin{angle}, fexp2 as cos{angle}, and
   returns the equivalent quaternion. The vector vexp must be a unit
   vector. (See also .UNIT.)

.Q=>.

   [qexp] .Q=>. [qvar]

   Stores qexp into variable qvar.

.Q>AXIS,ANGLE,SIN,COS.

   .Q>AXIS,ANGLE,SIN,COS. [qexp]

   Converts qexp into an axis and angle representation. This word returns
   its results in the predefined variables rot-axis, rot-angle in radians (0
   <= rot-angle <=pi), sin{angle}, and cos{angle}. .Q>AXIS,SIN,COS. is
   faster than .Q>AXIS,ANGLE,SIN,COS. but it does not compute the angle.
   This word is a statement in itself and cannot be used as part of another
   expression.

.Q>AXIS,SIN,COS.

    .Q>AXIS,SIN,COS. [qexp]

    Converts qexp into an axis and angle representation. This word returns
    its results in the predefined variables rot-axis, sin{angle}, and
    cos{angle}. .Q>AXIS,SIN,COS. is faster than .Q>AXIS,ANGLE,SIN,COS.
    because it does not compute the angle. This word is a statement in
    itself and cannot be used as part of another expression.

.QINV.

    .QINV. [qexp]

    Returns the inverse of qexp.

.QQ*.

    [qexp2] .QQ*. [qexp1]

    Returns the quaternion product of qexp2 and qexp1.

.QV*.

    [qexp] .QV*. [vexp]

    Returns the vector obtained by applying the rotation qexp to vexp.

.V>Q.

    .V>Q. [vexp]

    Returns the quaternion equivalent to the rotation vector, vexp, by
    treating .UNIT. vexp as an axis and .VMAG. vexp as an angle in radians.

SMACRO matrix-operator words

.M=>.

    [mexp] .M=>. [mvar]

    Stores mexp into mvar.

.M>Q.

    .M>Q. [mexp]

    Returns the quaternion equivalent to mexp.

.Q>M.

> .Q>M. [qexp]

> Returns the matrix equivalent to qexp.

SMACRO pose-operator words

.P=>.

> [pexp] .P=>. [pvar]

> Stores pexp into pvar.

.PINV.

> .PINV. [pexp]

> Returns the inverse of pexp.

.PP*.

> [pexp2] .PP*. [pexp1]

> Returns the POSE product of pexp2 and pexp1.

.PQ*.

> [pexp] .PQ*. [qexp]

> Returns a pose computed by multiplying the quaternion part of pexp by qexp. The vector part of pexp becomes the vector part of the result. The operator .PQ*. rotates the pose frame by a rotation expressed in the pose frame.

.PV+.

> [pexp] .PV+. [vexp]

> Returns a pose computed by multiplying the quaternion part of pexp by vexp, and then adding the result to the vector part of pexp. The operator .PV+. translates the pose frame by a translation expressed in the pose frame.

.QP*.

[qexp] .QP*. [pexp]

Returns a pose computed by multiplying the qexp by the quaternion part of
pexp. The vector part of the result is the vector part of pexp. The
operator .QP*. rotates the pose frame by a quaternion expressed in the
base frame.

.ROT,SIN,COS.

[pexp] .ROT,SIN,COS. [ivar] [fexp1] [fexp2]

Treats ivar as the axis of the pose frame and uses sin (fexp1) and cos
(fexp2) to define the angle of rotation, and then returns a pose computed
by rotating the quaternion part of pexp about the axis through the speci-
fied angle. The axis is one of the x, y, or z axes of the pose frame as
indicated by an ivar value of Ø, 1, or 2, respectively. (Use the pre-
defined variables X, Y, and Z) The vector part of the result is the
vector part of pexp. .ROT,SIN,COS. operates faster than .PQ*. or .ROT.
to rotate the pose frame by a quaternion expressed in the pose frame.

.ROT.

[pexp] .ROT. [ivar] [fexp]

Treats ivar as one of the axes of the pose frame and fexp as the angle of
rotation in radians, and then returns a pose computed by rotating the
quaternion part of pexp about the axis through the specified angle. The
axis is one of the x, y, or z axes of the pose frame as indicated by an
ivar value of Ø, 1, or 2, respectively. (Use the predefined variables X,
Y, and Z) The vector part of the result is the vector part of pexp. The
operator .ROT. operates faster than .PQ*. to rotate the pose frame by a
quaternion expressed in the pose frame.

.TRN.

[pexp] .TRN. [ivar] [fexp]

Treats ivar as the axis of the pose frame and fexp as the translation
distance, and then returns a pose computed by translating the vector part
of pexp along the specified axis by the specified distance. The axis is
one of the x, y, or z axes of the pose frame as indicated by an ivar
value of Ø, 1, or 2, respectively. (Use the predefined variables X, Y,
and Z) The quaternion part of the result is the quaternion part of
pexp. The effect of this word is to translate the pose frame by a vector
expressed in the pose frame. The operator .TRN. operates faster than
.PV+. to translate the pose frame by a vector expressed in the pose
frame.

.VP+.

[vexp] .VP+. [pexp]

Returns a pose computed by adding vexp to the vector part of pexp. The quaternion part of the result is the quaternion part of pexp. This word translates the pose frame by a vector expressed in the base frame.

SMACRO Boolean-operator words

(AND)

[boolean exp] (AND) [boolean exp]

Returns true only if both Boolean expressions are true.

(EQ)

[iexp] (EQ) [ivar]

Returns true only if the operands are equal.

(GE)

[iexp] (GE) [ivar]

Returns true only if iexp is greater than or equal to ivar.

(GT)

[iexp] (GT) [ivar]

Returns true only if iexp is greater than ivar.

(LE)

[iexp] (LE) [ivar]

Returns true only if iexp is less than or equal to ivar.

(LT)

[iexp] (LT) [ivar]

Returns true only if iexp is less than ivar.

(NE)

    [iexp] (NE) [ivar]

    Returns true only if the operands are not equal.

.EQ.

    [fexp1] .EQ. [fexp2]

    Returns true only if the operands are equal.

.EQZ.

    [fexp] .EQZ.

    Returns true only if fexp is equal to 0.

.GE.

    [fexp1] .GE. [fexp2]

    Returns true only if fexp1 is greater than or equal to fexp2.

.GEZ.

    [fexp] .GEZ.

    Returns true only if fexp is greater than or equal to 0.

.GT.

    [fexp1] .GT. [fexp2]

    Returns true only if fexp1 is greater than fexp2.

.GTZ.

    [fexp] .GTZ.

    Returns true only if fexp is greater than 0.

.LE.

    [fexp1] .LE. [fexp2]

    Returns true only if fexp1 is less than or equal to fexp2.

.LEZ.

    [fexp] .LEZ.

    Returns true only if fexp is less than or equal to 0.

.LT.

    [fexp1] .LT. [fexp2]

    Returns true only if fexp1 is less than fexp2.

.LTZ.

    [fexp] .LTZ.

    Returns true only if fexp is less than 0.

.NE.

    [fexp1] .NE. [fexp2]

    Returns true only if the operands are not equal.

.NEZ.

    [fexp] .NEZ.

    Returns true only if fexp is not equal to 0.

0-?

    [ivar1] 0-? [ivar2]

    Returns true only if the result of a bitwise AND of ivar2 with the one's
    complement of ivar1 is not 0.

1-?

    [ivar1] 1-? [ivar2]

    Returns true only if the result of a bitwise AND of ivar1 with ivar2 is
    not 0.

EQ_B

    [iexp] EQ_B [ivar]

    Truncates the operands iexp and ivar to 8 bits and returns true only if
    the truncated operands are equal.

GE_B

    [iexp] GE_B [ivar]

    Truncates iexp and ivar to 8 bits and returns true only if the truncated
    iexp is greater than or equal to the truncated ivar.

GT_B

    [iexp] GT_B [ivar]

    Truncates iexp and ivar to 8 bits and returns true only if the truncated
    iexp is greater than the truncated ivar.

LE_B

    [iexp] LE_B [ivar]

    Truncates iexp and ivar to 8 bits and returns true only if the truncated
    iexp is less than or equal to the truncated ivar.

LT_B

    [iexp] LT_B [ivar]

    Truncates iexp and ivar to 8 bits and returns true only if the truncated
    iexp is less than the truncated ivar.

NE_B

    [iexp] NE_B [ivar]

    Truncates the operands iexp and ivar to 8 bits and returns true only if
    the truncated operands are not equal.

S-EQ

    [svar] S-EQ [svar]

    Returns true only if the ASCII values of two string variables are
    equal. S-EQ assumes the lengths of the strings are equal.

^EQ^

    [ivar1] ^EQ^ [ivar2]

    Returns true only if the Boolean value of ivar2 is equal to the result of a bitwise AND of ivar1 with ivar2.

SMACRO file-operation variable words

File-var

    Contains all the file-operation and header variables. Showing this variable owner can be useful in debugging file operations.

next-record

    Points to the next record in the file.

record#

    Points to the current record in the file. All file access procedures use this variable.

source-blk

    Specifies the block (if any) that contains the source code for that record.

SMACRO file-operation header variable words

ass/rec

    ass/rec

    Contains the number of records removed from the free list and assigned to other lists.

avail-record

    avail-record

    Points to the beginning of the free list.

bytes/record

　　bytes/record

　　Specifies the number of bytes in each record in the file, including the
　　link and source fields.

f-segment

　　f-segment

　　Specifies the segment address for the file.

f-template

　　f-template

　　Specifies the address of the local template.

file-start

　　file-start

　　Specifies the address of the first physical record in the file segment.

first-record

　　first-record

　　Points to the first record in a list in the current file. This header
　　variable provides a simple way to manage files that consist of a single
　　list. The first-record variable contains the pointer to the beginning of
　　the list, and is updated as needed by the file operators. This variable
　　has other uses in multiple-list files.

max/rec

　　max/rec

　　Contains the total number of records allocated for the file.

SMACRO file-operation words

See Table B-2 at the beginning of this appendix for definitions of the phrases used in the syntax descriptions.

add-list

    add-list

    Stores the data from the local template to a record, removes the record
    from the free list, and makes the record the beginning of a new list.
    This operator leaves record# and first-record set to the record stored,
    increments ass/rec, sets source-blk and the source block field to the
    current block, and sets next-record and the link field to Ø. The word
    add-list aborts if the file is full.

add-record

    add-record

    Stores the data from the local template to a record, removes the record
    from the free list, and adds the record to the end of the current list.
    This operator leaves record# set to the record stored, increments
    ass/rec, sets source-blk and the source block field to the current block,
    and sets the next-record and link field to Ø. If there is no current
    list (that is, if record# is Ø), SMACRO executes add-list automatically
    in place of add-record. The word add-record aborts if the file is full.

clear-list

    clear-list

    Returns the entire current list to the free list. This operation does
    not abort if record# is Ø, but in this case no action takes place because
    there is no list to clear.

remove

    remove

    Removes the current record from the list pointed to by first-record, and
    returns it to the free list, sets first-record to the beginning of the
    resulting list, sets next-record to the record following the removed
    record, and decrements ass/rec. The operation of remove aborts if there
    is no current record, or if the current record is not on the list.

retrieve

    retrieve

    Retrieves the current record from the current file and leaves the data in
    the local template. The word retrieve aborts if record# is Ø.

retrieve-from-field

    retrieve-from-field [field] [destination]

    Retrieves the data from the specified field in the current record and
    stores the data in the specified destination. The word retrieve-from-
    field aborts if record# is Ø.

retrieve-from-fields

    retrieve-from-fields [field1] [field2] [destination]

    Retrieves the data from fields in the range field1 through field2 in the
    current record and stores the data in the specified destination. The
    destination must be the beginning of a set of consecutive variables whose
    total byte count matches the total of the fields being retrieved. The
    word retrieve-from-fields aborts if record# is Ø.

retrieve-l&r

    retrieve-l&r

    Retrieves the following three items: the current record to the local
    template, the link field to the variable next-record, and the source
    field to the variable source-blk. The word retrieve-l&r aborts if
    record# is Ø.

retrieve-link

    retrieve-link [var]

    Retrieves the record# from the link field of the current record and
    stores it in var. This word does not abort if record# is Ø.

retrieve-source

    retrieve-source [var]

    Retrieves the data from the source block field of the current record and
    stores it in var. This word does not abort if record# is Ø.

store

    store

    Stores the data present in the local template in the current record and
    sets the source block field to the current block. The word store aborts
    if record# is 0.

store-l&r

    store-l&r

    Stores the following three items: the local template to the current
    record, the variable next-record to the link field, and the variable
    source-blk to the source field. The word store-l&r aborts if record#
    is 0.

store-link

    store-link [var]

    Stores the value in var to the link field in the current record. The var
    must contain a valid record# for the current file. This operation does
    not abort if record# is 0.

store-source

    store-source

    Sets the source block field in the current record to the current block as
    specified by BLK + OFFSET. This word does not abort if record# is 0.

store-to-field

    store-to-field [field] [source]

    Stores the data from the specified source to the specified field in the
    current record. The source and the field must contain an equal number of
    bytes. The word store-to-field aborts if record# is 0.

store-to-fields

    store-to-fields [field1] [field2] [source]

    Stores the data from the source to the range of fields, field1 through
    field2, in the current record. The source must be the beginning of a set
    of consecutive variables whose total byte count matches the total of the
    fields stored. The word store-to-fields aborts if record# is 0.

~re-init-file

    ~re-init-file

    Assigns all records in the current file to the free list. This operator
    sets variables first-record and ass/rec to Ø, and fills all record fields
    (except the link field) with zeros.

~update-header

    ~update-header

    Stores the data present in the local copies of the header variables to
    the header of the current file.

SMACRO Boolean file-operation words

matches

    [var] matches [field]

    Searches the current list, testing to see if the contents of the speci-
    fied var equal the contents of the specified field in each record. This
    operation returns a true value and sets record# to that record when it
    finds a match between the two operands. The word matches aborts if
    record# is Ø.

matches-fields

    [var] matches-fields [field1] [field2]

    Searches the current list, testing to see if the contents of the speci-
    fied var equal the contents of the specified range of fields in each
    record. This operation returns a true value and sets record# to that
    record when it finds a match between the operands. The word matches-
    fields aborts if record# is Ø.

matches-fields-r

    [var] matches-fields-r [field1] [field2]

    Searches the current list, testing to see if the contents of the speci-
    fied var equal the contents of the specified range of fields in each
    record. This operation returns a true value, sets record# to that
    record, and retrieves the record to the local template when it finds a
    match between the operands. The word matches-fields-r aborts, if record#
    is Ø.

matches-r

>   [var] matches-r [field]

>   Searches the current list, testing to see if the contents of the speci-
>   fied var equal the contents of the specified field in each record. This
>   operation returns a true value, sets record# to that record, and
>   retrieves the record to the local template when it finds a match between
>   the operands. The word matches-r aborts if record# is Ø.

SMACRO statement words

abort

>   abort

>   Aborts the current process and displays the message **ABORTED.**

b-fill

>   [var] [#bytes] [char] b-fill

>   Starts at var and fills #bytes with the value of char (an 8-bit ASCII
>   character, not a variable). The parameter var cannot be a subscripted
>   array. (See also w-fill)

blank

>   [var] [#bytes] blank

>   Starts at var and fills #bytes with the ASCII space character. The
>   parameter var cannot be a subscripted array.

case

    case [var1]
    case: [var2] [codeA]
    case: [var3] [codeB]
    •
    •
    •
    case: [var41] [codeC]
    default: [default codeD]
    end-case

    Compares the value of var1 to the values of the case variables (var2
    through var41) and executes the code following the first variable match-
    ing var1. This statement executes the default code if none of the vari-
    ables match var1. You can use up to 40 cases (the statement compiles as
    a nested IF-THEN-ELSE comparison so the same maximum nesting limit
    applies). The operands var1 through var41 must be either integers or
    sequential variables.

case:

    (See case)

default:

    (See case)

default-state:

    (See state-table)

do

    (See while)

else

    (See if)

end-case

    (See case)

end-do

    (See while)

end-repeat

    (See repeat)

end-state-table

    (See state-table)

endif

    (See if)

enter-interrupt

    enter-interrupt

    Pushes all 8086 registers, except CS, SS, and S; pushes the variable
    page; sets DS to the SMACRO segment; sets ES to the FORTH segment; and
    sets the 24-bit page register to page 0. The enter-interrupt statement
    does not clear the interrupt mask. You can use this statement to pre-
    serve the state of the processor registers at the beginning of an inter-
    rupt routine. (See also exit-interrupt)

erase

    [var] [#bytes] erase

    Starts at var and fills #bytes with 0. The parameter var cannot be a
    subscripted array.

exit-interrupt

    exit-interrupt

    Restores the registers pushed on the stack by enter-interrupt and then
    executes a return from interrupt (IRET). You can use this statement at
    the end of an interrupt routine to restore the registers before continu-
    ing with normal processing. (See also enter-interrupt)

if

    if [boolean exp] then [code] else [code] endif

    Provides the standard if-then-else control structure up to a nesting
    level of 40.

move

    [var1] [var2] [#bytes] move

    Moves #bytes from var1 to var2. The parameters var1 and var2 cannot be
    subscripted arrays.

repeat

    repeat [code] until [boolean exp] end-repeat

    Provides the standard repeat-until control structure up to a nesting
    level of 40.

S=>

    [var1] S=> [var2]

    Moves var1 to var2. This statement does not affect the rest of var2 if
    var1 is shorter than var2. The variables var1 and var2 may be strings,
    owners, or arrays.

set-bit-in

    [var1] set-bit-in [var2]

    Sets to 1 the var2 bits corresponding to ones in bit mask var1.

state

    (See state-table)

state-table

```
state-table   [state-var1]     [state-var2] . . . [state-var7]
state:        [test-var1]      [test-var2]  . . . [test-var7]   [codeA]
state:        [test-var8]      [test-var9]  . . . [test-var14]  [codeB]
state:        [test-var15]     [test-var16] . . . [test-var21]  [codeC]
  .
  .
  .
default-state: [default code]
end-state-table
```

Compares the values of all state variables (state-var1 through
state-var7) to the values of the test-variables (test-var1 through test-
var7) in each line of the state table and executes the code on the first
line containing a match for every state variable. Following the match,
lines within the state table are ignored. SMACRO executes the default
code if none of the lines contains a match for every state variable.

You must use the same number of test variables in each line as there are
state variables. You may have up to seven state variables. A test vari-
able can be a variable, a negated variable (using the ~ prefix character
to indicate "not-equal"), or XX. XX is a don't-care variable that
matches any state variable. Corresponding state and test variables must
be of the same type. State tables accept only types strv, iv, bv, and
seqv.

State tables cannot be nested. The total number of test variables (not
counting XX don't-care variables) must be less than 40.

then

(See if)

until

(See repeat)

w-fill

[var] [#words] [integer] w-fill

Starts at var and fills #words with the specified integer value. The
parameter var cannot be a subscripted array. (See also b-fill)

while

    while [boolean exp] do [code] end-do

    Provides the standard while-do control structure up to a nesting level
    of 40.

XX

    (See state-table)

zero-bit-in

    [ivar1] zero-bit-in [ivar2]

    Sets to 0 the ivar2 bits corresponding to ones in bit mask ivar1.

~

    (See state-table)

~F

    ~F [FORTH word]

    Calls the specified FORTH word.

~PRINT

    ~PRINT [var]

    Displays the value of the specified variable. For an array variable, the
    entire array is displayed. ~PRINT does not work with a subscripted
    array.

~PRINT"

    ~PRINT" [string"]

    Displays the specified string.

Miscellaneous SMACRO words

Ø-SMACRO

 Ø-SMACRO

 Represents board Ø in the system vocabulary. (All boards have even
 numbers)

1Ø-SMACRO

 1Ø-SMACRO

 Represents board 1Ø in the system vocabulary. (All boards have even
 numbers)

12-SMACRO

 12-SMACRO

 Represents board 12 in the system vocabulary. (All boards have even
 numbers)

2-SMACRO

 2-SMACRO

 Represents board 2 in the system vocabulary. (All boards have even
 numbers)

4-SMACRO

 4-SMACRO

 Represents board 4 in the system vocabulary. (All boards have even
 numbers)

6-SMACRO

 6-SMACRO

 Represents board 6 in the system vocabulary. (All boards have even
 numbers)

8-SMACRO

Represents board 8 in the system vocabulary. (All boards have even numbers)

DEFINITIONS

DEFINITIONS

Enables the current vocabulary. You must precede DEFINITIONS with the name of a vocabulary.

LIST-O

LIST-O [name]

Creates a list owner.

m

m [name]

Adds a variable with the specified name to the most recently created list owner. You must declare this named variable in the same vocabulary as the list owner. (For example, you cannot add a variable from the SDEF vocabulary if the most recently created list owner is in the $DEF vocabulary)

page

page

Contains a copy of the four high-order address bits. Routines that per-form address calculations require this FORTH variable because the system does not allow access to the actual address register. To keep the infor-mation in this variable current, all code that sets the address register must also set this variable. In particular, an interrupt routine that changes the four high-order bits must first preserve the page variable before making the changes. The interrupt routine must then restore the page variable and reset the address register bits before executing an IRET. (See also enter-interrupt and exit-interrupt in the section "SMACRO statement words")

SDEF

    SDEF

    Sets the system vocabulary.

~INTERRUPT

    [interrupt#] ~INTERRUPT [routine]

    Sets the specified interrupt# to call the specified routine.

COMM Words

buffer-ready-f

    buffer-ready-f

    Indicates when the buffer is ready. You must include this integer vari-
    able in every vocabulary that COMM accesses.

COMM

    COMM

    Loads the communications utility.

COMM-PROCESS

    COMM-PROCESS

    The routine that performs the communications process. You must include
    this routine in the board process on the COMM board.

control-cycle-#-clks

    control-cycle-#-clks
    Contains the user-defined number of counts for the communications timer
    based on a 153-KHz counter cycle. The default value for this SMACRO
    variable is 1300 (hex). For debugging, you can change this value to 7FFF
    to obtain the longest possible interval between cycles.

ERASE-COMM-TABLE

    ERASE-COMM-TABLE

    Erases all entries from the communications table of a board, thus delet-
    ing all communication paths between control levels.

RESTART-COMM-TIMER

RESTART-COMM-TIMER

Restarts the communications timer (timer Ø on the COMM board).

SHOW-TABLE

SHOW-TABLE

Displays the contents of the current communications table. The first
column contains unimportant information which you can ignore. Each line
in the table represents either a transfer path from an output buffer to
common memory or a transfer path from common memory to an input buffer on
another level. Thus, two lines comprise a complete transfer path.

TO-DESTINATION

(See TRANSFER-FROM)

TRANSFER-FROM

TRANSFER-FROM [vocabulary buffer] TO-DESTINATION [vocabulary buffer]

Enters a buffer transfer into the communications table of a board, thus
adding a communication path between control levels.

WAIT-FOR-NEXT-COMM-CYCLE

WAIT-FOR-NEXT-COMM-CYCLE

Delays program execution until the communications timer begins the next
communications cycle. You can optionally include this statement in the
board process on the COMM board.

B.2 RSL WORDS

The following list describes the user words defined in RSL. All block refer-
ences are absolute, unless otherwise indicated. The RSL words fall into the
following categories:

- RSL operating system words
- Language words
- TASK command words
- RSL system parameter words
- Control level words

RSL Operating System Words

$DEF

> $DEF
>
>   Enables all levels to load their file definitions from the same source
>   block. Though the file definitions come from the same source block, $DEF
>   declares them in the correct vocabulary. You must define this word on
>   all control levels to set their vocabularies.

?ARR

>   ?ARR [array name]
>
>   Displays the following information for the specified array: record num-
>   ber, absolute source block number, number of sectors for each dimension,
>   movable name for each dimension, sector pose name, and current sector
>   list. ?ARR sets the editor default block to the last block number
>   displayed.

?LOC

>   ?LOC [location name]
>
>   Displays the following information for the specified location: record
>   number, absolute source block number, pose name, movable name, and a
>   matrix representing the resulting pose. ?LOC sets the editor default
>   block to the last block number displayed.

?MOVE-TO

?MOVE-TO

Displays the following information for all currently defined move-to
paths: record number, absolute source block number, path-^, object,
start location, and destination location. ?MOVE-TO pauses after display-
ing the information for each move-to path and waits for you to press any
key before displaying the information for the next move-to path. You can
press ^C to abort the operation of ?MOVE-TO before it displays all cur-
rent move-to paths. ?MOVE-TO sets the editor default block to the last
block number displayed.

?MTB

?MTB [movetable name]

Displays the specified movetable, its record number, and its absolute
source block number. ?MTB sets the editor default block to the last
block number displayed.

?OBJ

?OBJ [object name] [grip#]

Displays the following information for the specified grip# on the speci-
fied object: OBJECT-NAME-FILE record number, OBJ-GRIP-FILE record num-
ber, absolute source block number for the object grip, and name of the
grip movetable. ?OBJ sets the editor default block to the last block
number displayed.

?POSE

?POSE [pose name]

Displays a matrix representation of the specified pose and its configura-
tion flags, record number, and absolute source block number. ?POSE sets
the editor default block to the last block number displayed.

ABT

ABT [level name]

Aborts the control process of the specified level by setting the abort-f
variable to true. The level can be TASK, PATH, PRIM, or JOINT.

GO

GO

Starts the execution of all control level and communications processes
and issues the RESTART command to the TASK level by loading block 8921.
GO prompts you to initialize the robot interface.

HALT

HALT

Stops the execution of all control-level processes, the communications
process, and the robot interface by loading block 8924. HALT clears all
slave-board output buffers, sets offsets and prepares the system to exe-
cute the next GO command it receives. Block 8925 performs the same func-
tions as block 8924 except that block 8925 leaves the robot interface
active so that you can use the TT command. (See also TT)

Joint/comm

Joint/comm

Specifies the board segment of the JOINT/COMM board. You use this FORTH
constant with remote-slave words described in the section "Remote-slave
words".

POFF

POFF [level name]

Turns off the debug print facility for the specified control level by
setting the print-f variable to false. The level can be TASK, PATH,
PRIM, or JOINT. (See also PON)

PON

PON [level name]

Turns on the debug print facility for the specified control level by
setting the print-f variable to true. The level can be TASK, PATH, PRIM,
or JOINT. (See also POFF)

Prim

Specifies the board segment of the PRIM board. You use this FORTH con-
stant with remote-slave words described in the section "Remote-slave
words".

RECORD-POSE

RECORD-POSE [pose name]

Stores the current robot pose in the named pose variable. If the pose
name is not yet defined, RECORD-POSE defines it.

Task/path

Task/path

Specifies the board segment of the TASK&PATH board. You use this FORTH
constant with remote-slave words described in the section "Remote-slave
Words".

TT

TT

Executes one cycle of the full system and displays debug output for all
control levels. You must edit block 8923 to activate or deactivate the
robot interface during the operation of TT. You can edit block 919 on
each level to display the additional debug output. You must precede TT
with the HALT command if the robot interface is to be inactive. Alterna-
tively, you must precede TT with 8925 LOAD if the robot interface is to
be active. (See also HALT)

TTT

[#cycles] TTT

Performs the TT single-step function a number of times equal to #cycles.
(See also TT)

TYPE-POSE

[block#] [line#] TYPE-POSE [pose name]

Enters source code for the specified pose into the specified block,
beginning at the specified line.

Language Words

(See -mtb-)

-arr-

-arr-[array name] [base location] [x-#-sectors] [x-movetable]
    [y-#-sectors] [y-movetable] [z-#-sectors] [z-movetable]
    [sector pose]

Defines an array with the specified name and dimensions.

Where:

- array name contains the name of the array.

- base location specifies the location that is the origin (sector 0) of
  the array.

- x-#-sectors, y-#-sectors, and z-#-sectors specify the number of sec-
  tors along the x, y, and z axes of the array frame. Currently, the
  total number of sectors must be less than or equal to 20. The size of
  sector-list limits the total number of statements. You can increase
  the size of sector-list.

- x-movetable, y-movetable, and z-movetable contain the names of the
  movetables that give the displacements between sectors along the x, y,
  and z axes of the array frame. The movetables should consist only of
  tool frame motions. The array retains its shape if you move the
  location.

- sector pose contains the name of the pose RSL uses to store the posi-
  tion of the current sector during execution.

-imtb-

-imtb- [inverse name] [source name]

Defines an inverse movetable with the specified name based on the speci-
fied source movetable.

Where:

- inverse name contains the name for the new movetable.

- source name contains the name of the original movetable.

-loc-

    -loc- [location name] [pose] [movetable]

    Defines a location with the specified name. The specified pose and move-
    table combine to define the new location.

    Where:

    ● location-name contains the location name.

    ● pose contains the name of the pose.

    ● movetable contains the name of the movetable.

-mtb-

    -mtb- [name]

        --- [frame] [X] [Y] [Z]
        --- [r-tool] [axis] [angle]
        ●
        ●
        ●
        -mtb-end-

    Defines a movetable with the specified name. There are two parts to the
    movetable syntax: the name line (-mtb-) and the sequence of transform
    lines (---) terminated by -mtb-end-. Each transform line specifies
    either a vector translation or a rotation. You specify translations by
    giving the x, y, and z components of the vector (expressed in either the
    base or tool frame). You specify rotations by giving the angle and the
    axis (x, y, or z) of the tool frame. The unit of measurement for trans-
    lations is inches. For rotations the unit is degrees, within the range
    +180.00 to -179.99.

    Where:

    ● name contains the movetable name.

    ● frame contains either t-base or t-tool to specify the base frame or
      the tool frame, respectively.

    ● X contains the x component of the translation vector.

    ● Y contains the y component of the translation vector.

    ● Z contains the z component of the translation vector.

    ● r-tool specifies a rotation about the tool frame.

    ● axis contains X, Y, or Z to specify the axis about which to rotate.

    ● angle contains the angle to rotate in degrees.

-mtb-end-

    (See -mtb-)

-obj-

    -obj- [object phrase] [grip movetable]

    Defines an object grip with the specified name. The grip# specifies the
    grip position on the object and the specified grip movetable defines the
    grip position for the robot.

    Where:

    ● object phrase contains the object name and grip number.

    ● grip-mtb contains the name of the movetable that defines the grip
      position.

-path-

    -path- [path type] [object phrase] [location phrase]

    or,

    -path- move-to [object phrase] [start location phrase] [destination
    location phrase]

    The path statement syntax contains two parts: the path statement and a
    sequence of path-point lines. The -path- line defines the type and the
    parameters of the path; the -ppt- lines give the sequence of steps in the
    algorithm. See -ppt- for the path-point syntax.

    Where:

    ● path type is one of the RSL path types: approach-pickup, depart-
      pickup, approach-release, or depart-release.

    ● object phrase contains the object name and the grip number for this
      path.

    ● location phrase contains the type of goal (loc or arr) and the name
      that defines the goal of this path.

    ● start location phrase contains the location type (loc or arr) and the
      start location name.

    ● destination location phrase contains the location type (loc or arr)
      and the destination location name.

-pose-

-pose- [name] [pose numbers] [configuration flags]

Defines a pose with the specified name. The definition includes pose numbers and configuration flags. The pose numbers are the seven floating-point numbers that specify a quaternion and a vector. Refer to the robot transform documentation for information on the three configuration flags.

Where:

● name contains the name of the pose.

● pose numbers contains the seven floating point numbers for the quaternion and vector that represent the pose.

● configuration flags contains the three configuration flags, usually +1.0 or -1.0. See your robot transform documentation for details.

-ppt-

-ppt- goto [location phrase] [trajectory phrase]
Adds a goto path-point to the current path.

Where:

● location phrase contains the type (loc, arr, goal, or tool) and the name of the goal location.

● trajectory phrase contains the type of trajectory (cart or joint) and the trajectory parameters. (For descriptions of the trajectory parameters, see cart and joint)

-rr-

-rr- [name] [file] [size]

Defines a round-robin with the specified name and size in the specified file.

Where:

● name contains the name of the round-robin.

● file contains the name of the round-robin file.

● size specifies the number of records in the round-robin file.

approach-pickup

(See -path-)

approach-release

    (See -path-)

arr

    arr [name]

    Indicates an array in a location phrase. (See -path- and -ppt)

cart

    cart [translational max acceleration] [translational max velocity]
       [translational neighborhood] [rotational max acceleration]
       [rotational max velocity] [rotational neighborhood]

    Indicates a cartesian trajectory in a path-point trajectory phrase. When
    the trajectory routine reports done, the robot is within both the trans-
    lational and rotational neighborhood of the goal.

    Where:

- translational max acceleration contains the maximum allowed magnitude
  of the translational acceleration, in inches per cycle per cycle.

- translational max velocity contains the maximum allowed magnitude of
  the translational velocity, in inches per cycle.

- translational neighborhood contains the translational distance in
  inches from the current goal location at which the trajectory routine
  reports done.

- rotational max acceleration contains the maximum allowed magnitude of
  the rotational acceleration in degrees per cycle per cycle.

- rotational max velocity contains the maximum allowed magnitude of the
  rotational velocity, in degrees per cycle.

- rotational neighborhood contains the rotational distance in degrees
  from the current goal location at which the trajectory routine reports
  done.

depart-pickup

    (See -path-)

depart-release

    (See -path-)

goal

    goal [name]

    Indicates a goal movetable in a path-point loc phrase. (See -ppt-)

goto

    (See -ppt-)

joint

    joint [acceleration] [velocity] [delta]
    Indicates a joint trajectory in a path-point traj phrase.

    Where:

- acceleration contains the maximum allowed acceleration of any joint given as the percentage (between 0 and 100) of the hardware maximum for each joint.

- velocity contains the maximum allowed velocity of any joint given as the percentage (between 0 and 100) of the hardware maximum for each joint.

- delta contains the difference in degrees from the location joint values at which the trajectory routine reports done. When the trajectory reports done, all joint values are within this delta.

loc

    loc [name]

    Indicates a location in a location phrase. (See -path- and -ppt-)

move-to

    (See -path-)

nul

    nul

    The name of a predefined object, location, and movetable. Use nul to specify a nul value in the definition of paths and path-points.

r-tool

> (See -mtb-)

t-base

> (See -mtb-)

t-tool

> (See -mtb-)

tool

> tool [name]

> Indicates a tool movetable in a path-point location phrase. (See -ppt-)

TASK Command Words

MOVE-TO

> MOVE-TO [object] [grip#] [destination location type] [destination]
>   [array sector]

> Sends a move-to path to the PATH level. MOVE-TO uses the current loca-
> tion as the start location. The array sector specification is optional,
> you need to specify the array sector only if the destination location
> type is arr (indicating an array).

> MOVE-TO updates the current location to the path goal when PATH completes
> the path. MOVE-TO reports an error if it cannot find a specified path.
> After you issue MOVE-TO, the TASK level reports its status as executing
> until the PATH level reports its status as done. Then the TASK level
> also reports its status as done.

PAUSE

> PAUSE

> Sends PAUSE to the PATH level and sets the current location and object to
> nul. After you issue PAUSE, the TASK level reports its status as exe-
> cuting until the PATH level reports its status as done. Then the TASK
> level also reports its status as done.

RESTART

RESTART

Sends the RESTART command to the PATH level and sets the current location
and object to nul. After you issue RESTART, the TASK level reports its
status as executing until the PATH level reports its status as done.
Then the TASK level also reports its status as done.

TRANSFER

TRANSFER [object phrase] [source location phrase] [source sector list]
    [destination location phrase] [destination sector list]

Sends the following sequence of path commands to the PATH level:

1. move-to object source destination
2. approach-grasp object source
3. depart-grasp object source
4. move-to object source destination
5. approach-release object destination
6. depart-release object destination

RSL repeats the specified sequence of paths for each sector in the sector
list if the source or the destination consists of an array. If both the
source and the destination are arrays, the sector lists must have the
same lengths. RSL updates the current location as it completes the exe-
cution of each path.

After you issue TRANSFER, the TASK level reports its status as executing
until the PATH level indicates that all paths are complete by reporting
its status as done. Then the TASK level also reports its status as done.

RSL System Parameter Words

The following lists describe parameters that are associated with the JOINT,
PATH, and PRIM levels and with RSL.

JOINT parameters

These variables are set in the range of blocks 980 to 989 of the JOINT
level. The auto-load block of the JOINT D>M loads block 980.

a-sysmax

a-sysmax

Contains the maximum acceleration for each joint of the robot. This
6-element array describes acceleration in inches per cycle squared or
radians per cycle squared.

creep-delta

creep-delta

Contains the distance each joint is to move, relative to a joint limit.
The CREEP command uses this 6-element floating-point array to control the
movement of the joints.

creep-vel

creep-vel

Contains the velocity each joint is to use to reach the distance speci-
fied by creep-delta. The CREEP command uses this 6-element floating-
point array to control the movement of the joints.

lj-limit

lj-limit

Contains the lower joint limits for each joint of the robot. This
6-element array describes lower joint limits in inches or radians. The
JOINT-LIMIT-TEST routine uses these same limits to test for valid joint
values. You must edit the JOINT-LIMIT-TEST routine if you want this rou-
tine to use other limit criteria.

next-point-scale-threshold

next-point-scale-threshold

Determines when the CARTESIAN command is to report next-point status.
The next-point-scale-threshold variable has the value 0.5 for RSL
operation.

uj-limit

uj-limit

Contains the upper joint limits for each joint of the robot. This
6-element array describes upper joint limits in inches or radians. The
JOINT-LIMIT-TEST routine uses these same limits to test for valid joint
values. You must edit the JOINT-LIMIT-TEST routine if you want this rou-
tine to use other limit criteria.

v-sysmax

Contains the maximum velocity for each joint of the robot. This
6-element array describes the velocity in inches per cycle or in radians
per cycle.

PATH parameters

This variable is set in the range of blocks 980 to 989 of the PATH level. The
auto-load block of the PATH D>M loads block 980.

tp-cycles

tp-cycles

Specifies the delay (in number of cycles) between the tool-pose feedback
from the JOINT level and a robot's achievement of that pose. This vari-
able has a value of 2 when you are using RSL with VAL SLAVE. The TOOL-
POSE-^ routine uses this variable to set tool-pose-^.

PRIM parameters

These variables are set in the range of blocks 980 to 989 of the PRIM level.
The auto-load block of the PRIM D>M loads block 980.

joint-traj-delay

joint-traj-delay

Specifies the delay (using a floating-point number of cycles) between
issuing a command to, and the feedback pose from, the JOINT level.

joy-max-v

joy-max-v

Specifies the maximum translational velocity (using a floating-point num-
ber of inches per cycle) that you can obtain using the joystick. The
velocity switch on the joystick controller scales velocities down from
this maximum value.

joy-max-w

    joy-max-w

    Specifies the maximum rotational velocity (using a floating-point number
    of radians per cycle) that you can obtain using the joystick. The veloc-
    ity switch on the joystick controller scales velocities down from this
    maximum value.

RSL parameters

INV-TOOL-MTB

    INV-TOOL-MTB

    Defines an inverse of the tool point with respect to the robot wrist.
    You can define INV-TOOL-MTB as the inverse of TOOL-MTB by entering the
    sequence -imtb- INV-TOOL-MTB TOOL-MTB.

TOOL-MTB

    TOOL-MTB

    Defines the tool point with respect to the robot wrist. You can redefine
    this movetable to change the tool point; however, you must also redefine
    INV-TOOL-MTB at the same time.

Control-Level Words

abort-f

    abort-f

    Aborts control-level execution when this flag is true. (See also ABT
    under "RSL Operating System Words")

cycle-time

    cycle-time

    Records the number of 153-KHz clock ticks required for the levels to per-
    form the current execution cycle. You can use the PRINT-TIME routine to
    convert clock ticks to microseconds.

Display

    Enables you to display user-defined debug information. Display is a part
    of the board process that runs after the level executes its routines.
    You can turn the printing on with PON and turn the printing off with
    POFF. (See also PON and POFF under "RSL Operating System Words")

error-list

    error-list

    Contains the list of status-arg values. You can execute this sequential
    variable owner in Show mode to display the names for the status-arg
    values.

inc-command-#-in

    Indicates that a level has received a new command. You must increment
    this counter after setting the input command for a control level.

JS

    JS [joint array]

    Displays the joint angles, joint velocities, or joint accelerations con-
    tained in the specified joint array. You must edit this routine to
    accommodate your specific robot. For example, if you are using a PUMA
    760 robot, enter JS servo-com-joint to display the joint values (in
    degrees) commanded to the robot servo level. JS is defined only for the
    JOINT level.

List-display

    List-display

    Contains user-specified variables that are useful for debugging. Execut-
    ing List-display in Show mode displays the values of these variables.

max-cycle-time

    max-cycle-time

    Records the largest number of 153-KHz clock ticks required to complete an
    execution cycle since you issued RESTART. You can use the PRINT-TIME
    routine to convert clock ticks to microseconds.

min-cycle-time

min-cycle-time

Records the smallest number of 153-KHz clock ticks required to complete
an execution cycle since you issued RESTART. You can use the PRINT-TIME
routine to convert clock ticks to microseconds.

overflow-cycle

overflow-cycle

Contains the number of cycles since you issued RESTART in which the con-
trol level required longer than a cycle to complete its execution.

PDEF

PDEF

Sets the vocabulary for the PATH level. PDEF is defined only on the
TASK/PATH board.

print-f

print-f

Controls debug printing. PON sets this flag true and POFF sets this flag
false. (See also PON and POFF under "RSL Operating System Words")

TDEF

TDEF

Sets the vocabulary for the TASK level. TDEF is defined only on the
TASK/PATH board.

WAIT-TASK-DONE

WAIT-TASK-DONE

Waits for the status-report variable to indicate executing (that is, not
done) and then waits for the status-report variable to indicate done.
You can use this word in a load block to issue a sequence of commands to
the TASK level. For this situation, WAIT-TASK-DONE issues each succes-
sive command only after the previous command indicates done. You can use
ABT TASK to abort the operation of WAIT-TASK-DONE before all commands in
the sequence execute.

This appendix describes how RCS (with RSL version 1.6) allocates the MULTIBUS
address space, I/O space, interrupt assignments, and timers.

C.1 MULTIBUS ADDRESS SPACE

The following list describes the allocation of memory for RCS and RSL
version 1.6.

Address Range	Contents
0000-1FFFF	RSL processor
20000-3FFFF	PRIM processor
40000-5FFFF	TASK/PATH processor
60000-7FFFF	JOINT/COMM processor
80000-EFFFF	Common memory
80000-8FFFF	User files
90000-DFFFF	System dictionary
E0000-EEFFF	RCS communication buffer
EF000-EFBFF	Unused address space
EFC00-EFC1F	Disk control
EFC20-EFC7F	Remote/slave board semaphores
EFC80-EFFFF	Unused address space
F0000-FBFFF	Unused address space
FC000-FFFFF	FORTH PROMs

The unused address space shown in this list is available for user applica-
tions. You can use 24-bit addressing to increase the address space if your
MULTIBUS backplane includes the P2 connector option. This option enables you
to relocate the user files and the system dictionary in memory, and then add
up to three more processes in the address range 80000-DFFFF. (See the dpage
and fpage words for information on allocating memory to the system dictionary
and SMACRO files.)

C.2 MULTIBUS I/O SPACE ORGANIZATION

The following list describes the allocation of the I/O space for RCS.

I/O Address	Contents
0000-004F	Unused I/O space
0050-0051	Unused I/O space
0052-0053	Rimfire 45 disk and tape controller
0054-005F	Unused I/O space
0060-007F	Unused I/O space
0080-009F	J4 iSBX connector on 86/30
00A0-00BF	J3 iSBX connector on 86/30
00C0-00DF	Other 86/30 ports
00E0-00FF	Unused I/O space

All unused I/O address space and the J3 and J4 ports are available for user applications.

C.3 RCS INTERRUPT ASSIGNMENTS

The following list describes the assignments of the interrupts that affect the operation of RCS.

Interrupt Number	Function
0	6 millisecond time-out interrupt
1	8087 error interrupt
2	Communication bit input (not used on the board with the communications process)
3,4	On-board serial port (not required on slave boards)
5,6,7	Unused interrupts

C.4 TIMERS

Each 86/30 board has three programmable timers, numbered 0, 1, and 2. Timer 0, on the COMM board, is used by the COMM-PROCESS. Timer 0 on other boards is not used. Timer 1 is used by the debug routines TIME-P, START-TIMER, and READ-TIMER. Timer 2 is used for the on-board serial port. (Note that this timer can be used on slave boards that do not use the serial port.)

RCS uses the FORTH block structure for all source code. The disk map below
shows how RCS allocates blocks on the Winchester disk for RSL version 1.6.
(Block numbers begin at 1000 for historical reasons.)

Absolute Block Numbers	Contents
1000-1349	MBOOT
1350-1499	CUSTOM
1350-1359	Unused blocks
1360-1363	MAP
1364	BACKUP
1365-1369	Other tape blocks
1370-1383	CUSTOM setup blocks
1384	CUSTOM? map
1385-1397	DM? maps
1398	PRESERVE-FILE map
1399	PRESERVE map (PMAP)
1400-1401	Directory blocks
1402	System addresses
1403	Init-cm block
1404	Slave board names
1405	Function-keys block
1406-1412	System vocabulary declaration
1413-1419	Additional function key blocks
1420-1459	auto-load blocks
1460-1469	BOOT-SYSTEM blocks
1470-1479	Load base system
1480-1489	Load application
1490-1499	BOOT-BASE-SYSTEM blocks
1500-1599	Screen editor
1600-5999	D>M images
6000-6999	Reserved space for tape transfer
7000-7999	RCS source code
8000-8999	RSL source code
9000-9999	TASK source code
10000-10999	PATH source code
11000-11999	PRIM source code
12000-12999	JOINT source code
13000-30999	Available to user

In addition to the RCS blocks, the disk map includes blocks 8000-12999, which
are allocated for RSL. When you use RSL, block 3 (relative to the first block
in the level) is a load block that loads the control-level software. Simi-
larly, relative block 980 initializes the control level.

RCS uses a 10-block directory structure within these source-code blocks. The
system does not automatically maintain this directory information; you must
update the block-directory blocks when you add, delete, or move blocks.   For
more information on directories, see "Understanding Directory Block Conven-
tions" in Chapter 6, "Basic RCS Operations".

This appendix lists the 8087 operation codes and their RCS equivalents in alphabetical order based on the Intel Operation Codes (as in Table S-19 in the Intel 8086 Family User's Manual). RCS does not implement the complete 8087 instruction set.

Because FORTH uses only the length and the first three characters to differentiate the names of variables, NBS has changed the Intel names of some operation codes to ensure that the name of each code is unique.

As with the Intel assembler, unless the second letter is N, RCS assembles all operation codes with an FWAIT first.

RCS provides the following words to modify operation code mnemonics:

- d sets the destination bit.

- LNG sets the temp-real format required to use the FLD, FST, and FSTP operation codes.

- P indicates that the 8087 is to pop the result (the same as the Intel P suffix on the instruction mnemonic).

- rev indicates that the 8087 is to perform the indicated operation with the source and destination operands reversed (the same as the Intel R suffix on the instruction mnemonic).

- INT indicates that the operation is to use 32-bit integer arithmetic.

- WINT indicates that the operation is to use 16-bit integer arithmetic.

The alphabetical list of Intel operation codes and their RCS equivalents follows.

Operation	Intel	RCS	Modifier Words
Calculate 2^X-1	F2XM1	F2XM1	
Convert to absolute value	FABS	FABS	
Add real	FADD	FADD	
Add real and pop	FADDP	FADD	P
Load packed decimal	FBLD	none	
Store packed decimal and pop	FBSTP	none	
Change sign	FCHS	FCHS	
Clear exceptions	FCLEX	none	
Compare real	FCOM	FCOM	
Compare real and pop	FCOMP	FCOMP	
Compare real and pop twice	FCOMPP	FCOMPP	
Decrement stack pointer	FDECSTP	FDECSTP	
Disable interrupts	FDISI	none	

Operation	Intel	RCS	Modifier Words	E-2
Divide real	FDIV	FDIV		
Divide real and pop	FDIVP	FDIV	P	
Divide real reversed	FDIVR	FDIV	rev	
Divide real reversed and pop	FDIVRP	FDIV	rev P	
Enable interrupts	FENI	none		
Free register	FFREE	FFREE		
Add integer	FIADD	FADD	INT or WINT	
Compare integer	FICOM	FCOM	INT or WINT	
Compare integer and pop	FICOMP	FCOMP	INT or WINT	
Divide integer	FIDIV	FDIV	INT or WINT	
Divide integer reversed	FIDIVR	FDIV	rev INT or rev WINT	
Load integer	FILD	FLD	INT or WINT	
Multiply integer	FIMUL	FMUL	INT or WINT	
Increment stack pointer	FINCSTP	FINCSTPT		
Initialize 8087	FINIT	none		
Store integer	FIST	FST	INT or WINT	
Store integer and pop	FISTP	FST	P INT or P WINT	
Subtract integer	FISUB	FSUB	INT or WINT	
Subtract integer reversed	FISUBR	FSUB	rev INT or rev WINT	
Load real	FLD	FLD		
Load +1.0	FLD1	1FLD		
Load control word	FLDCW	FLDCW		
Load environment	FLDENV	FLDENVIR		
Load $\log_2 e$	FLDL2E	L2EFLD		
Load $\log_2 10$	FLDL2T	L2TFLD		
Load $\log_{10} 2$	FLDLG2	LT2FLD		
Load $\log_e 2$	FLDLN2	LE2FLD		
Load pi	FLDPI	PIFLD		
Load +0.0	FLDZ	ZFLD		
Multiply real	FMUL	FMUL		
Multiply real and pop	FMULP	FMUL	P	
Clear exceptions (no FWAIT)	FNCLEX	FNCLEX		
Disable interrupts (no FWAIT)	FNDISI	FNDISI		
Enable interrupts (no FWAIT)	FNENI	FNENI		
Initialize 8087 (no FWAIT)	FNINIT	FNINIT		
No operation	FNOP	none		
Save state (no FWAIT)	FNSAVE	none		
Store control word (no FWAIT)	FNSTCW	none		
Store environment (no FWAIT)	FNSTENV	FNSTENVIR		
Store status word (no FWAIT)	FNSTSW	FNSTSW		
Calculate partial arctangent	FPATAN	FPATAN		
Calculate partial remainder	FPREM	FPREM		
Calculate partial tangent	FPTAN	FPTAN		
Round to integer	FRNDINT	FRNDINT		
Restore saved state	FRSTOR	FRSTOR		
Save state	FSAVE	FSAVE		
Scale	FSCALE	FSCALE		
Calculate square root	FSQRT	FSQRT		
Store real	FST	FST		
Store control word	FSTCW	FSTCW		
Store environment	FSTENV	none		

Operation	Intel	RCS	Modifier Words
Store real and pop	FSTP	FSTP	
Store status word	FSTSW	none	
Subtract real	FSUB	FSUB	
Subtract real and pop	FSUBP	FSUB	P
Subtract real reversed	FSUBR	FSUB	rev
Subtract real reversed and pop	FSUBRP	FSUB	rev P
Test stack top against +Ø.Ø	FTST	FTST	
Make 8Ø86 wait while 8Ø87 is busy	FWAIT	FWAIT	
Examine stack top	FXAM	FXAM	
Exchange registers	FXCH	FXCH	
Extract exponent and significand	FXTRACT	FXTRACT	
Multiply Y and $\log_2 X$	FYL2X	FYL2X	
Multiply Y and $\log_2(X+1)$	FYL2XP1	FYL2XP1	

This appendix contains schematic wiring diagrams describing the design of a
joystick and the interface electronics housed in a separate chassis. The
joystick contains 4 smaller joysticks, 15 switches, a velocity-control knob,
and an indicator light. The joystick interfaces with the RSL PRIM level.

The following table lists the schematics.

Figure F-1.   Joystick switch layout.
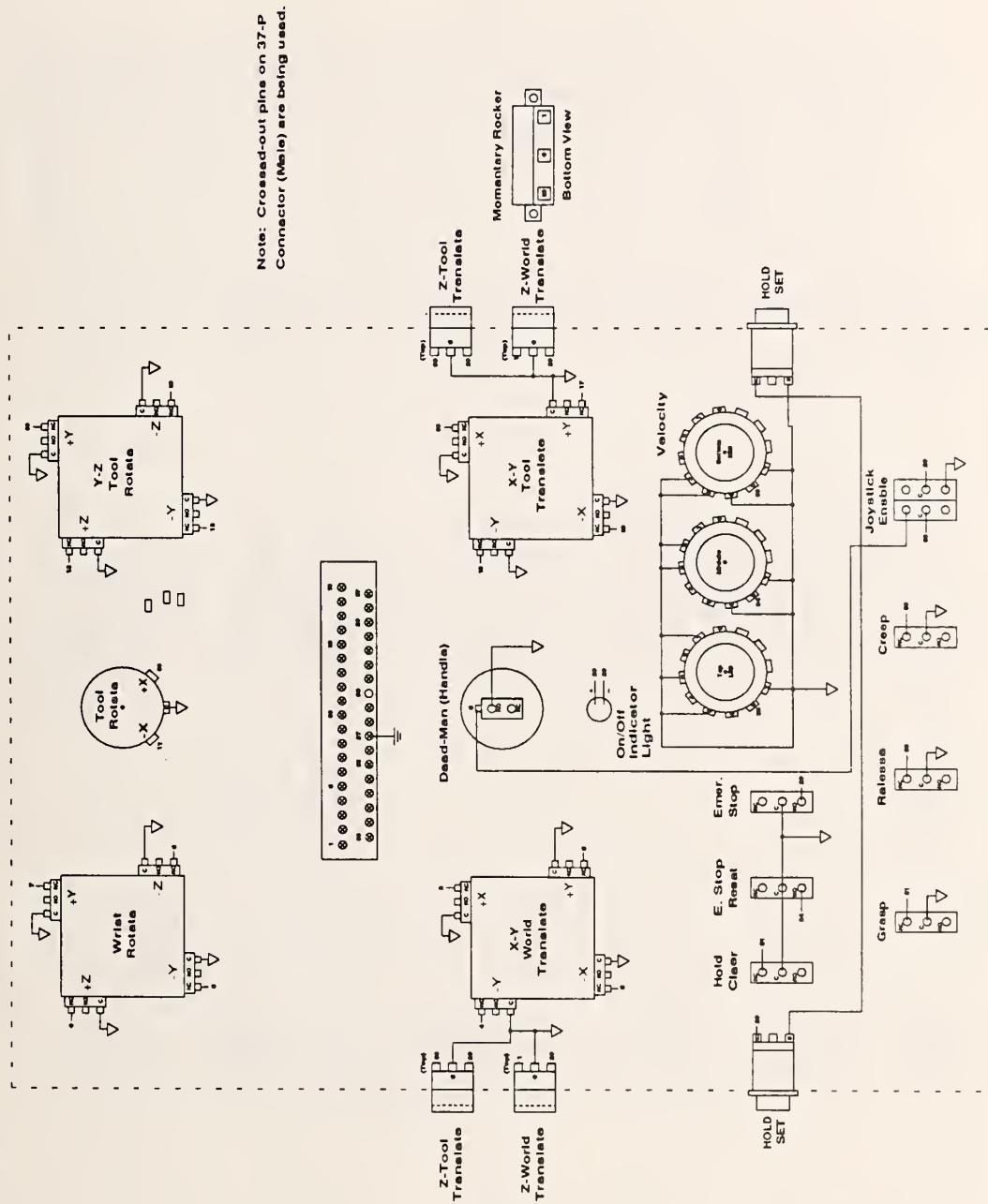
Figure F-2.   Joystick switch wiring diagram.

JOYSTICK CABLE FOR JOYSTICK
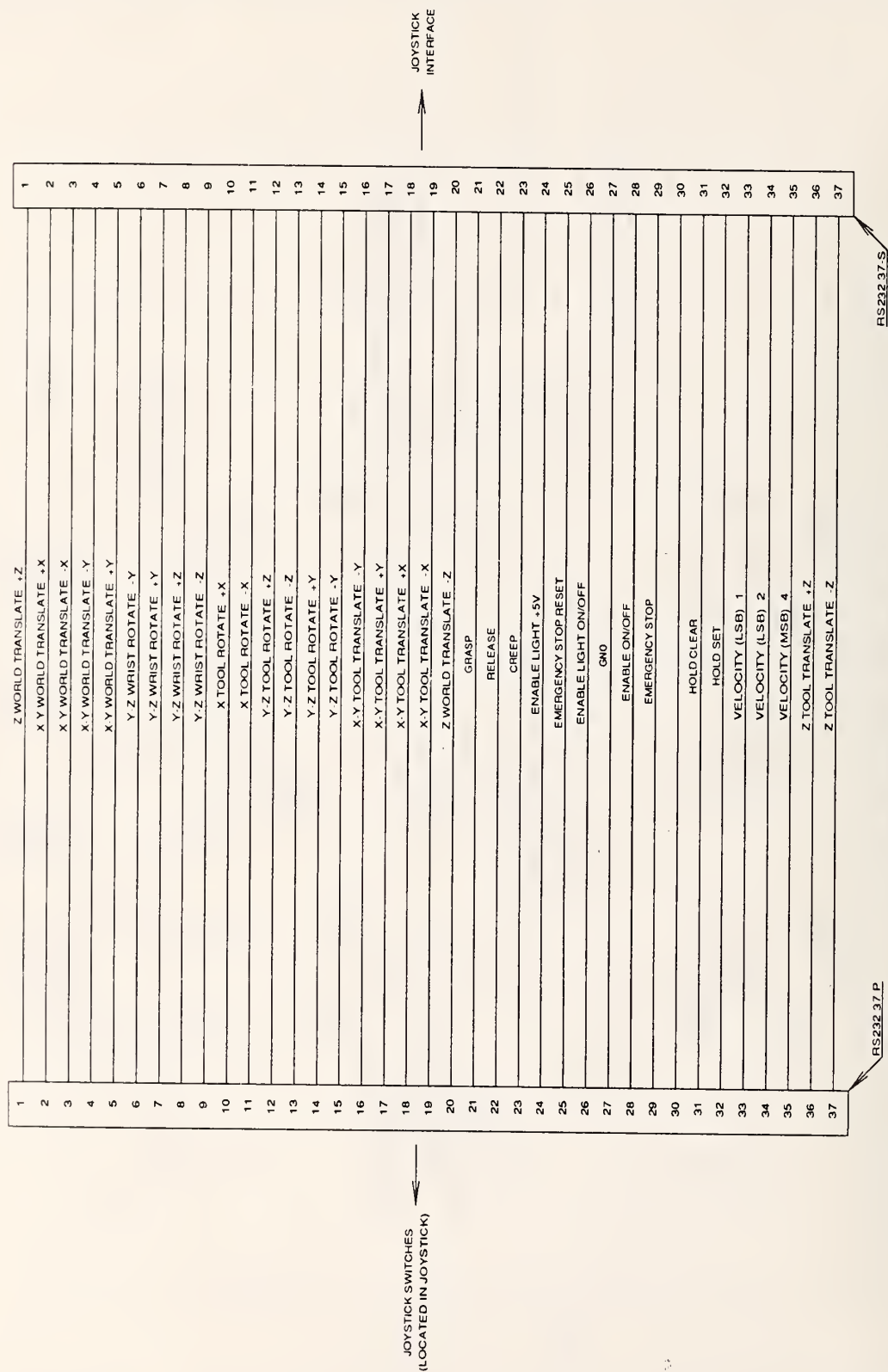
Figure F-3.   Joystick to interface electronics cable diagram.

Figure F-4(a). Joystick switch debounce circuitry (page 1 of 2)

DEBOUNCE CIRCUITRY FOR JOYSTICK
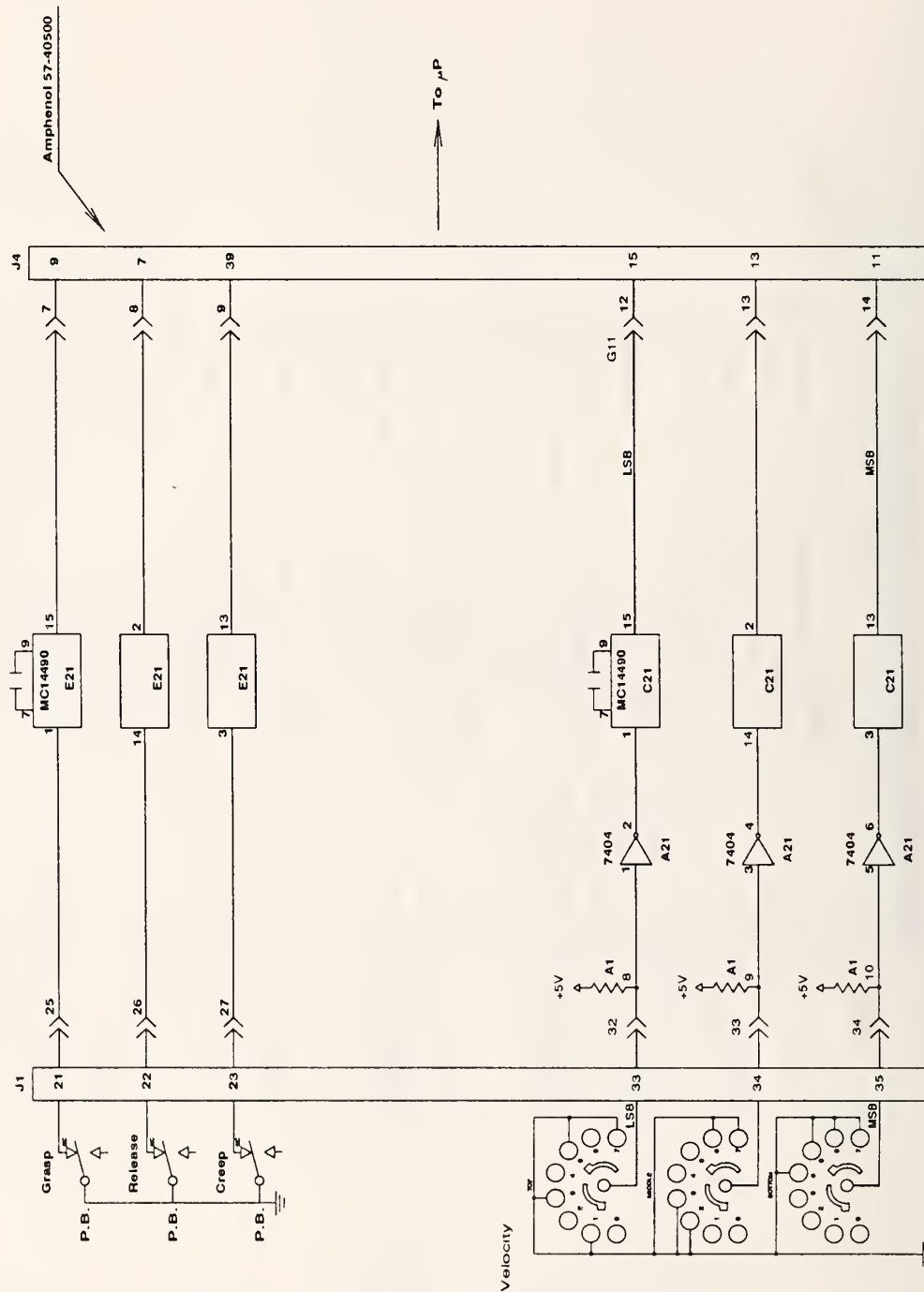
Figure F-4(b).   Joystick switch debounce circuitry (page 2 of 2)

Figure F-5. Emergency stop and hold set/clear circuitry.

This glossary defines terms that are unique to or have unique meanings in RCS or the RSL application. RSL terms are differentiated from RCS terms by placing RSL in parentheses after the term.

Absolute block number. The number used to specify the storage location of a block on the disk. See <u>Relative block number</u>.

AMRF. See <u>Automated Manufacturing Research Facility</u>.

Array. (RSL) An RSL data structure that contains a group of locations. An array is one-, two-, or three-dimensional. Movetables define the displacement between sectors of the array. Arrays are stored in an array file in common memory.

Automated Manufacturing Research Facility (AMRF). An experimental factory developed by NBS to operate as a small, totally automated, batch machine shop.

Block. A division of the disk containing 1,024 bytes, arranged in 16 lines of 64 characters each. The entire disk is organized into blocks, each of which has a unique block number.

COMM. An RCS utility that provides a communication protocol for passing commands and status information between control levels.

Common memory. Random-access memory in a central location that all processor boards in the system use to store the system dictionary, SMACRO files, and command and status information.

Communications dead time. The communications interval during which the contents of command, status, and data buffers and flags in common memory are changed. During this time, no other process may execute.

Communications table. A table used by the RCS utility COMM to define desired buffer transfers between processor boards.

Compile mode. One of the four RCS operating modes. RCS uses Compile mode when you load blocks of code containing compiling words. See also <u>Locate mode</u>, <u>Run mode</u>, and <u>Show mode</u>.

Configuration flags. Variables used to resolve ambiguities in the inverse transform for a robot.

Control level. A group of functionally bounded modules that handle inputs, decision processing, and outputs for one of the levels generated by the hierarchical task decomposition.

D>M. On the system disk, an area of 120 consecutive blocks, used to save a copy of local memory from the currently selected processor board. RCS enables you to save up to five D>Ms for each of seven processor boards. The RCS word [d>m#] D>M, where [d>m#] is a number from 1 through 5, enables you to move the specified D>M region from the disk to the local memory of the current board. The RCS word [d>m#] MEM>DISK moves code from the local memory of the current board to the specified D>M area on the disk. A D>M is also called a <u>disk image</u>, and is similar to an object file in a conventional system.

Directory block. A disk block that contains a description of the contents of other disk blocks. RCS uses a hierarchical directory block structure, in which directory blocks describe the contents of each 1000-, 100-, and 10-block section of the disk.

Disk image. See <u>D>M</u>.

Hierarchical task decomposition. An approach to process control that defines tasks in terms of successively more primitive modularized subtasks.

JOINT level. (RSL) The fourth, or lowest, control level in RSL's hierarchical task decomposition. The JOINT level generates specific commands that are transmitted to the robot to control its movement in real time. If the robot has attached sensors, the robot also sends status information back to the JOINT level. See also <u>PATH level</u>, <u>PRIM level</u>, and <u>TASK level</u>.

List owner. A SMACRO construct that enables you to group any type of variable under a specified name (the list owner). See also <u>sequential variable owner</u> and <u>variable owner</u>.

Locate mode. An operational mode that enables you to search for the source block of any SMACRO word. One of the four RCS operating modes. See also <u>Compile mode</u>, <u>Run mode</u>, and <u>Show mode</u>.

Location. (RSL) An RSL data structure that consists of a location name and a specified pose and movetable combination. A location defines a new robot position relative to a reference pose, using the movetable to specify the coordinate transformations required to move to the new position from the reference pose. RSL stores location definitions in a location file in common memory.

Master board. The single-board processor that handles user communication with the system through the user terminal. The RCS editor is on the master board. See also <u>slave board</u>.

Movetable. (RSL) An RSL data structure that consists of a movetable name and up to eight separate rotations or translations that define the coordinate transformations required to move from one robot position to another. RSL stores movetable definitions in a movetable file in common memory.

Object. (RSL) An RSL data structure that defines objects in terms of an object name and a list of grip numbers and associated movetables. The movetables define the orientation of each grip relative to the object frame. RSL stores object definitions in an object file in common memory.

Offset. The value of the FORTH variable OFFSET. The offset is usually a multiple of 1000 associated with the currently selected board. By subtracting the offset from the absolute block number, the system calculates the relative block number. See also <u>absolute block number</u> and <u>relative block number</u>.

Path. (RSL) An algorithm that specifies the sequence of steps required to perform a simple task, such as moving between locations or grasping an object. Paths are stored as linked lists of path-points in a path-point file in common memory. See also <u>path-point</u>.

PATH level. (RSL) The second control level in RSL's hierarchical task decomposition. The PATH level decomposes paths into a sequence of path-points and then into trajectories. See also <u>JOINT level</u>, <u>PRIM level</u>, and <u>TASK level</u>. (RSL)

Path-point. (RSL) An RSL data structure that consists of a path-point command and a pointer to the associated command parameters file. A path-point consists of a single sensor-based motion. A linked list of path-points defines an RSL path. See also <u>path</u>.

Pose. (RSL) An RSL data structure that defines the physical location of a robot. The pose definition consists of a pose name and its associated translation vector and rotation quaternion. RSL stores the pose definition in a pose file in common memory.

PRIM level. (RSL) The third control level in RSL's hierarchical task decomposition. The PRIM level decomposes trajectories into poses along a straight line. See also <u>JOINT level</u>, <u>PATH level</u>, <u>TASK level</u>, and <u>trajectory</u>.

Quaternion. A four-number representation of a rotation by angle about an axis $\hat{n}$. These numbers are expressed as: $\cos /2$, $\sin /2\ \hat{n}_x$, $\sin /2\ \hat{n}_y$, $\sin /2\ \hat{n}_z$.

RCS. See <u>Real-time Control System</u>.

Real-time Control System (RCS). A software system that uses hierarchical task decomposition, multiple processors, and cyclic execution to control real-time applications.

Relative block number. The absolute block number minus the offset; the offset is stored in the FORTH variable OFFSET. See also <u>absolute block number</u> and <u>offset</u>.

Robot Sensor Language (RSL). A real-time control application written by NBS. RSL implements a hierarchical task decomposition that uses four processors to run four hierarchical control levels.

Round-robin. (RSL) An RSL data structure that defines a circular, singly linked list. RSL stores round-robin definitions in a round-robin file in common memory.

Routine. A SMACRO program. All SMACRO programs start with the word routine, which assigns a name to the following SMACRO code, and end with the word end-routine. SMACRO routines can be longer than one block.

RSL. See Robot Sensor Language.

RSL algorithm. (RSL) The RSL code a user writes to accomplish a task. RSL compiles algorithms into a linked-list representation. Then RSL control levels interpret the algorithm, using environmental data to command the robot to execute a task.

RSL data. (RSL) Information about the robot environment, such as the name, size, or location of an object. This information is stored in common memory and is accessible to all control levels. Robot sensors can supply data to RSL, or you can enter data directly from the keyboard. See also RSL algorithm.

Run mode. The normal operating mode for executing the commands that control robotic equipment. Run mode is one of the four RCS operating modes. See also Compile mode, Locate mode, and Show mode.

Sector. (RSL) An element of an array. Sector numbers start at 0. See also array.

Sequential variable. A SMACRO variable type. The value of the first sequential variable is 0, and succeeding sequential variables contain successive integers. Sequential variables belong to sequential variable owners.

Sequential variable owner. A SMACRO construct that enables you to group sequential variables as members under a specified name (the owner). Members must be sequential variables. See also list owner and variable owner.

Show mode. An operating mode that enables you to display SMACRO variables and owners. Show mode is one of the four RCS operating modes. See also Compile mode, Locate mode, and Run mode.

Slave board. A single-board processor that implements one or more of the process control levels within the system. Direct user communication with a slave board is possible only with an ABCD switch box. Normally, communications between user and slave board occur through the master board. See also master board.

SMACRO. A set of word extensions to the FORTH programming language and operating system written by NBS for use in the RCS environment. The extensions include structured programming constructs such as case, if-then-else, repeat-until, and while-do statements. The extensions also include words and constructs to facilitate programming real-time control applications, such as state table statements and vector, quaternion, and matrix operator words.

SMACRO file. A linked list of records that resides in common memory. SMACRO files provide the primary method of communication between control levels.

State table. A construct that enables you to describe the possible states of its inputs and outputs. The state table lists the set of relevant input variables, the possible combinations of values the input variables may assume, and the required outputs for each combination of input values. The SMACRO language includes a state table statement to facilitate programming state tables.

System dictionary. A block of common memory that contains records with names and pointers for every variable and procedure in the system.

System vocabulary. A predefined vocabulary that contains system variables. Each processor board has a separate system vocabulary called SDEF. See also <u>user-defined vocabulary</u> and <u>vocabulary</u>.

TASK level. (RSL) The first, or highest, control level in RSL's hierarchical task decomposition. The TASK level decomposes all tasks into a sequence of path types. See also <u>JOINT level</u>, <u>PATH level</u>, and <u>PRIM level</u>.

Trajectory. A goal point and parameters describing the path to the goal point. RSL supports two trajectory types: Cartesian straight-line and joint interpolated.

User-defined vocabulary. A subset of the system dictionary defined by the user. You can add up to five vocabularies per processor board. See also <u>system vocabulary</u> and <u>vocabulary</u>.

User file. See <u>SMACRO file</u>.

Variable owner. A SMACRO construct that enables you to group variables as members under a specified name (the owner). Members can include the following SMACRO variable types: integer, byte, floating point, string, segment, one-dimensional integer array, two-dimensional integer array, one-dimensional floating-point array, and two-dimensional floating-point array. See also <u>list owner</u> and <u>sequential variable owner</u>.

Vocabulary. An independently linked subset of RCS words in the system dictionary. See also <u>system vocabulary</u> and <u>user-defined vocabulary</u>.

For additional information on robotics, robot interface specifications, the Real-time Control System, FORTH, and specific hardware components, see the documents listed in this bibliography.

ROBOTICS

The following books discuss robotics in general:

Asada, H., and Slotine, J.-J.E. Robot Analysis and Control. New York, NY: Wiley-Interscience, 1986.

Brady, M.; Hollerback, J.M.; Johnson, T.L.; Lozano-Pérez, T.; and Mason, M.T. Robot Motion: Planning and Control. Cambridge, MA: The MIT Press, 1982.

Coiffet, P., and Chirouze, M. An Introduction to Robot Technology. New York, NY: McGraw-Hill Book Company, 1982.

Craig, J.J. Introduction to Robotics--Mechanics and Control. Reading, MA: Addison-Wesley Publishing Company, 1986.

Engelberger, J.F. Robotics in Practice--Management and Applications of Industrial Robots. London, England: Kogan Page Limited, 1980.

Kane, T.; Likine, P.; and Levinson, D. Spacecraft Dynamics. New York, NY: McGraw-Hill Book Company, 1983.

Nof, S.Y. (editor) Handbook of Industrial Robotics. New York, NY: John Wiley & Sons, 1985.

Paul, R.P. Robot Manipulators: Mathematics, Programming, and Control. Cambridge, MA: The MIT Press, 1981.

Rehg, J.A. Introduction to Robotics--A Systems Approach. Englewood Cliffs, NJ: Prentice-Hall Inc., 1985.

Snyder, W.E. Industrial Robots: Computer Interfacing and Control. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1985.

ROBOT INTERFACE SPECIFICATIONS

For information on robot interface specifications, see the following publications:

Anon. "SLAVE Interface Specification for External Computer Path Control Using VAL II", Publication Number 397T1; Unimation Incorporated; Danbury, CT: January 1986.

Nashman, M. "A Low Level Robot Interface: The High Speed Host Interface", NBSIR 86-3393; National Bureau of Standards; Gaithersburg, MD: June 1986.

REAL-TIME CONTROL SYSTEM (RCS)

The following documents provide additional information on the NBS Real-time Control System:

Albus, J.S.; Barbera, A.J.; Fitzgerald, M.L.; and Nashman, M. "Sensory Interactive Robots", Presented at the 31st General Assembly of the International Institution for Production Engineering Research; September 1, 1981; Toronto, Canada.

Albus, J.S.; Barbera, A.J.; and Nagel, R.N. "Theory and Practice of Hierarchical Control", Proceedings of the Twenty-Third IEEE Computer Society International Conference; September 1981.

Albus, J.S.; Barbera, A.J.; and Fitzgerald, M.L. "Programming a Hierarchical Robot Control System", Proceedings of the 12th International Symposium on Industrial Robots/6th International Conference on Industrial Robot Technology; June 9-11, 1982; Paris, France.

Albus, J.S.; McLean, C.R.; Barbera, A.J.; and Fitzgerald, M.L. "An Architecture for Real-Time Sensory-Interactive Control of Robots in a Manufacturing Facility", Proceedings of the Fourth IFAC/IFIP Symposium-- Information Control Problems in Manufacturing Technology; October 26-28, 1982; Gaithersburg, MD.

Albus, J.S.; McLean, C.R.; Barbera, A.J.; and Fitzgerald, M.L. "Hierarchical Control for Robots in an Automated Factory", Proceedings of the 13th International Symposium on Industrial Robots/Robots 7 Symposium; April 17-21, 1982; Chicago, IL.

Barbera, A.J.; Albus, J.S.; and Fitzgerald, M.L. "Hierarchical Control of Robots Using Microcomputers", Proceedings of the 9th International Symposium on Industrial Robots; March 13-15, 1979; Washington, DC.

Barbera, A.J.; Fitzgerald, M.L.; and Albus, J.S. "Concepts for a Real-Time Sensory-Interactive Control System Architecture", Proceedings of the Fourteenth Southeastern Symposium on System Theory; April 1982; Blacksburg, VA.

Barbera, A.J.; Fitzgerald, M.L.; Albus, J.S.; and Haynes, L.S. "A Language Independent Superstructure for Implementing Real-Time Control Systems", Proceedings of the International Workshop on High-Level Computer Architecture; May 21-25, 1984; Los Angeles, CA.

Barbera, A.J.; Fitzgerald, M.L.; Albus, J.S.; and Haynes, L.S. "RCS: The NBS Real-Time Control System", Proceedings of the Robots 8 Conference and Exposition, Volume 2 - Future Considerations; June 4-7, 1984; Detroit, MI.

Fitzgerald, M.L., and Barbera, A.J. "A Low-Level Control Interface for Robot Manipulators", Proceedings of the Workshop on Robot Standards (Sponsored by the National Bureau of Standards and the Navy Manufacturing Technology Program); June 6-7, 1985; Detroit, MI.

Fitzgerald, M.L.; Barbera, A.J.; and Albus, J.A. "Real-Time Control Systems for Robots", presented at the SPI National Plastics Exposition Conference; June 1985; Chicago, IL.

Haynes, L.S.; Barbera, A.J.; Albus, J.S.; Fitzgerald, M.L.; and McCain, H.G. "An Application Example of the NBS Robot Control System", Robotics & Computer-Integrated Manufacturing, 1984; Washington, DC.

McCain, H.G. "A Hierarchically Controlled, Sensory-Interactive Robot in the Automated Manufacturing Research Facility", Proceedings of the IEEE International Conference on Robotics and Automation; March 25-28, 1985; St. Louis, MO.

FORTH

For more information on FORTH, see the following books that discuss FORTH in general, and the following FORTH reference manuals.

General FORTH Documents

The following books discuss FORTH in general:

Brodie, L. Starting FORTH. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1981.

Brodie, L. Thinking FORTH - A Language and Philosophy for Solving Problems. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1984.

Hogan, T. Discover FORTH - Learning and Programming the FORTH Language. Berkeley, CA: Osborne/McGraw-Hill, Inc., 1982.

Katzan, H. Invitation to FORTH. Princeton, NJ: Petrocelli Books, Inc., 1981.

Toppen, D.L. FORTH - An Applications Approach. New York, NY: McGraw-Hill, Inc., 1985.

Winfield, A.F.T. The Complete FORTH. New York, NY: Sigma/Wiley Press, 1983.

FORTH Reference Manuals

The following manuals provide reference information on FORTH. Note that the source of these reference manuals is also listed for your convenience.

Source: FORTH, Inc., 2309 Pacific Coast Highway, Hermosa Beach, CA
            90254; (213) 372-8493.

Manuals: FORTH Reference Manual, Fourth Edition, April 1979.

Using FORTH, Second, Revised, Edition, March 1980.

Intel 8086 User's Supplement to the PolyFORTH Reference Manual, March 1980.

HARDWARE REFERENCE MANUALS

The following reference manuals discuss processor and I/O boards, memory boards, the disk and tape controller board, the tape drive, the Winchester disk drive, the MULTIBUS chassis, terminals, and printers. The source of each manual or group of manuals is also listed for your convenience.

Processor and I/O Boards

For information on processor and I/O boards, see the following manuals:

Source: Intel Corporation, 3065 Bowers Avenue, Santa Clara, CA 95051;
          (408) 987-8080. Publications available from Intel Literature
          Sales, P.O. Box 58130, Santa Clara, CA 95052-8130;
          (800) 548-4725.

Manuals: OEM Systems Handbook, Publication Number 210941-004, 1986.

Microsystem Components Handbook, Volumes I and II, Publication Number 230843-002, 1985.

iSBC 86/14 and iSBC 86/30 Single Board Computer Hardware Reference Manual, Publication Number 144044-002, 1982.

iSBC 337A Multimodule Numeric Data Processor Hardware Reference Manual, Publication Number 142887-001, 1980.

iSBC 519 Programmable I/O Expansion Board Hardware Reference Manual, Publication Number 9800385B, 1979.

iSBC 534 Four Channel Communications Expansion Board Hardware Reference Manual, Publication Number 9800450-02, 1979.

iSBX 311 Analog Input Multimodule Board Hardware Reference Manual, Publication Number 142913-001, 1981.

iSBX 328 Analog Output Multimodule Board Hardware Reference Manual, Publication Number 142914-002, 1982.

iSBX 350 Parallel Multimodule Board Hardware Reference Manual, Publication Number 9803191-02, 1980.

iSBX 351 Serial Multimodule Board Hardware Reference Manual, Publication Number 9803190-03, 1984.

Memory Boards

For information on memory boards, see the following manual:

Source: Plessey Microsystems, P.O. Box 154, 1 Bluehill Plaza,
            Pearl River, NY 10965; (914) 735-4661.

Manual: PSM 512A MULTIBUS Error-Correcting Dram--User's Guide, Document
            Number PMUS/HB/10225, Issue 2, January 1984.

Disk and Tape Controller Board

For information on the disk and tape controller board, see the following
document:

Source: Ciprico Inc., 2955 Xenium Lane, Plymouth, MN 55441;
            (612) 559-2034.

Document: "Ciprico Product Specification--Rimfire 45A, MULTIBUS Disk
            Controller," Publication Number 21010084, Revision A, March 25,
            1985.

Tape Drive

The following manual provides additional information on the tape drive:

Source: Cipher Data Products, Inc., 10225 Willow Creek Road, San Diego,
            CA 92131; (619) 578-9100. Publications available from Cipher
            Data Products, Inc., Technical Publications Department, P.O. Box
            85170, San Diego, CA 92138; (800) 982-8808.

Manual: Model F880 Magnetic Tape Transport, Volume 1--Operation
            Maintenance, Technical Manual Number 799816-003, Revision Q,
            April 1986.

Winchester Disk Drive

For information on the Winchester disk drive, see the following manual:

Source: Priam Corporation, 20 West Montague Expressway, San Jose, CA
            95134; (408) 946-0293.

Manual: Fourteen-Inch Winchester Disc Drives-OEM Manual (Model 3350,
            Model 6650, and Model 15450), Publication Number 308002, Revision
            B, January 1984.

MULTIBUS Chassis

For information on the MULTIBUS Chassis, see the following manual:

Source: ETI Micro, 6918 Sierra Court, Dublin, CA 94568; (415) 829-6600.

Manual: 8223 MULTIBUS Chassis User's Manual, Publication Number 8323058223133Ø1, 1983.

Terminals

The following manuals provide information on terminals:

Source: TeleVideo Systems Inc., 117Ø Morse Avenue, Sunnyvale, CA 94Ø86; (4Ø8) 745-776Ø.

Manual: TeleVideo Model 95Ø CRT Terminal Installation and User's Guide, Document Number B3ØØØØ2-ØØ1, Revision B, April 1982.

Source: Digital Equipment Corporation, 129 Parker Street, Maynard, MA Ø1754; (8ØØ) 258-171Ø. Publications available from DEC Accessories and Supplies Group, P.O. Box CS2ØØ8, Nashua, NH Ø3Ø61; (8ØØ) 258-171Ø.

Manual: VT1ØØ User Guide, 3rd Edition, Publication Number EK-VT1ØØ-UG-ØØ3, 1981.

Source: Micro-Term, Inc., 512 Rudder Road, Fenton, MO 63Ø26; (314) 343-6515.

Manuals: Operating Manual--Model ERGO 3Ø1, Publication Number 1-562ØØØØ4-ØD, March 1983. [This terminal is VT1ØØ compatible.]

           ERGO 3Ø1FK Addendum--Programmable Function Keys, Publication Number 7985ØØ14-ØA, June 1984.

Source: Datamedia Corporation, 74Ø1 Central Highway, Pennsauken, NY Ø81Ø9; (6Ø9) 665-54ØØ.

Manual: Elite 1521A Video Terminal Operator's Handbook, Publication Number Ø81ØØØ1-ØØØ-B, April 1978.

Printers

For information on printers, see the following manuals:

Source: Apple Computer, 2Ø525 Mariani Avenue, Cupertino, CA 95Ø41; (4Ø8) 996-1Ø1Ø.

Manual: Imagewriter User's Manual, Part I: Reference, Publication Number Ø3Ø-Ø73Ø-A, 1983.

Source: Digital Equipment Corporation, 129 Parker Street, Maynard, MA
01754; (800) 258-1710. Publications available from DEC
Accessories and Supplies Group, P.O. Box CS2008, Nashua, NH
03061; (800) 258-1710.

Manual: <u>LA120 DECwriter III User Guide</u>, Publication Number
EK-LA120-UG-001, 1978.

Source: Integral Data Systems, Inc., Route 13 South, Milford, NH 03055;
(603) 673-9100.

Manual: <u>The Paper Tiger, IDS-460 Impact Printer--Owner's Manual</u>,
Publication Number 9000-000-728, Second Edition, April 1981.

U.S. DEPT. OF COMM. **BIBLIOGRAPHIC DATA** **SHEET** (See instructions)	1. PUBLICATION OR REPORT NO. NIST/TN-1250	2. Performing Organ. Report No.	3. Publication Date September 1988

4. TITLE AND SUBTITLE

The NBS Real-Time Control System User's Reference Manual.

5. AUTHOR(S)
Stephen A. Leake and Roger D. Kilmer

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions) **NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY** **(formerly NATIONAL BUREAU OF STANDARDS)** **U.S. DEPARTMENT OF COMMERCE** **GAITHERSBURG, MD 20899**	7. Contract/Grant No.
	8. Type of Report & Period Covered Final

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

SAME AS ITEM #6 ABOVE.

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The NBS-developed Real-Time Control System--RCS-- is a hierarchically-structured controller designed to use sensory feedback for real-time control of automated systems. This manual describes the basic structure of RCS and the programming features available to develop application software. In addition to a detailed description of the structure of RCS, examples illustrating the use of RCS for the control of robotic systems are presented.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)
Control architecture; FORTH; hierarchical; RCS; real-time control; robot control; robot programming; SMACRO: sensory feedback.

13. AVAILABILITY

☒ Unlimited

☐ For Official Distribution. Do Not Release to NTIS

☒ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

381

15. Price
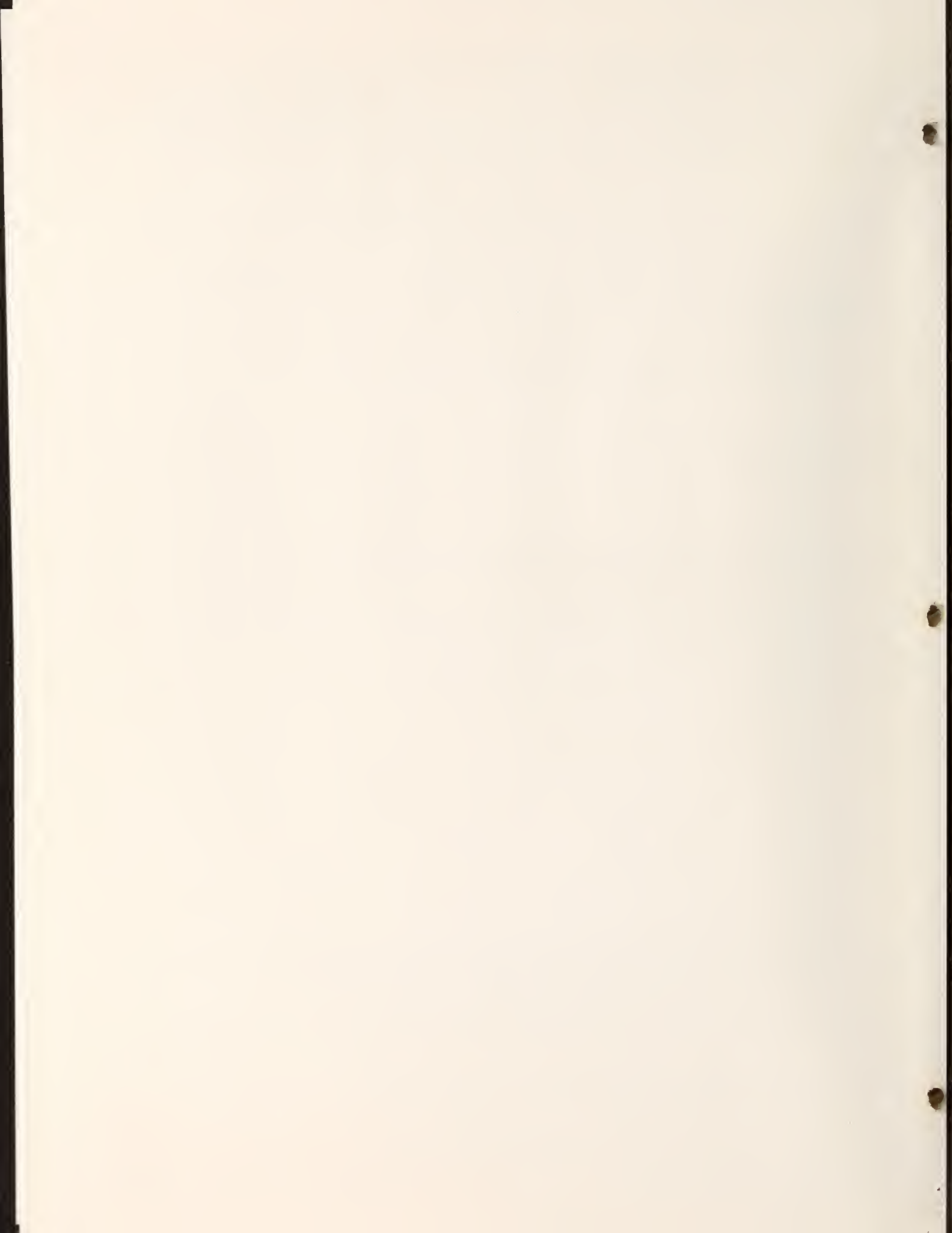
METRIC SYSTEM WITH U.S. EQUIVALENTS

METRIC UNIT (1)		U.S. EQUIVALENT
LENGTH		
millimeter	(mm)	0.04 inches
centimeter	(cm)	0.39 inches
decimeter	(dm)	3.94 inches
meter	(m)	39.37 inches
dekameter	(Dm)	32.81 feet
hectometer	(hm)	109.36 yards
kilometer	(km)	0.62 miles
myriameter		6.2 miles

AREA		
square centimeter	(sq cm)	0.155 sq inches
square meter	(m²)	1.196 sq yards
are	(a)	119.60 sq yards
hectare	(ha)	2.47 acres
square kilometer	(sq km)	0.3861 sq miles

WEIGHT		
milligram	(mg)	0.015 grains
centigram	(cg)	0.154 grains
decigram	(dg)	1.543 grains
gram	(g)	0.035 ounces
dekagram	(Dg)	0.353 ounces
hectogram	(hg)	3.527 ounces
kilogram	(kg)	2.2046 pounds
quintal		220.46 pounds
metric ton		1.1 tons

METRIC UNIT (1)		U.S. EQUIVALENT
VOLUME		
cubic centimeter	(cu cm)	0.061 cubic inches
cubic decimeter	(cu dm)	61.023 cubic inches
cubic meter		1.3 cubic yards
stere (cubic decimeter)	(dm)	1.308 cubic yards

CAPACITY, CUBIC		
milliliter	(ml)	0.061 cubic inches
centiliter	(cl)	0.6 cubic inches
deciliter	(dl)	6.1 cubic inches
liter	(l)	61.02 cubic inches
dekaliter	(Dl)	0.35 cubic feet
hectoliter	(hl)	3.5 cubic feet
kiloliter		1.31 cubic yards

CAPACITY, DRY		
deciliter	(dl)	0.18 pint
liter	(l)	0.908 quart
dekaliter	(Dl)	1.14 pecks
hectoliter	(hl)	2.84 bushels

CAPACITY, LIQUID		
milliliter		0.27 fluidrams
centiliter		0.338 fluidounces
deciliter		0.21 pints
liter		1.057 quarts
dekaliter		2.64 gallons