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A11103089621 Barbera, Anthony J/An architecture for a QC100 .U57 NO.500-23, 1977 C.2 NBS-PUB-C E & TECHNOLOGY:

## NEW BOOK SHELF

JEN 18 1978

# AN ARCHITECTURE FOR A ROBOT HIERARCHICAL CONTROL SYSTEM



**NBS Special Publication 500-23** U.S. DEPARTMENT OF COMMERCE National Bureau of Standards

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### **COMPUTER SCIENCE & TECHNOLOGY:**

### An Architecture for a Robot Hierarchical Control System

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#### National Bureau of Standards Special Publication 500-23 Nat. Bur. Stand. (U.S.), Spec. Publ. 500-23, 227 pages (Dec. 1977) CODEN: XNBSAV

Library of Congress Cataloging in Publication Data Barbera, Anthony J.

An architecture for a robot hierarchical control system.

(Computer science & technology) (NBS special publication ; 500-23)

Supt. of Docs. no.: C13.10:500-23

I. Robots, Industrial. I. Title. II. Series. III. Series: United States. National Bureau of Standards. Special publication; 500-23. QC100.U57 no. 500-23 [T59.4] 602'.1s 629.8'92 77-17960

#### U.S. GOVERNMENT PRINTING OFFICE WASHINGTON: D.C.

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 Price \$4.25 - Stock No. 003-003-01874-1

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	RDMOD	-	Reads in Program Table and Location	DT-2
	RECORD	_	Table for disc.	DI-8
			on disc.	DI-10
	SAMPLE	_	Allows operator to call up Program or Location module.	DI-12
3rd	Level of	Со	ntrol Hierarchy	
	EMOVE	-	Calls appropriate primitives for each elemental move command.	DI-16
2nd	Level of	Со	ntrol Hierarchy	
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	MATI	-	input signal.	DI-30
	CALD	-	Calculates the distance between two location points.	DI-32
	POL	-	Calculates the delta joint values for an	DT 24
	ACC	-	Executes interpolated trajectory using	0כ-דע
	DETECT	_	values from POL. Uses proximity sensors to detect presence	DI-40
			of object.	DI <b>-</b> 44
	DAL	-	object.	DI-48
	GRASP	-	Causes fingers to close with a defined force.	DI-52
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	PTOUCH	-	Uses proximity sensors to locate top of	
			an object.	DI-58
	COOR	-	Transforms external coordinates into joint	( _
			coordinates and vice versa.	DI-62
lst	Level of	Со	ntrol Hierarchy	
	SERVO	-	Outputs joint position commands through ARMOUT.	DI-66

Output driver that sends output values DI-70 to interface. ARMIN Input driver that stores input values in a \_ DI-71 buffer.

ARMOUT

\_

#### Program Module (Module #2)

PROGS	-	Reads in editor commands and calls appropriate subroutine.	DII-2
Editor Comma	inds		
INSERT PRINT DELETE AVOID LOOP		<pre>Causes elemental move commands to be entered in program table. Causes the program table to be printed out as elemental move commands. Deletes specified lines from program table. Creates avoidance paths by inserting additional location points. Creates the additional lines in an indexed repeat pattern.</pre>	DII-6 DII-10 DII-14 DII-18 DII-22
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#### ACKNOWLEDGEMENTS

I wish to express my thanks to Drs. James Albus and John Evans for their invaluable help, advice and suggestions. Many of the ideas presented in this report were a result of many hours of discussion with them.

I wish to thank Ellen Lowenfeld for her able assistance in developing the computer programs.

I am indebted to Debbie Ingram for the uncountable hours she spent in the typing and preparation of this report.

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#### AN ARCHITECTURE FOR A ROBOT HIERARCHICAL CONTROL SYSTEM

#### Anthony J. Barbera

#### ABSTRACT

Complex automation systems, such as industrial robots, require a computerbased control system for the effective utilization of this advanced technology. This report describes such a control system developed at the National Bureau of Standards. The approach has been to partition the control system into a hierarchy of different functional levels. This has proven to be a powerful technique in obtaining sensor-controlled robot behavior at a minimum cost of programming time and computer size. Further, this partitioning has greatly simplified the implementation of additional functions and sensors. This report discusses the control system, its implementation and use, and provides a documented listing of all of the control programs.

Key Words: Adaptive; automation; computer; control; goal-oriented; hierarchical control; robot; sensors.

#### I. CONTROL SYSTEM ARCHITECTURE

#### 1. Introduction

The National Bureau of Standards program in automation focuses NBS resources on developing a basic understanding of the technology of computer based automation and then develops those standards and guidelines that will stimulate the diffusion of this technology to enhance productivity in both Government and industry.

Specifically this program attempts:

- to provide standards for the interfaces between modular components of computer-aided manufacturing systems,
- 2) to provide standards for the computer control languages used to program automation systems,
- to provide performance measures for specification and procurement of robots and numerically controlled machine tools, and
- 4) to carry out research in dynamic measurement and computer control for computer based automation systems.

It is work in this last area, the development of dynamic sensors and computer control techniques that has led to the control system architecture for robots described in this report.

#### 1.1 Industrial Robot Control Systems

Industrial robots are proving themselves to be flexible, general purpose automation systems that will contribute significantly to the development of automatic factories. These industrial robots utilize essentially the same control mechanisms that were developed for numerically controlled (NC) machine tools. That is, the motions of an industrial robot are determined by numbers that are stored in the memory of a computer or on a tape or some other storage device. Each degree of freedom (each axis) of the robot has a position servo system that drives the joints to the values commanded by the stored numbers of the control program.

Robots have presently found use in a number of industries in such diverse operations as removing parts from presses, spray painting, spot welding automobile bodies and loading and unloading parts from machine tools. All of the applications of these robots have two characteristics in common. First, these operations involve a rather high volume production where changes to the robots' programs do not have to be made often. At present, industrial robots are not being used in a batch type of environment (i.e. where parts are made in small lots or batches and control programs must be quickly changed) because of the time and difficulty required to program the robot to do a new task. Second, these operations are also characterized by a highly constrained work environment, either due to the nature of the work (e.g. unloading work pieces from a press) or by the installation or redesign of positioning equipment (e.g. installing very accurate indexing transfer lines to maintain repeatability in the positioning of automobile bodies on a spot welding assembly line). Although present industrial robots have a high degree of positional repeatability, they cannot in any way sense slight misalignments of parts in their environment. This lack of sensory feedback creates the requirement that the position of the objects they are to work with must be accurately maintained to match the position locations stored in the robot's program.

#### 1.2 PROBLEM

Thus the situation can be summarized as follows: There exists a sophisticated piece of general purpose manufacturing hardware - the industrial robot - whose effective and widespread use is seriously hampered by the difficulty and amount of time necessary to communicate even simple operations to it, and by the requirement of a tightly constrained work environment.

#### 1.3 SOLUTION

The solution to this problem is the development of a higher level control system that will make it faster and easier to program the robot and that can interact with sensory data to modify the robot's motions in real time to cope with misalignments in its environment.

#### 1.4 ADDITIONAL CONTROL SYSTEM REQUIREMENTS

Several additional requirements are identified here that are felt to be important for promoting the effective use of computer controlled robots within the environment of developing CAD/CAM systems (Computer-Aided Design/Computer-Aided Manufacturing).

- the control system should be as <u>general purpose</u> as possible so that each type of task does not require a different unique control system (e.g. the control system that causes the robot to load parts in and out of a vice on a machine tool, should also allow a robot to spot weld automobile bodies, spray paint bath tubs, or drill holes in an aircraft wing panel).
- 2) The control system should be modular and partitioned to make higher control levels independent from specific robot designs. This allows the same higher levels of the control system to be universally used to direct any robot. The system should be designed to facilitate the addition of new modules at any level. This will enhance flexibility in new applications.
- 3) The control system should allow for the creation of robot application programs off-line. These programs should be independent of an individual robot in much the same way that the part program created by an APT programmer is independent of a particular machine tool. Obviously, a robot or machine tool with three degrees of freedom cannot execute a program requiring six degrees of freedom; however, to the extent that robots or machine tools are functionally equivalent, the same application programs should be useable.
- 4) The control system should allow for the entry of location points in the robot's work space from other data bases in a computer-aided manufacturing system, such as the CLDATA file from APT. In addition, these location points should be defined in a relative manner so that the same set of location points can be post-processed to specify these locations for a particular robot. This is a specific facet of the general requirement that the control system should be as compatible as possible with the Integrated Computer Aided Manufacturing concept, i.e. the use of standard interfaces between modules of well-defined functions that can interact with common data bases.

#### 1.5 Research Control Systems

A number of groups have developed control systems (1, 2, 3, 4, 5) to solve the basic problem stated above. These higher level control systems rely on a computer to provide the information processing necessary for real time control of the robot in accord with its incoming sensory feedback data. These systems have some form of a higher level language, usually resembling a general purpose computer language like FORTRAN. This provides a communication interface to the robot so that the programmer can specify, off-line, a complex task which may require the use of sensory feedback. However, none of these control systems meets all of the additional requirements stated above.

#### 2. THE NBS ROBOT CONTROL SYSTEM

The National Bureau of Standards (NBS), with its unique view of standards, measurement science, numerical control machining, and computer applications, together with input from manufacturing industries, has developed an architecture for a hierarchical control (6, 7) system. In carrying out this work, NBS has adopted the strategy of modular design, well-defined interfaces, and integratability into total CAD/CAM systems. The architecture of this control system, its present implementation, and future development are the subject of this report.

#### 2.1 The Three Modules of the NBS Control System

The hierarchical control system for the execution of complex tasks involving sensory feedback makes up module #1 of the complete NBS control system shown in Figure 10.

Input to the highest level in the hierarchy of module #1 comes from module #2. In module #2 a sequence of elemental moves ("GOTO" statements) is produced. These commands are interpreted by module #1 as an executable program. This program is a procedural description of a task, and as such can be used to instruct any module #1 control hierarchy to control a robot to carry out this specified task

Module #3, the location module, is used to record the coordinate values for all the location names used in the program module. These are X, Y, Z values in a standard coordinate system. This location table is transformed by a postprocessor in module #1 to a table of coordinate values that define these points in a particular robot's work space.

#### 2.1.1 Hierarchical Control Module

The control system architecture (Figure 1) is based on a hierarchical structure, where simple primitive operations are executed at the lowest levels. A complex task command enters the hierarchy at the highest level and results in the generation of a sequence of simple primitive commands to the next lower level. Each primitive, in turn, produces a sequence of a joint position commands to the lowest level to accomplish the task. The partitioning of the control system into this hierarchy of control levels does much to simplify the control problem and to allow complex-looking behavior to be commanded simply and quickly using a small computing system. Each control level uses incoming data (both higher level commands as well as sensory feedback) to branch to the appropriate subroutine calls of the next lower control level. Additional primitive operations or the implementation of another type of sensor require only the addition of a new subroutine that will accomplish this function.



Figure 1

This chart shows the three levels-in the control hierarchy. Each level receives commands from the next higher level and responds by generating ordered sequences of simpler commands to the next lower level. Sensory feedback is used to close control loops where appropriate.

The elemental move command GOTO POSITION 12 GRASP PROXIMITY causes the third level to generate a sequence of primitive commands (INTERPOLATE TO POSITION 12; MOVE X, Y, Z; SEARCH (with proximity sensors); BALANCE (with proximity sensors); GRASP). As a result of these primitive function commands interacting with the sensory feedback, the second level generates the correct sequence of joint position commands to the first level. The first level servos the joints to these positions by generating the necessary drive signals to the actuators.

The test bed for evaluating this control system has been a six axis research manipulator (Figure 2) which is controlled by one of the minicomputers in the Institute for Computer Sciences and Technology's Experimental Computer Facility at NBS.

Two types of manipulative tasks were designed to evaluate the performance of the different programming techniques at each level in the hierarchy.

The first task is a simple transfer operation (Figure 3). It requires the arm to move to a particular location, pick up an object, and place it at another defined location.

The second task is an insertion operation (Figure 4). A peg is moved to a hole and inserted. The diameter of the peg is 1.3 cm. The diameter of the hole is 1.5 cm. The insertion part of this task requires the hand to follow a straight line motion for a distance of about 7.6 cm.

These two tasks are meant to simulate the type of transfer and simple assembly operations performed by industrial robots.

Infrared proximity sensors (Figure 5) developed at NBS will be used to demonstrate how the control system can interact with sensory feedback data in real time. The sensors themselves are the subject of another report.

#### 2.1.1-1 First Level of the Control Hierarchy

The lowest level in the hierarchy (Figure 1) is where servo control functions are computed. This is the level at which most industrial robots in use today are programmed and controlled. The input commands are joint positions which are compared to the feedback from the joint position indicators. If these values are different, a drive signal is generated to move each joint until the position error is nulled.

The control system at this level is shown schematically in Figure 6. During teaching or programming, a hand controlled unit is used that allows the operator to control the motion of each individual joint, using rate control. When the joints of the robot are in a desired configuration, the programmer presses a "record" button which stores the positional value of all of the joints in the memory of the robot. During playback, these position values are recalled from memory and compared with the actual measured positions of the joints. If there are any discrepancies, the servo system sends a command to the actuator to move the joint until the error disappears.

Most of the robots being sold today have controls of this type. These controls may be specially hardwired units, or they may be based on minicomputers or microcomputers, but the control concepts are the same. A typical robot may be able to store 100 program steps or more.





**TRANSFER TASK** 

#### INSERTION TASK



Figure 4 - This schematic represents the motion required for an insertion task. The hand is to move to a point over the hole, follow a straight line path into the hole, which required recording two additional points between the beginning of the approach path and the destination point.



Figure 5 - Proximity Sensor affixed to a robot's gripper enables a robot to locate and grasp objects that are not precisely positioned. Infrared radiation, produced by light-emitting diodes and carried by fiber-optic bundles, is projected downward in two beams. Radiation reflected from the target enters a parallel set of fiber-optic bundles. Strength of reflected radiation acts as a feedback signal that informs robot how close gripper is to its target. Experimental system in photograph is under development at the National Bureau of Standards.



Figure 6 - Illustration of a typical first level control system used on industrial robots. The robot is led through a series of points by means of a teaching box which allows each of the joints To repeat the to be moved by the operator. These points are recorded on a memory storage system. operation, this switch is thrown to cause these recorded points to dirve the robot.

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Some controls allow branching from one set of program steps to another, depending on external conditions. This feature is useful, for example, in spot welding of automobile bodies, where the control program must be changed to accommodate a mix of body styles on a typical automobile assembly line.

Some tasks require the path of the robot hand to follow a straight line (such as inserting a cutter into the spindle of a machine tool).

Programming a straight line motion with the rate control box is a particularly time consuming job since most industrial robots have one or more rotary joints that cause the hand to travel along a circular arc instead of a straight line (Figure 9).

Thus, a simple insertion task requires the operator to continually readjust a number of joints in order to program the hand to move along a straight line.

The transfer and insertion tasks described above were programmed by three different operators using a rate control box. Their times for the first level of control are shown in Figure 7 and 8.

This first level of control does not require the use of a computer. However, a computer is necessary to implement the second and third levels of this hierarchical control system. These higher control levels are required for increased capabilities in speed and ease of programming, and for real time interaction of the robot with the environment through the use of sensory feedback.

#### 2.1.1-2 Second Level of the Control Hierarchy

The commands to the second level of the control system are calls to primitive function subroutines to be executed. These low level primitives are the basic, general purpose, operations that can be sequenced together to accomplish more complicated tasks. They are called, one at a time, by the different input commands such as GRASP, or RELEASE, or MOVE X, Y, Z, etc. A command call like GRASP will, together with whatever feedback is appropriate for this primitive, cause the second level to generate the correct sequence of joint position outputs to the next lower level (servo level) to accomplish this operation.

Programming at this second level is much enhanced over the first level since coordinate transformations are now possible with the computer. Inputs to the robot, to move it to the desired positions and orientations to be recorded, can now be in the form of values in an external coordinate system. Thus, the arm can be commanded in terms of X, Y, Z coordinate space through the use of a joystick. Moving the joystick in a desired direction provides inputs into the computer that are the delta X, Y, Z coordinate offsets from the present position. This X, Y, Z command becomes the input to the second level. The







Figure 9 - This figure illustrates the required coordination of a number of joints in order to obtain a typical straight line motion of the hand. For each incremental move along the straight line path, joints 2 (elevation), 3 (boom), and 5 (wrist flex) must be adjusted.

coordinate transformation routine is then called to calculate all of the joint motions required to cause the robot's hand to move along the commanded straight line. The operator is one level removed from the servo system and, therefore, no longer has to worry about moving the individual joints. This is the power of a hierarchy. As higher levels are added, the input commands become simpler and more procedure oriented, while the sequences of the detailed operations required to accomplish the tasks are generated by the lower levels in response to these commands.

If the transfer and insertion tasks are programmed at the second level, using a joystick, there is a significant reduction in programming time (Figures 7 & 8). In addition, the programming becomes easier and less tedious since the operator no longer has to concern himself with what series of joint motions is required to move the arm to the new location.

In addition, the coordinate transformation routine makes it possible for the control system to interact with sensory data. Most sensors provide information that will require the robot to move along vectors in the sensor-based coordinate system, not in the joint coordinate system of the robot.

The sensor generated commands for motions of the arm in terms of the sensor's coordinate system are transformed into the proper joint coordinate values. Thus, causing real time dynamic interaction of the robot with its environment through sensor controlled movement.

#### 2.1.1-3 Third Level of the Control Hierarchy

The third level in the control hierarchy receives its input commands in the form of elemental move commands. The elemental move is a basic unit building block in the description of a task. It is in the form of a motion and an operation. Most, if not all tasks, can be broken down into a sequence of these elemental move commands, where the hand of the robot executes some trajectory through space to a destination point and performs some function. Of course, the trajectory or the function may default to a null value. These elemental moves are programmed by the operator in the form of "GOTO" statements. An example of an elemental move command would be "GOTO PALLET (04), GRASP." This command, along with any appropriate sensory data, would generate a sequence of calls to the second level to execute the required primitive functions.

At this third level, the operator is programming in a much more task procedural language as opposed to the robot joint position language of the first level. The joint positions of the robot that define the location PALLET (04) still have to be recorded in a table of points. However, these points can be entered under joystick control or as the X, Y, Z coordinates of the location. Once a location is stored under



Figure 10 - The three modules of the control system in their relation to each other and the robot.

some arbitrary name (like PALLET (04)), it can be used in any number of elemental move statements. Of course, the stored locations can be programmed in any sequence, not just the order in which they were entered.

Recording and programming the transfer and insertion tasks at the third level shows a further reduction in programming time (Figure 7 & 8). The programming is even easier for the operator to accomplish since he is giving elemental move assignments which describe the task in much the same way as it would be described by one person to another. Large reductions in recording and programming time occur when arrays of locations are used as will be explained later in the report.

#### 2.1.2 Program Module

The application program is entered in the program module (module #2) with the control system editor. The application program takes the form of a sequence of GOTO statements using arbitrarily named locations such as PALLET (04), NEUTRAL, VISE, etc. Each statement (elemental move) may also include a list of desired functions such as GRASP, INSERT, etc. These elemental move commands might be entered through a computer terminal by the operator, by an APT part programmer at the same time that he is writing the part programs for a NC tool, or through a function button programming box on the shop floor.

Thus, the program module produces a procedural description of the tasks to be performed in terms which are as independent as possible of the particular robot that may perform it.

#### 2.1.3 Location Table Module

The values in the location table provide a relative description of the positions of all of the location points. These values can be postprocessed to specify the location points in the coordinate space of any particular industrial robot that is sufficiently flexible to carry out the task (i.e., in most cases, a six-axis robot). The concept is to allow these relative locations to be entered by the programmer as X, Y, Z coordinate locations at the same time he is creating the program module, or to be processed from some data base such as a CLDATA file of an APT program. The CLDATA file (the X, Y, Z and surface normal angle data) has a certain level of machine independence and can be postprocessed to provide the location points for a particular robot as well as for a particular machine tool. Another source of these location points is from a particular robot trained in its own workspace. These specific location points can be converted into standard coordinates for use by another robot through an inverse postprocessor.

Thus, an attempt has been made to separate the description of the task as much as possible from the particular robot that might carry out its operation. The control system interfaces to the particular robot through that robot's own coordinate transformation subroutine. The coordinate transformation routine can be used with a post processor to generate the robot- specific location table from a robot-independent location table. It is also used during execution of the program for real time transformation between external or sensor-based coordinate systems and the robot's joint coordinate system.



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#### 3. THE NEXT LEVELS OF CONTROL

Ongoing work at the Bureau includes the addition of the fourth and fifth levels of the control hierarchy (Figure 11), and the completion of the modular design, its standard interfaces and the postprocessors to provide the general purpose control system described above.

The next sections will discuss the basic conceptual functions of the fourth and fifth levels of control and an overall view of the complete control system to be integrated into the computer-aided manufacturing operation.

#### 3.1 Fourth Level Control

This level of control takes care of the complete operation of a robot in its associated work station. Its input is in the form of a task to be completed, such as "SPOT WELD A CAR BODY" or "CUT 50 GEARS OF TYPE #36" etc. Sensory feedback data comes not only from the robot's sensors, but also from sensors throughout the work station. These work station sensors provide the additional feedback required to allow the robot to cope with all of the error conditions that are within its capability to correct. This reduces the need for external supervision and intervention to a minimum.

The input task command, together with the sensory feedback from the robot and the workstation, result in the fourth level sending out sequence of elemental move commands to the third level. Different prerecorded sequences of elemental move commands can be decided upon as a result of the particular input task and sensory feedback.

As an example, consider the task to make a particular gear from a pallet of gear blanks. To accomplish this task command, the fourth level will send the sequence of elemental moves to the third level to cause the robot to load and unload the parts from the pallet to the vise on a machine tool table, and to change cutters in the machine tool for the different cutting operations.

This sequence of elemental moves will be the main execution program. In addition, a number of sequences of elemental moves can be programmed and named to be used as subroutines. These will be sent to the third level when certain conditions arise. For example, suppose one of the cutters breaks while in the machine tool. A sensor on the tool or on the robot can report this data back to the fourth level. This condition will cause a branch to a preprogrammed sequence of elemental moves. This sequence will command the robot to remove the broken cutter from the tool and replace it with a new cutter. The program then returns control to the proper point in the execution program.

Thus, the fourth level control system has the responsibility of accomplishing tasks for an entire work station. This level receives

sufficient sensory data to cope with problems that might hinder the execution of that task, and outputs the preprogrammed sequences of elemental moves to correct these situations.

#### 3.2 Fifth Level Control

The fifth level of control has the responsibility of accomplishing a project that might involve assigning a number of tasks to a number of different work stations; or scheduling a number of tasks to the same work station. Its feedback might consist of one of its fourth level control stations reporting back that a task has been completed, or that a machine tool is inoperative. This fifth level would respond by issuing a new task to the particular work station or rerouting materials to another work station and assigning it the task that the disabled station could no longer accomplish.

The fifth level interfaces to higher level computer-aided manufacturing and management information systems' data bases to provide them with information (processed feedback) about the work being done on the factory floor, maintenance and repair situations, productivity, efficiency of machine utilization, etc. Figure 12 gives an illustration of the processing of information both up and down the hierarchy.

These five levels of control carry out the responsibility of the actual manufacturing or production in a factory. They should integrate into total CAD/CAM systems as well as have the capability of a stand alone system at any level depending on the resources of the manufacturing unit involved.



Figure 12 (a) & (b)

Each level in the hierarchy has information flowing into and out of it. The output being a function of the inputs (a).

Each level's sensory input is composed of three types (b). There is raw sensor data such as the voltage levels from proximity sensors indicating relative reflected intensity.

There is preprocessed sensor data such as might come from a vision system where sophisticated data manipulation and pattern recognition is performed by some sensor unit and its output is a sensor input to the control system.

The other sensor feedback is information from the lower levels of the hierarchy that is a reporting of their effectiveness in completing their input task. This takes the form of an interpretation of their sensor data in light of the input command. These are additional outputs from each level, not as commands to the next lower level, but as inputs to the higher levels. As with the other outputs they are also predetermined functions.


Figure 12 (c) - Thus, each level not only generates information in a descending path to the lower levels but also processes and reports information back up the hierarchy. At each higher level, this reporting takes on a more and more sophisticated form such that the fifth level may report to a management information system that an extra hour will be required to produce a set of differentials while the original raw sensor data to the second level might have been a proximity sensor signal level.

### 4. MODULAR DESIGN

Modular design offers several very important advantages. It provides a partitioning of the system into identifiable units, each of which is comprehensible and lends itself more easily to a solution. This modularization also aids in the separation of the control system into those sections that are of a general nature and therefore robotindependent, and those sections that are specific to the individual robot (e.g. the coordinate transformation routine, the servo system etc.). This allows the creation of a general purpose, universal control system that can run any robot if the robot-dependent modules are supplied.

Modularization encourages the use of standard interfaces which aids in the set up of the functional organization of the system and simplifies the information links between the modules themselves, and between these modules and the other components of the CAD/CAM system. It clearly defines where the responsibility for each function lies, which simplifies the writing and debugging of code.

The concept of modularization has been extended to the level of partitioning the control system module, the program module, and the location table module into a number of simple subroutines. In the control system, each primitive operation (like GRASP) is a separate subroutine which is called when the appropriate condition occurs. Therefore, once the control system architecture is supplied, the addition of new primitive functions is merely the addition of the new subroutines. Interaction with sensors is handled in the same way.

A sensor subroutine is written and added into the system. Whenever the system is commanded to interact with the sensor's feedback, a call to its subroutine is made. This usually includes calls to the coordinate transformation routine to provide the necessary joint position commands to cause motion of the robot in the sensor's coordinate system. In this way, sensors of any type can be implemented and the control system made to interact with their feedback by the addition of simple subroutines. This makes the control system flexible and easily modifiable for new applications.

### 5. NBS CONTROL SYSTEM PHILOSOPHY

This control system has been designed as a completely deterministic hierarchy of input - output patterns. The hierarchical architecture has provided a separation of responsibilities into different function levels. Each level becomes a group of preprogrammed function generators that respond to a limited set of input states with a defined set of output states.

If a response to a certain set of input conditions is not programmed, the control system can neither decide on the proper output nor "learn" the correct response. All of the intelligence to cope with the environment must come from human intervention in the form of preprogrammed functions. The location points and procedure must be specified for each task. A human operator must construct the appropriate subroutines to recognize and respond to the input patterns.

However, within this set of defined input states, this deterministic system exhibits goal directed, adaptive behavior, responding to sensory feedback to modify the robot's motions in real time. In this way, the assigned task is accomplished in spite of perturbations in the environment.

This use of a hierarchical system of simple deterministic functions has demonstrated large increases in capabilities as each new level is added. At each higher level, input patterns that correspond to more complex task assignments and more sophisticated processed sensory data, are used to generate sequences of simpler commands to the next lower level. The degree of "intelligent" behavior that can eventually be exhibited by a control system based on this concept is an important area of continuing research and development.

## 6. SUMMARY

The partitioning of the control system into simple modules and the interaction of these modules in a hierarchical fashion has proven to be a powerful technique in obtaining sophisticated sensor-controlled robot behavior at a minimum cost of programming time and computer size. This architecture also provides a flexible framework for the incorporation of additional functions and sensors.

II. USER'S GUIDE

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## II. USER'S GUIDE

### EXECUTING APPLICATIONS PROGRAMS (Module #1 - Control Hierarchy)

The compiling and linking of subroutines into an executable load module are the only operator interface to the host computer's operating system. All other functions are maintained internally to the control system programs.

Real time control over the execution of the different control system modules is accomplished by a set of function switches. These switches are polled at periodic intervals (approximately every 20 milliseconds). Branches to different subroutine calls are made on the basis of these switch values. Thus, the operator can interact with the control system in real time. He can, for example, stop the arm in the middle of a trajectory modify the application program, and/or change a location point using either the joystick control or entering the X, Y, Z coordinate values, and then continue the execution of the new application program either at the point it was interrupted or at any other designated step in the program.

### 1.1 Control Hierarchy - Operator Interactions

See Table 1 for a listing of the panel switches and their interactions with the control system.

### 1.2 Initializing Program

Once execution begins (i.e. execution of the compiled and linked subroutines on the user's computer) the control system initially reads in from the storage unit the assigned application program and location table and prints the following messages on the terminal:

---SW 28 UP--- INTERRUPTS RUN PRUGRAM ---SW 29 UP--- TEACH LOCATION TABLE ---SW 30 UP--- ENTER PROGRAM SEQUENCE ---SW 31 UP--- RECORD LOCATION TABLE ON DISC \*\*\* TYPE [CR] \*\*\* TO CONTINUE

This identifies the functions of switches 28 thru 31. If an existing application program and location table is available, then, by typing in a carriage return, this application program will be initiated. After the entry of a carriage return the next message is sent to the terminal:

---SW 35 DOWN--- AND \*\*\* TYPE [CR] \*\*\* TO INITIALIZE THE SERVOS WITH THE STARTING LOCATION

This reminds the operator to be sure that switch 35 is in the down position. This switch will start the execution of the program. When

# Control Hierarchy - Operator Interactions

Input Channel Number	Function	Description
26	Velocity Control	Voltage readings from a potentiometer used to control relative velocity of arm by specifying the number of inter- polation points to be used.
28	Interrupt (abort)	When set, immediately stops execution and provides the operator with the option of editing program or location table or recording them on disc.
29	Enter Location	When set, this switch calls up the location module to allow entering of points in the location table. When reset, causes an exit from location module.
30	Edit Program	When set, this switch calls up the program module to allow editing of program table. When reset, causes an exit from pro- gram module.
31	Store on disc	When set, causes the location table to be stored on disc.
34	Pause	Temporarily suspends all execution so long as it is set. When reset, execution continues.
35	Start, Repeat	After initialization procedure, this switch is set to begin execution. The program will continue to repeat as long as this swtich remains set. If reset, it stops the program after execution of last line of program table.

Table 1 cont.

Input Channel Number

Function

## Description

36

Straight Line Velocity Voltage readings from a potentiometer used to control the velocity of the straight line portions of the trajectories. the carriage return is typed in, the program sends the joint position values of the starting location to the servo system.

TURN ON SERVOS ---SW 35 UP--- TO EXECUTE PROGRAM. ---SW 35 REMAINS UP--- FOR REPEATED EXECUTION.

### 1.3 Executing Program

The servo system can now be turned on since a known set of joint position values has been commanded. The program cycles here, testing switch 35 until this switch is flipped up. When this switch is in the up position, the application program is executed. Switch 35 will not be polled again until after the last executable line of the application program. If the switch is still up at this time, the application program is repeated. If it is down, the control system cycles here, continuously polling switch 35.

Once switch 35 is flipped to the up position, the application program is executed without any further messages being printed on the terminal except error conditions.

### 1.4 Interrupting Execution

At any time, the interrupt (abort) switch (switch 28) can be set. This causes an immediate halt in the executing program, stopping the arm at its present position. The following message is printed on the terminal:

YOU ARE AT PROGRAM STEP 11 11 GOTO BOX(03) GRASP PROXIMITY VEL(50) SEND(0) WAIT(0) ---SW 29 UP--- TEACH LOCATION TABLE ---SW 30 UP--- ENTER PROGRAM SEQUENCE ---SW 31 UP---RECORD ON DISC \*\*\* TYPE [CR] \*\*\* TO CONTINUE

In this instance, the control system was executing line 11 of the application program when interrupted. The elemental move statement (GOTO BOX (O3) GRASP PROXIMITY) that is in line number 11 is also printed out.

#### 1.5 Continuing After Interrupt

After the desired changes have been made, a carriage return is entered and the system responds with:

#### WHICH PROGRAM STEP DO YOU WANT?

The operator can respond with any program line number, and execution will begin at that point in the program. If a zero or carriage return is entered, the initialization phase is carried out and the system awaits switch 35 to be set to begin executing the program.

## Program Module - Operator Interactions

Input Channel Number	Function	Description
28	Interrupt (abort)	When set immediately stops execution of the program and allows the program module to be called.
30	Edit Program	When set, calls up the program module to allow editing of the program table. When reset, causes an exit from the program module.

Editor Commands

Command Symbol	Function
Insert (XX)*	Specifies the program table line number XX where new line(s) are to be inserted.
Print (XX-YY)	Specifies the first (XX) and last (YY) line of the section of the program table to be printed. Once print command given, a minus sign will cause previous line to be printed, a carriage return will cause the next line to be printed.
<u>D</u> elete (XX-YY)	Specifies the first (XX) and last (YY) line of the section of the program table to be deleted. This section will be printed out as it is deleted.
<u>S</u> tart NNN	Once the insert command has been called, this command enters the name (NNN) of the starting location in the program.
Loop	Specifies that all of the following elemental move inputs between this command and the command FINISH are to be repeated the number of times required by the indexed values of the location names used.
Finish	Causes the termination of the LOOP sequence
Name	Causes the names of the indexed locations to be printed out on terminal with the option to change them.
<u>A</u> void XX I <sub>1</sub> I <sub>2</sub> ···I <sub>10</sub> YY	Causes the insertion of up to 10 (I <sub>10</sub> ) additional intermediate location points between the specified location points XX and YY. Used to create special trajectories using detailed path segments.

\* All editor commands default to just their first letter for faster editing.

## Elemental Move Functions

Command Symbol	Function
<u>G</u> oto XX(YY-ZZ)*	Specifies a destination point (XX) for this trajectory. If it is an indexed location, the value of the particular index (YY) is specified. If it is used in a loop, then the range of indexed values(YY-ZZ) is specified.
<u>G</u> rasp	A grasp command - the fingers close on an object with a predefined amount of force.
Release	A release command - the fingers open completely.
<u>Grasp</u> Proximity	Center hand over object using the proximity sensors, then pick it up.
<u>Release</u> <u>Proximity</u>	Locate an object with proximity sensors and place the held object on top of it.
<u>U</u> nstack	Locate top of a stack with the proximity sensors, then pick up the top object.
Touch	Locate the top of an object of unde- fined height using proximity sensors.
Detect	Locate an object using the proximity sensors.
Balance	Center hand over an object using the proximity sensors.
<u>L</u> ine	Move to the destination point through a straight line trajectory rather than an interpolated trajectory.
Send (XX)	Cause channel number XX to output a +5 voltage level.
<u>W</u> ait (XX)	Suspend execution until channel number XX receives +5 voltage signal.

\* All elemental move commands default to just their first letter for faster entry.

## 2. ENTERING APPLICATION PROGRAMS (Module #2 - Program Module)

If a new program is to be entered or the present one modified, then switch 30 is set and a carriage return typed.

#### 2.1 Program Module - Operator Interactions

See Table #2 for a summary of the operator interactions through the switch panel.

#### 2.2 Indexed Location Name Entry

When the editor is called, the names that have been assigned indexed values are printed out on the terminal.

THESE ARE THE CURRENT INDEXED LOCATIONS BOX STACK DO YOU WANT TO ENTER NEW INDEXED NAMES?

If the answer is yes, then the program responds with:

ENTER INDEXED NAMES (E.G. PALLET CUTTER STACK)

As an example, consider a pallet with an array of parts to be machined by a milling tool. The program to be entered should cause the robot to load and unload these parts from the vise, insert the correct end mill cutter in the tool at the beginning and remove it at the end, and air brush off the chips after each operation. For this task, PALLET will be set up with indexed locations corresponding to the array of parts on the pallet. Therefore, in answer to the request for indexed names made above, the operator enters the name PALLET:

% PALLET\*

The system responds with the message:

EDITOR IS NOW AVAILABLE FOR PROGRAM ENTRY

\*All operator entered commands will be preceded by a percent sign (%).

### 2.3 Editor Commands

The editor that has been written for this control system is line oriented and has commands to insert, delete or print specified line numbers.

#### 2.3.1 Table of Editor Commands

See Table #3 for summary of all of the editor commands.

### 2.3.2 Elemental Move Functions

See Table #4 for a description of all of the presently implemented function commands for writing an application program.

#### 2.3.3 INSERT and LOOP Commands

To enter the application program that will accomplish the machining task described above, the following commands are typed in:

% INSERT 01 % START NEUTRAL % GOTO ENDMILL GRASP % GOTO TOOL RELEASE % LOOP % GOTO PALLET (01 - 06) GRASP PROX % GOTO VISE RELEASE % GOTO NEUTRAL SEND (03) WAIT (13) % GOTO AIRHOSE GRASP % GOTO CHIP VELOCITY (10) % GOTO AIRHOSE RELEASE % GOTO VISE GRASP % GOTO PALLET (01 - 06) RELEASE % FINISH % GOTO TOOL GRASP % GOTO ENDMILL RELEASE % GOTO NEUTRAL SEND (04)

The above program, which is 14 statements long, will cause the robot to execute the following actions - start at some initial location named "neutral" - move from this location to the location of the end mill cutter - pick up the end mill cutter and insert it into the spindle of the milling tool - move over to the first work piece on the pallet, locate it with proximity sensors, pick it up and put it in the vise go back to its neutral safe position -send a voltage level out on channel three to cause the machine tool to begin cutting - wait until the interlock signal from the machine tool on channel 13 goes high, indicating that the machining operation is finished - go to the location of the air hose - pick it up and blow off the chips by taking the air hose to a position named "chip" which is above the vise replace the air hose - go to the vise and remove the machined part - return the part to the pallet - locate and pick up the next part - repeat all of the above procedures for all six parts - then remove the end mill cutter from the tool and replace in the tool rack - go back to the neutral position and send out a signal on output channel four indicating that the job is finished.

The advantage of indexing names is obvious here, where the task has to be described only one time for one part. The "loop" command will cause all of the statements between it and the "finish" command to be repeated, for each of the six pallet positions.

### 2.3.4 PRINT Command

The edit program immediately generates the complete sequence of elemental move commands for all of the indexed positions. Thus, if a print command is given to display lines one thru 20, the following would occur:

%	PRINT	01 - 20				
	START	N*				
01	GOTO	E	GRASP	VEL(50)	SEND(0)	WAIT(0)
02	GOTO	Т	RELEASE	VEL(50)	SEND(0)	WAIT(0)
03	GOTO	PALLET(01)	GRASP PROX	VEL(50)	SEND(0)	WAIT(0)
04	GOTO	V	RELEASE	VEL(50)	SEND(0)	WAIT(0)
05	GOTO	N		VEL(50)	SEND(03)	WAIT(13)
06	GOTO	А	GRASP	VEL(50)	SEND(0)	WAIT(0)
07	GOTO	С		VEL(10)	SEND(0)	WAIT(0)
80	GOTO	А	RELEASE	VEL(50)	SEND(0)	WAIT(0)
09	GOTO	V	GRASP	VEL(50)	SEND(0)	WAIT(0)
10	GOTO	PALLET(01)	RELEASE	VEL(50)	SEND(0)	WAIT(0)
11	GOTO	PALLET(02)	GRASP PROX	VEL(50)	SEND(0)	WAIT(0)
12	GOTO	V	RELEASE	VEL(50)	SEND(0)	WAIT(0)
13	GOTO	N		VEL(50)	SEND(03)	WAIT(13)
14	GOTO	А	GRASP	VEL(50)	SEND(0)	WAIT(0)
15	GOTO	С		VEL(10)	SEND(0)	WAIT(0)
16	GOTO	А	RELEASE	VEL(50)	SEND(0)	WAIT(O)
17	G010	V	GRASP	VEL(50)	SEND(0)	WAIT(O)
18	GOTO	PALLET(02)	RELEASE	VEL(50)	SEND(0)	WAIT(O)
19	GOTO	PALLET(03)	GRASP PROX	VEL(50)	SEND(0)	WAIT(0)
20	GOTO	V	RELEASE	VEL(50)	SEND(0)	WAIT(0)

As can be seen, the program has been expended to its full sequence of elemental moves. The channel numbers for the interlocking commands "SEND" and "WAIT" are listed for each program line. A velocity value is also listed for each line. This is the maximum velocity that the hand is to reach for that particular move. If it is not specified during programming then a default value of 50 cm/sec is entered in the program sequence.

<sup>\*</sup>All location names other than indexed names, default to their first letter.

#### 2.3.5 AVOID Command

The program entered above is a minimum description of the task to be completed. There might, however, be peculiarities about the work environment that will prevent the trajectories from being executed as described. For example, suppose there is a building support column between the "NEUTRAL" position and the "VISE" position. To prevent the arm from colliding with the column, the following entry can be made:

% AVOID VISE POINT NEUTRAL

From the single entry of this one command, the entire application program will be scanned for all instances where the trajectory to be executed is between the vise and the neutral position. At every one of these points in the program, the additional elemental move - "GOTO POINT" - will be inserted. Thus, if a print out of lines three to seven is called for:

PRINT 03 - 07				
GOTO PALLET(01)	GRASP PROX	VEL(50)	SEND(0)	WAIT(0)
GOTO V	RELEASE	VEL(50)	SEND(0)	WAIT(0)
GOTO P		VEL(50)	SEND(0)	WAIT(O)
GOTO N		VEL(50)	SEND(03)	WAIT(13)
GOTO A	GRASP	VEL(50)	SEND(0)	WAIT(0)
	GOTO PALLET(01) GOTO V GOTO P GOTO N GOTO A	GOTO PALLET(O1) GRASP PROX GOTO V RELEASE GOTO P GOTO N GOTO A GRASP	PRINT 03 - 07GOTO PALLET(01)GRASP PROXVEL(50)GOTO VRELEASEVEL(50)GOTO PVEL(50)GOTO NVEL(50)GOTO AGRASPVEL(50)	PRINT 03 - 07GOTO PALLET(01)GRASP PROXVEL(50)SEND(0)GOTO VRELEASEVEL(50)SEND(0)GOTO PVEL(50)SEND(0)GOTO NVEL(50)SEND(03)GOTO AGRASPVEL(50)SEND(0)

#### 2.3.6 DELETE Command

-----

Once a program is written it can easily be modified by the "DELETE" and "INSERT" editor commands. As an example, suppose this pallet of parts was to go to a work station to have a number of holes drilled in the parts. The only difference in the description of the task is that now a drill bit instead of an end mill cutter is to be inserted into the machine tool.

To accomplish this program change, line one will be deleted and a new line will be inserted. This new line will require the robot to go to a position named "DRILL" to pick up the drill bit to be used for this machining operation. To delete line one, the following command is given:

% DELETE 01 01 GOTO E GRASP VEL(50) SEND(0) WAIT(0)

When a delete command is given, the system deletes the specified line(s) and prints it (them) out on the terminal. The remainder of the program is closed up around the deleted line so that a print out of lines one to three would look like this:

%	PRINT 01	- 03				
	START	NEUTRAL				
01	GOTO	Т	RELEASE	VEL(50)	SEND(0)	WAIT(0)
02	GOTO	PALLET(01)	GRASP PROX	VEL(50)	SEND(0)	WAIT(0)
03	GOTO	V	RELEASE	VEL(50)	SEND(0)	WAIT(0)

To enter a new line, the "INSERT" command is given:

%	INSERT O	]			
	START NEL	JTRAL			
01	GOTO T	RELEASE	VEL(50)	SEND(0)	WAIT(0)

The "INSERT" command causes the line presently at the specified line number to be printed out. Any new line(s) inserted here will be placed in the program in front of the displayed line. The new line can now be entered:

% GOTO DRILL GRASP

If a print out of lines one to three is called for:

%	PRINT 01 -	03				
	START	NEUTRAL				
01	GOTO	D	GRASP	VEL(50)	SEND(0)	WAIT(0)
02	GOTO	Т	RELEASE	VEL(50)	SEND(0)	WAIT(0)
03	GOTO	PALLET(01)	GRASP PROX	VEL(50)	SEND(0)	WAIT(0)

The new line has been inserted and the other program lines moved back to accommodate it. This change is also to be made at the end of the program where the drill bit is removed from the machine tool and returned to its holder.

Thus, by two "DELETE" and "INSERT" commands, the program has been modified to cause the next machining operation to be accomplished on this pallet of parts.

#### 2.3.7 RECORD Command

Once the application program is written, it can be stored on disc for future use. The editor command "RECORD" accomplishes this:

% RECORD THE PROGRAM HAS BEEN STORED ON DISC

### 2.4 New Functions

If there are additional functions that are required, for example, a special insertion technique is required to place a cutter into a spindle, then these special motions and perhaps the use of touch or force sensing to adjust the positioning of the cutter as it is

inserted into the spindle, can be defined in a new FORTRAN subroutine or combination of existing subroutines. Then this subroutine(s) can be specified by a single function call like INSERT so that a command to insert a cutter into a tool might be programmed as:

% GOTO TOOL INSERT

The addition of these extra functions and their programming code words is a simple modification with this control system and will be explained in some detail in the next chapter.

### 2.5 Exit Program Module

To exit the program module, switch 30 is flipped down and a carriage return is typed in. The control system responds with the following list of options:

---SW 29 UP--- TEACH LOCATION TABLE ---SW 30 UP--- ENTER PROGRAM SEQUENCE ---SW 31 UP--- RECORD LOCATION TABLE ON DISC \*\*\* TYPE [CR] \*\*\* TO CONTINUE

The operator can now set switch 29 and type a carriage return to call up the location table module with its associated routines.

# Location Module - Operator Interactions

Input Channel Number	Function	Description
28	Interrupt (abort)	Stops execution of program so location module can be called.
29	Enter Location	Causes location module to be called up so location points can be entered. Resetting this switch causes an exit from the location module.
31	Coordinate Printout	While under joystick control, this switch causes X, Y, Z coordinate values of the present location of the arm to be printed out. Resetting switch returns control of joystick.
32	Joystick Control	Causes the signals from the joystick box to control the motions of the arm. Resetting this switch causes the present location of the arm to be stored in the location table.
34	X, Y, Z Entry	Allows location point to be entered as an X, Y, Z coordinate position.

#### 3. ENTERING LOCATION POINTS (Module #3 - Location Module)

Once the program is written, it only remains that those location names referenced in the program have their corresponding position values stored in the location table. This section explains how the user is to enter these location points and what data the system will request to completely describe these points.

#### 3.1 Location Module - Table of Operator Interactions

See Table #5 for a summary of the operator's interactions through the function switch panel.

#### 3.2 Mode of Entry

As in the programming module, the names of the indexed locations are printed on the terminal and the option to change them is given.

The system then prints out the following message to indicate which panel switches are to be used for the different modes of location point entry:

---SW 32 UP--- FOR JOYSTICK CONTROL ---SW 34 UP--- FOR XYZ ENTRY ---SW 32 & 34 DOWN--- FOR MANUAL ENTRY \*\*\* TYPE +1 \*\*\* TO RECORD AN ARRAY OF INDEXED LOCATIONS \*\*\* TYPE [CR] \*\*\* TO RECORD LOCATIONS ONE AT A TIME

#### 3.3 Array Entry

To record the array of location points for the six positions on the pallet in the previous example and to use the joystick to maneuver the arm to the proper positions, requires panel switch 32 to be set and a +1 to be typed on the terminal.

The system responds with a series of requests. The operator's responses will exactly specify the array of locations to be recorded:

ENTER LOCATION NAME AND INDEX NUMBERS E.G. PALLET (01-20)

The array to be specified is the six positions on the pallet as shown in Figure 13a, so the following is entered:

% PALLET (01-06)

ENTER ARRAY DIMENSIONS (E.G. 4,5)

The array of parts on the pallet, as shown in Figure 13a, is a 3 by 2 array therefore the entry is:



 $\times$ 



% 3,2

ENTRY X,Y,Z DELTAS (DECIMAL CM) BETWEEN ARRAY POSITIONS ALONG FIRST DIMENSION.

The first dimension is along the sequential ascending index values (i.e. along the row 01-02-03), therefore the delta X, Y, Z offsets will be +10. cm in the X, 0.0 cm in the Y and 0.0 cm in the Z (given that the pallet lies in an X-Y plane) and will be entered as:

% 10.,0,0

ENTER X,Y,Z DELTAS (DECIMAL CM) BETWEEN ARRAY POSITIONS ALONG SECOND DIMENSION.

% 0,-15.,0

Control is now turned over to the joystick box to move the arm to the correct position for PALLET(01). The following message is also sent out to the terminal to provide further information.

TO RETURN TO THE TEACH LOCATION MODE FLIP SW 29 TO THE DOWN POSITION. FLIP SW 31 UP TO DISPLAY XYZ VALUES.

At any time, while the arm is under joystick control, switch 31 can be flipped up for a print out on the terminal of the the x,y,z coordinate values of the present location of the hand. This information can be used by the operator for future entry of locations in terms of their X, Y, Z coordinate values. Once the arm has been positioned at the location PALLET(01) using joystick control, switch 32 is flipped down. This causes the system to record this position as PALLET(01).

The remaining five positions in the array are computed from the position of this location and the array dimension data supplied above.

As mentioned earlier in the report, it is with the recording and programming of arrays of locations that large savings in time can be obtained.

3.4 Approach Path

The next request from the location module is:

ENTER DELTA X,Y,Z (DECIMAL CM) TO START OF APPROACH PATH

This data is required for the specification of the approach path to be used for this location. The approach path concept simplifies much of the trajectory calculation. It is illustrated in Figure 14. Location "PALLET(01)" has the coordinate values  $X_1$ ,  $Y_1$ ,  $Z_1$ . The direction in



which the hand approaches this point is critical. If the object shown is sitting on top of a table, then it would be disastrous to approach it from below.

The operator designates the delta X, delta Y, delta Z offsets from the location point to the start of the desired approach path (for the example in Figure 14 delta X=0, delta Y=0 delta Z=10cm). These values are stored in the location table. During execution, the hand moves quickly through space to the start of the approach path. It decelerates at this point and follows a straight line path from here to the actual location point. During this approach path maneuver, the orientation of the hand in space is maintained.

The non-critical portion of the trajectory, from one approach path to the other, can be executed at high speed by simple interpolation between all the joint values without regard for close tolerances on this motion. The use of an approach path, therefore, modularizes the trajectory into segments that can be easily executed by simple subroutines.

The operator's response to the above request for the delta offset values would be:

% 0,0,10.
\*\*\* TYPE +1 \*\*\* IF HAND WILL STOP AT THIS LOCATION
\*\*\* TYPE [CR] \*\*\* IF HAND DOES NOT STOP HERE.

This information is requested to provide a flag for each location. If the flag indicates that the hand is to stop at that location then an acceleration profile is created for the trajectory to this point. If the flag indicates that the hand does not stop at that location, then no acceleration profile is created and the trajectory passes through that point at the velocity specified in the elemental move command.

This completes the data required to totally describe a location. The operator is now given the opportunity of entering another location point or displaying the location table itself on the terminal for his inspection:

\*\*\* TYPE[CR] \*\*\* FOR ANOTHER POINT \*\*\* TYPE +1 \*\*\* TO DISPLAY TABLE

#### 3.5 Exit Location Module

To exit from the teach-location portion of the control system, switch 29 is flipped down and a carriage return is entered.

#### 

## III. CONTROL SYSTEM IMPLEMENTATION

## III. CONTROL SYSTEM IMPLEMENTATION

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## III. CONTROL SYSTEM IMPLEMENTATION

This chapter will concern itself with the manner in which information is processed by the subroutines to accomplish all of the responsibilities of the control system. Included here will also be an example of the procedure used to incorporate a new subroutine into the control system. The system documented here, is presently implemented on a 16 bit word length minicomputer, running under DOS (Disc Operating System), with 32K words of core and a 1.2 million byte disk storage system. All of the subroutines (except the I/O drivers) have been written in FORTRAN, compiled on this computer and their object modules linked to form a single run-time load module. If a prerecorded robot application program and table of location points are to be used, then these two files are assigned to the load module at run time. These files are read in from the disc by the subroutine RDMOD.

The load module contains all of the control system modules - the program module, the location module and the control system hierarchy including all of the support subroutines.

The operator communicates with the control system through a CRT terminal, the previously described switch panel and the joystick box.

#### 1. CONTROL SYSTEM OPERATION

The architecture of this control system is based on a non-intelligent, deterministic system. Essentially, all data that is an input to the control system (control flags, location table pointers, sensory data, etc.) is treated as a form of a pointer (or address) to a file location, subroutine call, or section of code. The control system has been partitioned into different control levels which have been further partitioned into simple general purpose subroutines. A high level command input is in the form of pointers and flags which cause control to branch to the appropriate sequences of subroutine calls. Incoming sensory feedback data is typically tested against a threshold level. The section of code to be executed is determined by whether the sensory data is above or below the threshold value. Thus, this hierarchical system executes real time control over the robot by testing and branching to sequences of simple subroutines.

### 1.1 Control Hierarchy (Module #1)

The control hierarchy receives input commands as individual lines (elemental moves) from the program table. Each line is an input to the third level ("EMOVE") to generate the correct sequence of calls to the second (primitive) level (see Figure 15 for a diagram of the subroutines in the hierarchy). The pointers to the location table address the proper position values of the end points of the trajectories.



call up the program module (PROGS), location module (LOCTAB) or to begin executing the robot program Figure 15 - The schematic representation of the interconnection of the control system subroutines. in the control Mierarchy. The third level of the Mierarchy (EMOVE) čalls the different primitives of the second level which output to the servos through a call to the subroutine SERVO. All input and output between the control system and the external world occur through the drivers ARMIN and t EXPRO is the executing program that monitors the switchboard for commands from the operator ARMOUT



Trajectories are modularized into 3 path segments (Figure 14), a critical path segment at each end of the trajectory (the approach paths) and a non-critical segment that is the portion of the trajectory between the two approach paths. The approach paths are executed at a relatively slow velocity with accurate control of the path and orientation of the hand. This is accomplished through a call to "STLINE." The non-critical middle section of the trajectory is executed at relatively high velocity with simple liner interpolation between the joint values that specify the end points of the two paths. A call to "CALD" determines the distance between these two end points. This value is used by "POL" and "ACC" to generate the joint position commands to move the arm through this trajectory segment at the designated velocity.

Sensory feedback for real time control is obtained through calls to "ARMIN" to read in the values from the A/D converter. The subroutines that process this information use simple algorithms to generate new position commands, in many instances requiring coordinate transformation (a call to "COOR") to command motion in joint coordinate space in accord with feedback in sensor coordinate space. These joint position commands are sent to the arm by a call to "SERVO" which calls the driver "ARMOUT" to output these values to the D/A interface which is connected to the hardware servo system.

## 1.2 Program Module (Module #2)

When an elemental move command is entered by the operator, the programming module codes these English-word-like statements into a number of pointers and flags (see Figure 16). All of the subroutines contained in the programming module are used to generate or edit this table of pointers and flags which will form the input commands to the third level of the control hierarchy.

The relationships between the subroutines of the programming modules is shown in block diagram form in Figure 17.

The detailed workings of these subroutines are covered by the next chapter where the functional flow charts and the documented FORTRAN code is listed.

The functional activities of the programming routines can be summarized in the following manner. Editor commands (INSERT, DELETE, PRINT, AVOID, RECORD, LOOP, NAME) are decoded by a test on the ASCII value of their first letter by the subroutine PROGS. This determines which of the editor subroutines is to be called. Other subroutines (LIMIT, NEXT) search the operator entered commands for the key information symbols. The subroutines "LINE" and "LOCPT" code the Englishlike elemental move commands into the proper location table pointers and function flags. The subroutines "PLINE" and "PTNAME" decode these pointers and flags into the English-like elemental move commands and print them on the terminal. i<sup>th</sup> line in program table

1	2	3	4	5	6
Pointer	Pointer	Velocity	Interlock	Optional,	Function
for present	for	indicator	channel	not presently	code
location	destination	in cm/sec	numbers	used	number

Specific example for the elemental move command GOTO PALLET (03) GRASP PROX VELOCITY(15) SEND(03) WAIT(10). The line in the program table would look like (assuming the present position was neutral):

|--|

The following is the corresponding function code number for the presently implemented functions.

Function	Code Number
anach	1
volozco	1
release	2
grasp proximity	3
release proximity	4
detect	5
balance	6
unstack	7
touch	8
line	9

\*The output channel number is multiplied by 100 and added to the input channel number.

Figure 16 - The program table representation of an elemental move command.

Ň



Figure 17 - The schematic representation of the interconnections between the subroutines of the program module. PROGS monitors the operator's input commands and branches to the appropriate subroutine call to execute these commands.

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The output from the program module (in the form of a program table) becomes the sequence of commands to the third level of the hierarchical control system. Each line in this table corresponds to an elemental move command and contains six positions for pointers and flags (Figure 16).

## 1.3 Location Module (Module #3)

The subroutines of the location module perform the function of generating and storing the required information for each location point so it can be used by the control system in the execution of the elemental move commands. A block diagram of these subroutines is shown in Figure 18. Translation of the location name into the correct pointer value is accomplished by "LOCPT." When arrays of locations are to be entered, "ARRAY" requests the necessary dimensional information and "ARRLOC" generates the required values for each location of the array. When joystick control is to be used, "LOCTAB" makes a call to "JOY" which reads in the present joint position values of the arm by a call to "POS." "JOY" also reads in the commanded x, y, z offsets from the joystick by a call to the assembly language input driver, "ARMIN" and generates the new joint position commands by a call to "COOR" to perform the coordinate transformations. These joint position commands are sent to the arm by a call to "SERVO" which outputs these values to the hardware servos by a call to the assembly language output driver "ARMOUT." In the present system, the location table can store information on 86 different locations. Indexed location names are assigned pointer values of one to 60 (three indexed names are allowed - each containing twenty locations). One arbitrary name for each letter of the alphabet is allowed and assigned pointer values 61 through 86. The last two pointer locations (89 and 90) do not store position information. Instead. the ASCII code for the complete names of the indexed locations reside in these positions.

A pointer to the location table designates a group of four sequential lines of seven positions each. The information stored in these four lines is detailed in Figure 19. Two of the lines are particular for the specific robot executing the application program. They contain the joint indicator values that characterize the position of the arm for that location point.

The other two lines contain information that describe the location in an external X, Y, Z coordinate system. This information is robotindependent in that it can be post-processed by another robot's coordinate transformation routine into joint position values specific for that robot. Therefore, the table of location points, stored in terms of this external coordinate system, can reside in a central control computer to be post processed by the specific coordinate transformation routine of the robot that is to use this location table.



The schematic representation of the interconnections between the subroutines of the ule. LOCTAB monitors the operator's input commands and branches to appropriate Figure 18 - The location module. subroutine calls.

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Line 1	J1 <sub>LP</sub>	J2 <sub>LP</sub>	J3 <sub>LP</sub>	J4 <sub>LP</sub>	յ5 <sub>LP</sub>	J6 <sub>LP</sub>	
Line 2	Х <sub>LP</sub>	Υ <sub>LP</sub>	Z <sub>LP</sub>	i	j	k	STOP FLAG
Line 3	ih	j <sub>h</sub>	<sup>k</sup> h	۵X	ΔY	ΔZ	
Line 4	J1 <sub>APP</sub>	J2 <sub>APP</sub>	<sup>J3</sup> APP	J4 <sub>APP</sub>	J5 <sub>APP</sub>	J6 <sub>APP</sub>	

Pointer XX locates a set of four - 7 element-lines in the location table (LTAB(XX,1-4,1-7)) to completely describe a single location point.

Line 1 and line 4 contain the position values of the six joints to describe the location point and the starting point of the approach path. These two lines will contain values unique to a particular robot's position servos.

The other 2 lines (line 2 and line 3) contain the description of the location point in an external coordinate system system. Line 2 contains a description of the location point in the same format as used by the CLDATA file to store location values. These are the coordinates of  $(X_L, Y_L, Z_L)$  the location point and the i, j, k unit vectors to describe the direction of the handwrist axis (surface normal). This provides a 5 axis description. The 6th axis, the direction of a vector perpendicular to the hand wrist axis and passing through the two finger tips (the hand rotation) is described by the unit vectors i, j, k, in line 3. The delta X, Y, Z distances ( $\Delta X, \Delta Y, \Delta Z$ ) from the location point to the start of the approach path are also contained in line 3. The stop flag, to indicate if the hand comes to a stop at this location (used to decide on acceleration-deceleration profiles) is stored in the seventh position of line 2.

<u>Pointer Value</u>	Name Description
1 - 20	20 pointers allocated for the first indexed location name
21 - 40	20 pointers allocated for the second indexed location name
41 - 60	20 pointers allocated for the third indexed location name
61 - 86	26 pointers allocated for 26 names each starting with a different letter of the alphabet.

Figure 19 - The Location Table representation of a location point.

### III-10
## 2. IMPLEMENTING A NEW FUNCTION

#### 2.1 Subroutine Design

Functions, specified by elemental move commands entered in the program module, are executed by branches to the appropriate subroutine (or sequence of subroutines). Therefore, a new function, such as implementing a new operation using sensor feedback, requires the addition of the user supplied subroutine(s) to accomplish it. In addition, modifications have to be made to two subroutines (LINE, PLINE) in the program module and one subroutine (EMOVE) in the control hierarchy module.

The approach in developing these subroutines that are the primitive functions has been to make them as general as possible. This allows them to be more easily used in sequences to perform other operations as well. To this end, it is also advisable to limit their scope to a very simple action. Again, using sequences of these simple actions to perform more complex actions.

As an example, consider a user requirement to insert a part into a vise where the part is to be pushed against a bottom plate within the vise to properly seat it. A subroutine to accomplish this seating action using a force sensor in the wrist would be written by the user. It might employ a simple algorithm such as:

- (a) read in the sensor value
- (b) if its above a predetermined threshold value go to (e) otherwise continue
- (c) move a defined incremental distance in the -z direction
- (d) go to (a)
- (e) exit subroutine.

This subroutine might be called FORCE. It performs a very limited, simple action. This action in itself is insufficient to accomplish the actual operation (which will be called INSERT). The primitive (RELEAS) to cause the hand to release the part must also be called. This releasing action could have been written into the primitive FORCE but this would have increased the complexity of its actions and thereby narrowed its range of application to other operations.

### 2.2 Control Hierarchy Modification

To implement this new subroutine requires a modification in the control hierarchy's third level (EMOVE) to test for its function code number in the elemental move command input and to branch to its calling statement. Figure 16 shows that code numbers 1 through 9 are presently being used. Therefore, this INSERT operation could be assigned number 10. The value of the function code number is used to control two multiple "GOTO" statements in EMOVE. In this way, the function number acts much as an address to the location of code to execute it. Figure 20 shows how the relevant code is to be modified for this example.

	ł	EMOVE	before modifications (changes handwritten in)
c		FUN=1 Goto(	+ELE(6) 20,20,20,3,4,20,20,7,8,20)FUN 20
	IF	THERE THIS	IS AN APPRUACH PATH, IT IS GENERATED AND EXECUTED BY CALL TO 'STLINE'.
50		CALL IF(EA CALL	STLINE(-LTAB(ELE(2),3,4),-LTAB(ELE(2),3,5),-LTAB(ELE(2),3,6),1) ABORT_LT.=2000)GOTO 40 WAIT(34) //
	тні	S MULI CODE	TIPLE 'GOTO' STATEMENT CAUSES THE BRANCHING TO THE APPROPRIATE TO CARRY OUT THE FUNCTION SPECIFIED. 10 Call Force Call Release (0)
C C	THI	GOTO S IS 1	$\begin{array}{ccc} (110,1,2,3,4,5,6,7,8,110) \\ FUN \\ \hline \\ GOTO \\ 435 \\ \hline \\ HE CODE FOR A 'GRASP PROXIMITY' FUNCTION. THE HAND IS \\ \hline \\ \\ \end{array}$
	V	EMOVE	after modifications
c c		FUN=1 Goto(	+ELE(6) 20,20,20,3,4,20,20,7,8,20,20)FUN
C C	IF	THERE THIS	IS AN APPROACH PATH, IT IS GENERATED AND EXECUTED BY Call to 'Stline'.
20		CALL IF(EA CALL	STLINE(-LTAB(ELE(2),3,4),-LTAB(ELE(2),3,5),-LTAB(ELE(2),3,6),1) BORT.LT2000)GOTU 40 WAIT(34)
	THI	S MULT CODE	IPLE 'GOTO' STATEMENT CAUSES THE BRANCHING TO THE APPROPRIATE TO CARRY OUT THE FUNCTION SPECIFIED,
10		GOTO( CALL CALL CALL GOTO	110,1,2,3,4,5,6,7,8,110,10)FUN FORCE FELEAS(0) STLINE(~OFF(1),=OFF(2),=OFF(3),1) 435
C C	тні	5 1 <b>5 1</b>	HE CODE FOR A 'GRASP PROXIMITY' FUNCTION. THE HAND IS

Figure 20 (a) - Shows the section of code in "EMOVE" before and after the modifications required for the addition of a new function. In this example, the new function code number (10) plus one gives the value of the variable "FUN" used to specify the section of code to be executed through a multiple "GOTO" statement. The code required to execute the "INSERT" function is, first, a call to the user written "FORCE" subroutine to seat the part, a call to "RELEAS" to let go of the part, a call to "STLINE" to move back the distance covered during the "FORCE" subroutine and to branch to statement 435 to test for interlock signals.

LINE before modifications č 'TOUCH' С , change to 66 64 IF(CS(PN), NE, 8276)GOTO 65 ASCIL Code for the PROG(PLN, 6) = 8letter "I". GOTO 81 Ç IF (CS (PN). NE. 8265) GOTO 85 66 С ILINE! PROG (PLN, 6) = 10 C 65 IF(CS(PN), NE, 8268)GOTO (85 GOTO 81 PROG(PLN,6)=9 GOTO 81 C C TEST FOR A 'VELOCITY' COMMAND, IF THERE IS ONE THEN DECODE THE Ç ASCII FORM OF THE SPECIFIED VELOCITY (CM/SEC) BY A

LINE after modifications

I TOUCH!

```
c
c
64
         IF(CS(PN).NE.8276)GOTO 65
         PROG(PLN, 6) = 8
         GOTO 81
```

000 'LINE'

65

C C C

66

C C

```
IF(CS(PN), NE. 8268)GOTO 66
PROG(PLN,6)=9
GOTO 81
```

```
'INSERT'
```

```
IF(CS(PN),NE,8265)GOTO 85
PROG(PLN, 6) = 10
GOTO 81
```

TEST FOR A VELOCITY' COMMAND, IF THERE IS ONE THEN DECODE THE ASCII FORM OF THE SPECIFIED VELOCITY (CM/SEC) BY A

Figure 20 (b) - Shows section of code in "LINE" before and after modifications to code and store the new function command in program table. The additional code is a test for the first letter ("I") of the new function command (INSERT). If an "I" is detected then the appropriate function code number (here, it is a 10) is stored in the sixth position of the present line of the program table.

PLINE before modifications

COMMON/CMD/CS(50). PN. PLN C Change to 11 DIMENSION FN(6,10) 1.0 DATA FN/6\*! 2 'GR', 'AS', P 1,3\*1 1, 'RE', 'LE', 'AS', 'E ',2\*' ۰, 3 4 IGRI, 'AS!, 'P I, 'PRI, 'OX', ! ... 5 'RE', ILE', IAS', IE I, IPR', IOXI, 1, 6 'DE', 'TE', 'CT', 3\*' 7 'BA1, LA1, NC1, E 1,2\*1 2 change to a comma 1, 8 'UN', ISTI, IACI, IK 1,2\*1 . IN , SE , RT 3\*1 9 'TO', 'UC', 'H ', 3\*' 1 !LI!, !NE!,4\*! 1

С С

#### PLINE after modifications

С	С	Μ	Μ	0	N	1	С	Μ	D	1	C	S	(	5	0	)	,	Ρ	N	,	P	L	Ν								
D	1	Μ	Ε	Ν	Ş	Ī	0	Ņ		F	N	(	6	,	1	1	)														
D	A	T	A		F	Ν	/	6	*	Į			ł	,																	
2		ł	G	R	ļ	,	ł	۵	S	ŧ	,	9	P		ł	,	3	*	ł			ł	,								
3		ł	R	Ē	ł	,	I	L	E	ł	0	ł	4	S	ł	,	ł	E		ł	,	2	*	ł			۲	,			
4		ł	G	R	ŧ	,	I	4	S	Į	,	ŧ	P		ŧ	,	Ŧ	Р	R	ļ	,	ł	0	X	ł	,	۲			۲	ş
5		ŧ	R	E	ŧ	,	ł	L	E	ŧ	,	I	۵	S	ŧ	,	ł	E		ł	,	ł	Ρ	R	I	,	ł	۵	X	ŧ	,
6		ł	D	E	ŧ	,	I	T	E	ţ	,	ł	¢	T	ŧ	,	3	×	ł			ļ	,								
7		ŧ	₿	₽	ł	,	ŧ	L	A	ŧ	,	ŧ	N	С	I	,	ł	E		Į	,	2	*	ł			I	,			
8		ł	U	Ň	1	,	ŧ	S	T	ł	,	ŧ	4	C	ł		ļ	K		ł	ø	2	*	ł			ļ	,			
9		Į	T	0	I	,	Ŧ	U	С	ł	,	P	Н		ł	,	3	*	ŧ			I	,								
1		ļ	Ł	I	ļ	,	I	N	E.	ł	,	4	×	ł			ł	,													
1		ŧ	I	Ņ	I	,	ţ	Ş	E	ţ	,	ŧ	R	T	ŧ	,	3	*	I			ł	1								

C C

IF THE FIRST LINE OF THE PROGRAM MODULE IS TO BE PRINTED OUT,

IF THE FIRST LINE OF THE PROGRAM MODULE IS TO BE PRINTED OUT,

Figure 20 (c) - Shows section of code in "PLINE" before and after modifications to cause a print out of the new function name. The array that contains all of the possible function names is enlarged by one line and the letters to be printed out are stored.

2.3 Program Module Modification

Two subroutines (LINE, PLINE) in the program module are to be altered so that the new function command, INSERT, can be recognized and coded into its function number (LINE), and decoded and printed on the terminal (PLINE) by the editor PRINT command. The modifications for this example are illustrated in Figure 20.

## 3. PORTABILITY

The partitioning of the entire control system into a number of modules with well-defined interfaces to the rest of the system results in a large number of the modules being independent of both the robot they are controlling and the computer system they are running on. Those instances where the control system must interface to either the host computer system or to a particular robot can be contained in a limited number of modules. These modules have been identified and it is only these modules that require alteration for portability of the control system (Table 6).

## 3.1 Input Channels

As mentioned before, the operator communicates with the control system through a terminal, a switch panel, and a joystick control box. The values of the switches and the joystick control box are read into an input buffer through a call to the assembly language driver ARMIN. Thus subroutine reads in 64 channels through a 14 bit A/D (Analog to Digital) converter and stores these values in the common variable INBUF(64). This call takes approximately 4 milliseconds to execute (the maximum conversion frequency of the A/D unit is 20 kilohertz). Table 7 provides a summary of the functions of the 64 input channels.

## 3.1.1 Function Switch Panel

The switch panel consists of eight switches which can be set to +5.0 volts or reset to 0.0 volts. These values are read into the computer through the D/A converter with a value -4000 corresponding to a +5.0 volts and zero corresponding to 0.0 volts.

## 3.1.2 Joystick Control Box

The joystick control box uses a joystick in two dimensions actuating two potentiometers to provide the delta offsets in the X and Y direction. The Z motion is provided by two buttons, one for up and one for down. Push buttons also provide control of the wrist roll, wrist flex, hand roll and opening and closing of the fingers. A detailed listing is provided in Table 7.

## 3.1.3 Joint Position Indicator Input

The joint position indicators are also read in through the A/D converter and range from +10 to -10 volts resulting in values of -8383 to +8383 into the computer.

## 3.2 Output Channels

A call to the output driver ARMOUT will cause the values in the first 16 locations in the common variable OUTBUF(64) to be sent to the interface. The system allows 64 output channels but only 16 are presently implemented.

## Table 6

## Non-Portable Functions

These are the subroutines whose functions are tailored to either the host computer's system or the particular robot, and must be modified to allow the control system to be implemented with a different computer or robot.

Subroutine Name	Function
RDMOD	Used to interface control system to host computer's file accessing method. Causes the previously recorded location table and program table to be read from host computer's mass storage into the control system's programs.
RECORD	Causes the program table and location table to be written into the host computer's mass storage system.
ARMIN	An assembly language input driver to read the input values from the system interface and store in a input buffer to be accessed by the control system subroutines.
ARMOUT	An assembly language output driver that sends the values stored in an output buffer to the system interface.
COOR	This is the coordinate transformation routine that allows conversion of X, Y, Z coordinate values into the corresponding joint coordinate values and vice versa for a particular robot. As provided here, only a three axis (two shoulder rotational and a boom prismatic joint) coordinate transformation is done, with the remaining 3 wrist joints pantographing the shoulder moves. This was all that was required for the demonstration using workpieces on a bench top. However, the complete 6 axis coordinate transformation routine is being implemented and is required for complete general purpose programming of the robot.

# Table 7

Listing of the input channels read into the command variable "INBUF(64)" by the call to ARMIN.

INPUT CHANNEL NUMBER	FUNCTION	INPUT VOLTAGE RANGE	CORRESPONDING COMPUTER VALUES
1 2 3			
4 5 6 7	joint #6 position	-10 to +10	8191 to -8191
7 8 9 10	joint #2 position	-10 to +10	8191 to -8191
10	joint #3 position	-10 to +10	8191 to -8191
13	joint #4 position	-10 to +10	8191 to -8191
14 15 16	joint #5 position	-10 to +10	8191 to -8191
17	joint #1 position	-10 to +10	8191 to -8191
19 20 21 22 23 24	joint #7 position	-10 to +10	8191 to -8191
25 26*	trajectory velocity	2.7 to 4.0	-2160 to -3160
27* 28** 29** 30** 31**	control finger grasp-release interrupt-abort enter location edit program store on disc, or display XYZ values	0, 4.6 0, 4.6 0, 4.6 0, 4.6 0, 4.6	0, -3700 0, -3700 0, -3700 0, -3700 0, -3700
32** 33**	joystick control	0, 4.6	0, -3700
34**	pause, or enter location with XYZ values	0, 4.6	0, -3700
35**	start, repeat	0, 4.6	0, -3700

# Table 7 cont.

INPUT CHANNEL NUMBER	FUNCTION	INPUT VOLTAGE RANGE	CORRESPONDING COMPUTER VALUES
36** 37* 38* 39* 40* 41* 42* 43 44 45 46	straight line velocity control wrist roll wrist flex hand roll X motion Y. motion Z motion	0, 4.6 0, 4.6 0, 4.6 .9 to 1.9 .9 to 1.9 0, 4.6	0, -3700 0, -3700 0, -3700 -730 to -1450 -730 to -1450 0, -3700
47 48 49 50 • • •	proximity sensor proximity sensor not used	0 to -10v 0 to -10v	0 to 8191 0 to 8191

\* Joystick Box Input Channels \*\* Switch Panel Input Channels

## 3.2.1 Joint Position Command Outputs

The position command output values to the six joints and the fingers of the robot are sent on the first seven output channels. These channels in the interface unit (see Appendix A for a detailed description of the interface unit) are connected to a digital to analog converter to provide analog signals to the hardware servo system. Output values from the computer range from 0 to 32767 corresponding to the range of +10 volts to -10 volts respectively (with 16383 corresponding to zero volts).

#### 3.2.2 Brake Control Output

Output channel number 8 is used as a digital output for individual control of the seven sets of brakes (one for each joint and one for the fingers). A fifteen bit word is sent out on channel 8 with the first seven bits used as switch values for setting the brakes. With all of the bits equal to one (i.e. the value of the word's 32767), the brakes are released. To set the brake on the fingers, the seventh bit is set to zero. This requires the number 32703 (i.e. 32767-64) to be sent.

#### 3.2.3 Interlock Channels

There are eight additional output channels (numbers 9 thru 16) that can be used either as digital or analog outputs to control other devices or send interlocking signals on. The "SEND" command presently outputs a value(8192) on the specified channel number that results in an analog signal level of +5 volts.

## 4. ADVANTAGES OF HIERARCHICAL CONTROL SYSTEM

A summary listing of the advantages afforded by the hierarchical control system architecture described in this report is given in Table 8.

## Table 8

### Summary of Control System

### (1) The system has been modularized, resulting in:

- (a) easily defineable functional specifications, interfaces, and communications requirements;
- (b) the defining and isolation of those parts of the control system that are specific to the host computer and particular robot;
- (c) relative independence of the robot programs and their standard coordinate location tables from the particular robot, thereby allowing off-line programming as well as location table generating from other data bases such as CLDATA files;
- (d) a control system compatable with the addition or deletion of extra functions, sensors etc. (accomplished with addition or deletion of subroutines along with minor modifications to the existing system);
- (e) quick and simple control system code generation and debugging.
- (2) <u>The system has been structured as a deterministic hierarchy of</u> <u>functional levels resulting in</u>:
  - (a) sophisticated programming techniques using simple higher level language commands to ease and speed program entry, where the hierarchy provides amplification of a single command into the large sequences of detailed steps required to accomplish it;
  - (b) minimal information processing and transfer within and between levels due to the deterministic feature where only a limited set of states are allowed; the hierarchy that provides a fast and efficient method of chosing between these states based on simple tests of input information flags;
  - (c) the ability for real time sensor control of a multiaxis robot on a small computing system; this is due to the simplicity of information processing (described above) which requires a relatively small number of computations allowing the trajectories to be modified in real time in accord with the sensory feedback.

- (3) The control system has been written in FORTRAN IV resulting in:
  - (a) relative portability of the system to other host computers (where the computer-dependent modules have been identified);
  - (b) an ease in understanding of the code due to the simplicity of FORTRAN and its universal use;
  - (c) the ability of the user to add additional features easily by writing his own FORTRAN subroutines;
  - (d) the ability to implement the control system in assembly language on microprocessor or minicomputers since it is a rather straight forward task to cross code FORTRAN statements into assembly language.

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APPENDIX A



#### APPENDIX A

#### Interface Design

Data transfer between the laboratory hardware and the PDP-11/45 minicomputer is handled via a DR11-C interface card in the computer. This card has 16 data input lines, 16 data output lines, two interrupt lines and two sync lines, one (data transmitted) for input synchronization, and one (data present) for output synchronization.

The DR11-C is connected to the laboratory interface by forty parallel wires powered by 7406 line drivers. These are open collector circuits with resistors connected to the power supply voltage at the receiving end.

The laboratory interface hardware consists of two parts: an input section and an output section.

Input:

A sixty four channel analog multiplexer followed by a 14 bit analog to digital converter forms the heart of the input section. This unit has a range -10 volts to +10 volts. Negative voltages are converted to 2's complement form.

Output from the A/D converter is carried to the computer on the 16 data input lines. Since the A/D converter has only a 14 bit output, the most significant (sign) bit is connected to the three most significant computer input lines. This causes the computer to read the correct values for both positive and negative (2's complement) numbers.

Data transfer between the A/D converter and the computer is signaled by a pulse on the data transmitted line. This pulse, initiated by the computer, indicates that the data lines have been sampled. This data transmitted pulse is used to step the analog multiplexer to the next input and to initiate the analog to digital conversion cycle on the new input input voltage. The input software is timed to sample the input data at a rate slower than the conversion rate of the A/D system. Thus, a "conversion completed" signed is not required by the computer, and only one control line is needed to advance the converter to the next channel.

The multiplexer is operated in a sequential mode. It is reset to the zeroth channel by a reset pulse derived from the output section. Each data transmitted pulse steps the multiplexer to the next sequential channel. The input section is therefore completely under computer control.

#### Output:

A sixteen channel digital demultiplexer routes output signals from the DR11-C to sixteen holding registers. These provide either digital output directly, or are connected to digital to analog converter so as to provide analog voltages. Data transfer between the DR11-C and the output section is initiated by a pulse on the data present line. The data present pulse occurs simultaneously with the appearance of data on the DR11-C output lines. This pulse is delayed in the laboratory interface hardware for two microseconds before actuating the digital demultiplexer so as to allow the data lines time to settle. The delayed data present pulse gates the output data into the selected holding register and then steps the address counter to the next address.

The most significant (sign) bit of the output is decoded as a reset signal and is used to set the demultiplexer address counter to Channel 1 as well as to reset the analog multiplexer address in the input section.

Using the sign bit for control means that only 15 bits of output are available for data. Numerical output is restricted to the range 0 to 32,767. The digital to analog converters are adjusted such that numerica 0 corresponds to +10 volts; 16,384 corresponds to zero volts, and 32,767 corresponds to -10 volts.

#### Comments

This report describes an architecture for a control system. Its emphasis has been on the partitioning of the control system into a hierarchy of functional levels. This approach provides a way of thinking about the problem that has been very instructive to us. Of course, the decomposition of a problem or task into sequences of simpler actions is a very old technique. Indeed, it is an implicit fundamental method used by human beings in almost all things they do. So, in that sense, the use of a hierarchical design for a robot control system is hardly a novel idea.

However, instead of the hierarchy being implicit in our approach we have made it the explicit starting frame work. The benefits that we feel have derived from this are many and several have been discussed in the report.

The control system actually implemented in this report is a minimum configuration for a robot performing simple manipulative tasks. It is provided here as an example of how to construct a sensory interactive, goal directed control system when one uses a hierarchical framework to structure the problem. It also demonstrates the ease of greatly increasing control capabilities by the addition of higher levels in the hierarchy while retaining the already developed lower levels. Thus, the system is upwards compatible to almost any degree of complexity of behavior.

Increases in complexity of behavior will usually require increasingly complex sensory data processing such as might occur with force or low level vision. We view the sensory processing required occuring in an ascending hierarchy parallel to the descending control hierarchy with the exchange of differing degrees of processed information between these two hierarchies at all levels. Thus, the control hierarchy will continue to make simple tests on sensory feedback input and branch to appropriate programmed responses regardless of the complexity of the sensory data processing.

This sensory data processing will be occuring in the sensor feedback hierarchy not in the control hierarchy.

#### USE OF MICROPROCESSORS

One of the major points of this approach has been the partitioning of a sensory interactive control system into a number of functional ' levels. Implicit in this, is the idea that each of these function modules is an independent system, operating all the time, communicating to other control or sensory modules through standard interfaces anytime it needs to receive or send information. The use of a single computer severely restricts this type of system. These modules can be made to appear to be independent and parallel through complex software manipulation such as real time multi-tasking operating systems on a serial computer. But even a fast computer soon runs out of time to perform all the functions as the requirements of the control system increase.

The obvious solution is for each level of the hierarchies to reside in an inexpensive microprocessor. Information to be exchanged would be placed in common memory. Several levels might be combined into one microprocessor depending on the simplicity of and number of functions to be handled. A separate microprocessor could be allocated for the coordinate transformation routine and one for safety and error checking routines. Future development work will address the use of microprocessors in these hierarchical network structures.

#### PROGRAMMING STRATEGY

This report presents not only a philosophical approach to the design of a control system but also the documented FORTRAN programs that implement a minimum configuration sensory interactive control system. This has been done to provide both a concrete example of a hierarchical control system and a starting point for anyone wishing to pursue robot control system development.

Both the programs and techniques of data handling can be improved and will be. The programming approach has been to make the system as table driven as possible, to make the applications programs as totally separate from the data as possible. We are updating the system in an attempt to realize these goals.

As new levels, functions, and sensors are added and programming techniques are improved, additional reports will be written and distributed.

# Control Hierarchy (Module #1)

EX	PR0	-	Executive program to oversee entire	DT-2
RD	MOD	-	Reads in Program Table and Location	
RE	CORD	_	Table for disc. Stores Program Table and Location Table	DT <del>-</del> 8
CA			on disc.	DI-10
SH	MPLE	-	or Location module.	DI-12
3rd Lev	el of	Coi	ntrol Hierarchy	
EM	OVE	-	Calls appropriate primitives for each elemental move command.	DI-16
2nd Lev	el of	Cor	ntrol Hierarchy	
ST	LINE	-	Generates a straight line motion.	DI-24
WA	IT	-	Suspends execution and waits for an input signal.	DI <b>-</b> 30
CA	LD	-	Calculates the distance between two	DT 20
PO	L	-	Calculates the delta joint values for an	D1-32
AC	C	_	interpolated trajectory.	DI <del>-</del> 36
	TFOT		values from POL.	DI-40
DE	IECI	-	Uses proximity sensors to detect presence of object.	DI-44
BA	L	-	Uses proximity sensors to center hand over	יי דת
GR	ASP	-	Causes fingers to close with a defined force.	DI-40 DI-52
RE	LEAS	-	Causes fingers to open completely.	DI <b>-</b> 56
			object.	DI-58
CO	OR	-	Transforms external coordinates into joint coordinates and vice versa.	DI <b>-</b> 62
lst Lev	el of	Cor	ntrol Hierarchy	
SE	RVO	-	Outputs joint position commands through	
. ΔD	MOUT		ARMOUT.	DI <b>-</b> 66
AK		_	to interface.	DI-70
AR	MIN	-	Input driver that stores input values in a buffer.	DI-71



DI-2

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PROGRAM : EXPRO	
ARGUMENTS :	
CALLED BY :	
CALLS SUBROUTINES : RDMO	D SAMPLE ARMIN SERVO EMOVE WAIT
INPUT DATA : LTAB(90,3,6	) = THE PRESENT LOCATION TABLE MODULE THAT IS EITHER READ IN FROM THE DISC BY 'RDMOD' OR IS UPDATED BY A CALL TO 'SAMPLE'
PROG(105,6)	= THE PRESENT PROGRAM MODULE THAT IS EITHER READ IN FROM THE DISC BY 'RDMOD' OR IS UPDATED BY A CALL TO 'SAMPLE'
SW-35	INPUT SWITCH -35- WHOSE VALUE IS EITHER O OR -4000 (O TO +5 VOLTS). THIS SWITCH IS USED TO HOLD THE PROGRAM IN AN INITIAL STATE UNTIL EXECUTION WHICH IS SIGNALED BY FLIPPING THIS SWITCH TO THE UP POSITION. THIS SWITCH IS ALSO USED TO INDICATE WHETHER THE PROGRAM IS TO BE EXECUTED ONCE OR REPEATEDLY.
SW-28	THE VALUE OF THIS SWITCH IS SET EQUAL TO THE VARIABLE 'EABORT' AND IS USED AS AN ABORT SWITCH WHICH STOPS THE EXECUTION OF THE PROGRAM AND CALLS 'SAMPLE'. THIS ALLOWS THE MODIFICATION OF THE PROGRAM MODULE, THE LOCATION TABLE MODULE, THE STORING OF THESE TWO MODULES ON DISC, AND THE RETURN TO EXECUTION OF THE PROGRAM AT ANY SPECIFIED LINE IN THE PROGRAM MODULE.
LL	= THE SPECIFIED LINE OF THE PROGRAM
KK	= FLAG RETURNED FROM A CALL TO 'SAMPLE' TO INDICATE IF A RE-ENTRY TO A PARTICULAR LINE IS DESIRED.
OUTPUT DATA : ELE(6)	= THE VALUES OF THE LOCATION TABLE POINTERS AND THE FUNCTION FLAGS FOR LINE 'LL' OF THE PROGRAM MODULE (AN 'FLEMENTAL MOVE' COMMAND)
КК	= FLAG USED TO INDICATE WHETHER THE CALL TO 'EMOVE' IS FOR THE EXECUTION OF A LINE IN THE PROGRAM MODULE (KK=O), OR THAT EXECUTION IS TO BEGIN AT AT LINE 'LL' IN THE PROGRAM MODULE WITH THE ARM STARTING AT SOME ARBITRARY LOCATION. COMES FROM THE CALL TO 'SAMPLE' WHERE RE-ENTRY INTO THE EXECUTION OF THE PROGRAM MODULE IS SPECIFIED TO BE AT LINE 'LL' AND THE PRESENT LOCATION OF THE ARM MIGHT BE ANYWHERE IN ITS WORKING SPACE. (KK=1).

С			
C C C C C C C C C	-	Fι	JNCTION: SUPPLIES THE THIRD LEVEL OF THE HIERARCHY WITH AN ELEMENTAL MOVE COMMAND, IE. REQUESTS THE EXECUTION OF A SINGLE LINE OF THE PROGRAM MODULE. ALSO, ALLOWS THE ENTERING OF NEW PROGRAM LINES AND LOCATION POINTS, AND INITIALIZING THE SYSTEM TO BEGIN EXECUTION.
6			<pre>IMPLICIT INTEGER (B-Z) COMMON/ARMBUF/INBUF(64),OUTBUF(64) COMMON/STEP/LL COMMON/LMOD/LTAB(90,4,7),PRES,DEST COMMON/PMOD/PROG(105,6),ENDP,BRNCH(6),M COMMON/OUT/JPOS(8) COMMON/EM/ELE(6) EQUIVALENCE(EABORT,INBUF(28))</pre>
C C	IN	III	TIALIZE THE FLAG 'KK'.
c			K K = 0
C C C C	Τŀ	HIS	S SUBROUTINE ('RDMOD') READS THE PROGRAM MODULE AND THE LOCATION TABLE MODULE FROM THE DISC AND STORES THEM IN THE MATRICES PROG(105,6) AND LTAB(90,3,6).
0			CALL RDMOD(1,0)
С С С С	Τŀ	IIS	S ROUTINE ALLOWS THE ENTRY OF NEW PROGRAM LINES AND LOCATION POINTS, AND ALLOWS A RE-ENTRY INTO THE EXECUTION OF THE PROGRAM AT A SPECIFIED LINE 'LL'.
3400 C	)		CALL SAMPLE(1) GOTO 4000 CALL SAMPLE(0) IF(LL.LE.0)GOTO 4000 KK=1 GOTO 301
с с с	A	RE	EQUEST IS MADE FOR THE OPERATOR TO FLIP SW-35 TO THE DOWN POSITION SO THAT THE STARTING LOCATION JOINT POSITION VALUES CAN BE SENT TO THE SERVOS.
4000 4001 5000			WRITE(6,4001) FORMAT(8X'SW 35 DOWN AND',/ 1 8X'***TYPE [CR]***TO INITIALIZE THE SERVOS WITH THE ',/ 1 24X'STARTING LOCATION.') READ(6,5000)FHH FORMAT(I3)
	Τŀ	ΗE	INPUTS ARE READ INTO THE COMPUTER AND SW-28 (THE 'ABORT' SWITCH IS CHECKED TO SEE IF IT HAS BEEN SET. IF IT HAS, THEN RETURN TO THE ROUTINE 'SAMPLE' TO DETERMINE WHAT ACTION SHOULD BE TAKEN.
U			CALL ARMIN IF(EABORT.LT2000)GOTO 3400

С INSTRUCT THE OPERATOR TO NOW TURN ON THE SERVOS. AND THAT С С SW-35 IS TO BE FLIPPED UP TO BEGIN EXECUTION OF THE PROGRAM. С WRITE(6,4002) 4002 FORMAT(8X'TURN ON SERVOS, ',/ 1 8X'---SW 35 UP---TO EXECUTE PROGRAM.',/ 1 8X'LEAVE --- SW 35 UP--- FOR REPEATED EXECUTION.') С С SET THE VARIABLE 'M' EQUAL TO THE NUMBER OF EXECUTABLE LINES IN THE С PROGRAM. С С С SET THE VARIABLE 'FR' EQUAL TO THE LOCATION TABLE POINTER С FOR THE STARTING LOCATION OF THE PROGRAM. SEND OUT THE JOINT POSITION VALUES FOR THIS LOCATION TO THE SERVOS, AND С С WAIT UNTIL SW-35 IS FLIPPED UP BEFORE CONTINUING WITH С THE EXECUTION OF THE PROGRAM. С FR = PROG(1, 1)DO 200 FRR=1,6 200 JPOS(FRR)=LTAB(FR, 1, FRR) CALL SERVO(0) CALL ARMIN IF(EABORT.LT.-2000)GOTO 3400 CALL WAIT(35) С С PLACE THE VALUES (LOCATION TABLE POINTERS AND FUNCTON FLAGS) С OF THE PROGRAM LINE 'LL' INTO THE MATRIX 'ELE(6)'. THIS IS AN C 'ELEMENTAL MOVE' THAT WILL BE USED AS A COMMAND TO THE THIRD LEVEL OF THE CONTROL SYSTEM BY A CALL TO 'EMOVE'. С С 305 LL = 1301 DO 202 J=1,6 ELE(J) = PROG(LL, J)202 С С TEST TO ASCERTAIN THAT BOTH A PRESENT LOCATION (ELE(1)) AND A С DESTINATION (ELE(2)) POINTER ARE AVAILABLE. IF NOT, THEN С PRINT OUT AN ERROR MESSAGE ON THE TERMINAL AND RETURN TO С THE SUBROUTINE 'SAMPLE' TO DETERMINE WHAT IS TO BE DONE NEXT. С IF(LTAB(ELE(1), 1, 1).EQ.0)GOTO 100 IF(LTAB(ELE(2),1,1).NE.0)GOTO 300 100 WRITE(6,101) FORMAT(8X'PROGRAM HAS NO LOCATION VALUE --- ',/ 101 GOTO 3400 С THIS SUBROUTINE CALL CAUSES THE EXECUTION OF A SINGLE PROGRAM C С MODULE LINE ('ELEMENTAL MOVE' COMMAND). С 300 CALL EMOVE(KK) KK = 0С С THE INTERRUPT SWITCH 28 ('EABORT') IS CHECKED TO С SEE IF IT IS SET.

С	
	IF(EABORT.LT2000)GOTO 3400
С	
С	THE PROGRAM LINE COUNTER ('LL') IS INCREMENTED. IF THIS VALUE DOES
С	NOT EXCEED THE LAST EXECUTABLE LINE, THEN JUMP BACK TO
С	STATEMENT 301 TO CARRY OUT ITS EXECUTION.
С	
	LL = LL + 1
	IF(PROG(LL,2).NE.0)GOTO 301
С	
С	NCE THE ENTIRE PROGRAM HAS BEEN EXECUTED, THEN TEST SWITCH 35. IF
С	IT IS UP THEN REPEAT THE PROGRAM. IF IT IS DOWN, THEN SIT
С	HERE AND CONTINUE MONITORING IT.
С	
	CALL WAIT(35)
С	
C C	BRANCH BACK TO STATEMENT 305 TO BEGIN EXECUTION.
	GOTO 305
	END





**RE TURN** 

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С --- SUBROUTINE : RDMOD С С --- ARGUMENTS : LTM = IF LTM=1 READ THE LOCATION TABLE MODULE С OFF THE DISC AND STORE IN THE MATRIX 'LTAB(90,4,7)'. С С IF LTM=0 DO NOT READ IN THE LOCATION С TABLE MODULE FROM THE DISC. READ THE PROGRAM MODULE IN С ΡM = IF PM = 1С FROM THE DISC AND STORE IN THE С MATRIX 'PROG(105,6)'. С IF PM = 0DO NOT READ IN THE PROGRAM С MODULE FROM THE DISC. С С --- CALLED BY : EXPRO С С --- CALLS SUBROUTINES : С С THE PROGRAM MODULE ASSIGNED TO DEVICE NUMBER 7. --- INPUT DATA : С AND THE LOCATION TABLE MODULE ASSIGNED TO DEVICE С NUMBER 4. С С --- OUTPUT DATA : PROG(105,6) = THE MATRIX CONTAINING THE С PROGRAM MODULE. С NTAB(90,4,7) = THE MATRIX CONTAINING THE С LOCATION TABLE MODULE. С ENDP = THE PROGRAM MODULE LINE NUMBER С OF THE LAST ELEMENTAL MOVE С С --- FUNCTION: READS IN THE PROGRAM MODULE AND THE LOCATION С TABLE MODULE FROM THE DISC AND STORES THEM С IN THEIR PROPER MATRICES IN THE COMMON BLOCK. С SUBROUTINE RDMOD(LTM, PM) IMPLICIT INTEGER (B-R), (U-Z) COMMON/LMOD/LTAB(90,4,7), PRES, DEST COMMON/PMOD/PROG(105,6), ENDP, BRNCH(6), M С С TEST IF 'PM' SET EQUAL TO ONE. IF IT IS, THEN READ IN С THE PROGRAM MODULE ASSIGNED TO DEVICE NUMBER 7 FROM THE С DISC. С IF(PM.NE.1)GOTO 400 DO 15 JK=1,105 READ(7, 15, END=100)(PROG(JK, J), J=1, 6)15 FORMAT(6(2X, 16))100 CONTINUE С С TEST IF 'LTM' SET EQUAL TO ONE. IF IT IS, THEN READ IN С THE LOCATION TABLE MODULE ASSIGNED TO DEVICE NUMBER 4 С FROM THE DISC. С 400 IF(LTM.NE.1)GOTO 40 DO 14 JB=1,90 DO 14 JC=1,4 READ(4, 14, END = 40)(LTAB(JB, JC, J), J = 1, 7)14 FORMAT(7(2X, 16))40 RETURN END



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DI-10

--- SUBROUTINE : RECORD С С C --- ARGUMENTS : LTM = IF LTM=1 STORE THE LOCATION TABLE MODULE С (LTAB(90,4,7)) ON THE DISC UNDER С THE NAME ASSIGNED TO DEVICE 2. С IF LTM=0 DO NOT STORE THE LOCATION TABLE С ON THE DISC. C C PM = IF STORE THE PROGRAM MODULE PM = 1(PROG(105,6)) ON THE DISC UNDER С THE NAME ASSIGNED TO DEVICE 3. С DO NOT STORE THE PROGRAM MODULE ON PM = 0С THE DISC. С С --- CALLED BY : PROGS SAMPLE С С --- CALLS SUBROUTINES : С --- INPUT DATA : NTAB(90,4,7) = THE MATRIX CONTAINING THE LOCATION С С TABLE MODULE. С PROG(105,6) = THE MATRIX CONTAINING THE PROGRAM С MODULE. С С --- OUTPUT DATA : THE LOCATION TABLE MODULE STORED ON DISC UNDER С THE NAME ASSIGNED TO DEVICE 2. С THE PROGRAM MODULE STORED ON THE DISC UNDER THE С NAME ASSIGNED TO DEVICE 3. С С --- FUNCTION: STORES THE LOCATION TABLE MODULE (LTAB(90,4,7)) AND С THE PROGRAM MODULE (PROG(105,6)) ON DISC UNDER С ASSIGNED NAMES. С SUBROUTINE RECORD(LTM, PM) IMPLICIT INTEGER(B-Z) COMMON/LMOD/LTAB(90,4,7), PRES, DEST COMMON/PMOD/PROG(105,6), ENDP, BRNCH(6), M С С TEST IF 'PM' SET EQUAL TO ONE. IF IT IS, THEN WRITE THE С PROGRAM MODULE ONTO THE DISC. С IF(PM.NE.1)GOTO 400 DO 15 JK=1,105 WRITE(3, 15)(PROG(JK, J), J=1, 6)15 FORMAT(6(2X, 16))END FILE 3 С С TEST IF 'LTM' SET EQUAL TO ONE. IF IT IS, THEN WRITE THE С LOCATION TABLE MODULE ONTO THE DISC. С 400 IF(LTM.NE.1)GOTO 40 DO 14 JB=1,90 DO 14 JC=1,4 WRITE(2, 14)(LTAB(JB, JC, J), J=1, 7)14 FORMAT(7(2X, I6))END FILE 2 40 RETURN END



C --- SUBROUTINE : SAMPLE С C --- ARGUMENTS : KG = USED AS A FLAG TO CHOOSE THE MESSAGES TO BE PRINTED OUT ON THE TERMINAL. С С С --- CALLED BY : EXPRO С С --- CALLS SUBROUTINES : ARMIN LOCTAB PROGS RECORD PLINE С C --- INPUT DATA : LL = THE PRESENT PROGRAM LINE NUMBER THAT IS С BEING EXECUTED. С INBUF(28) = THE ABORT SWITCH VALUE. С INBUF(29) = THE VALUE OF THE SWITCH THAT IS USED FOR С CALLING UP THE TEACH LOCATION POINT С PROGRAMS. С INBUF(30) = THE VALUE OF THE SWITCH THAT IS USED FOR С CALLING UP THE ROUTINES FOR ENTERING С A PROGRAM. С INBUF(31) = THE VALUE OF THE SWITCH USED TOС INDICATE IF THE PROGRAM MODULE AND THE С LOCATION TABLE MODULE ARE TO BE STORED ON С DISC. С --- OUTPUT DATA : LL С = THE NUMBER OF THE PROGRAM LINE TO BE С EXECUTED NEXT. С С --- FUNCTION: THIS PROGRAM IS CALLED BY THE ABORT SWITCH AND ALLOWS С THE ENTRY OF NEW OR MODIFIED LOCATION VALUES, THE EDITING OF THE PROGRAM MODULE, THE STORING OF THE NEW С С LOCATION TABLE MODULE AND PROGRAM MODULE ON DISC, AND С THE ABILITY TO RETURN TO THE EXECUTION PROGRAM С AT ANY LINE IN THE PROGRAM MODULE. С SUBROUTINE SAMPLE(KG) IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64), OUTBUF(64) COMMON/PMOD/PROG(105,6), ENDP, BRNCH(6), M COMMON/IND/IN(30), FL(6), NAME(3), NPT(3, 20) COMMON/STEP/LL EQUIVALENCE(EABORT, INBUF(28)) С С TEST ARGUMENT 'KG', IF EQUAL TO ZERO, THEN SKIP NEXT MESSAGE. С 5000 IF(KG.EQ.0)GOTO 6000 WRITE(6,6240) 6240 FORMAT(8X'---SW 28 UP--- INTERRUPTS RUN PROGRAM') GOTO 6235 С С PRINT OUT PRESENT PROGRAM LINE NUMBER AND PRINT OUT THE ENGLISH С TEXT OF THIS LINE AS THE ORIGINAL 'GOTO' STATEMENT. С 6000 WRITE(6,6200)LL 6200 FORMAT(8X'YOU ARE AT PROGRAM STEP', 14) IF(LL.EQ.0)GOTO 425 MR = 0DO 204 J=101,105

```
DO 204 L=1,6
        MR = MR + 1
.204
        IN(MR) = PROG(J,L)
        CALL INDEX(1)
        CALL PLINE(LL)
С
    PRINTS OUT ON TERMINAL THE VARIOUS OPERATIONS AVAILABLE TO THE USER.
С
С
425
        WRITE(6,6201)
        FORMAT(8X'---SW 28 UP--- RETURNS PROGRAM TO BEGINNING')
6201
        WRITE(6,6225)
6235
        FORMAT(8X'---SW 29 UP--- TEACH LOCATION',/
6225
        1 8X'---SW 30 UP--- RECORD PROGRAM SEQUENCE',/
        1 8X'---SW 31 UP--- STORE LOCATION TABLE ON DISC',/
        1 8X'***TYPE (CR)*** TO CONTINUE')
        READ(6,6001)TR
6001
        FORMAT(I4)
С
С
    READS IN THE SWITCH VALUES TO DETERMINE WHICH IS THE PROPER SUBROUTINE
С
        TO BRANCH TO.
С
        CALL ARMIN
        DO 6203 J=1,4
        K = 27 + J
        CHKV=IABS(INBUF(K))
        IF(CHKV.GT.2000)GOTO(45,11,12,13)J
6203
        CONTINUE
        GOTO 45
        CALL LOCTAB
11
        GOTO 5000
12
        CALL PROGS
        GOTO 5000
        CALL RECORD(1,0)
13
        WRITE(6,225)
225
        FORMAT(2X'LOCATION TABLE STORED')
        GOTO 5000
45
        IF(KG.EQ.1)GOTO 40
        WRITE(6, 6220)
6220
        FORMAT(8X'WHICH PROGRAM STEP DO YOU WANT?')
        READ(6,6221)LL
6221
        FORMAT(14)
40
        RETURN
        END
```





DI-16
С --- SUBROUTINE : EMOVE С С --- ARGUMENTS : KK = IF KK = 1THEN THE STRAIGHT LINE DISTANCE С FROM THE PRESENT LOCATION OF THE С ARM WHICH MIGHT BE POSITIONED С ANYWHERE IN THE WORK SPACE, TO THE С DESTINATION SPECIFIED IN THE GIVEN С LINE OF THE PROGRAM MODULE IS CALCULATED С AND USED AS THE TRAJECTORY FOR THIS С COMMANDED 'ELEMENTAL MOVE'. С THE TRAJECTORY IS ASSUMED TO BE BETWEEN IF KK=0C THE TWO LOCATION TABLE POINTERS SPECIFIED С BY THE 'ELEMENTAL MOVE' COMMAND (ELE(6)). С IE. THE ACTUAL LOCATION OF THE ARM IS С CONSIDERED TO BE THE SAME AS THAT DEFINED С BY THE JOINT POSITION VALUES OF С THE 'PRESENT LOCATION'POINTER С IN THIS ELEMENTAL MOVE COMMAND. С С --- CALLED BY : RUNPRO С С --- CALLS SUBROUTINES : STLINE WAIT GRASP POS POL DETECT С RELEAS PTOUCH COOR BAL SERVO CALD ACC С С --- INPUT DATA : KK = THE FLAG THAT INDICATES WHETHER OR С NOT THE ACTUAL LOCATION OF THE ARM С IS AT THE LOCATION SPECIFIED BY THE С 'PRESENT LOCATION' POINTER (ELE(1)) С FROM THE ELEMENTAL MOVE COMMAND. С = THE ABORT SWITCH ('EABORT') USED TO SW-28 С BRANCH THE CONTROL SYSTEM BACK TO С THE SUBROUTINE 'SAMPLE' TO ALLOW С MODIFICATION OF THE PROGRAM OR С LOCATION TABLE MODULES AND RE-ENTRY INTO С THE PROGRAM AT A SPECIFIED LINE. С ELE(6) = THE MATRIX THAT CONTAINS A SINGLE С 'ELEMENTAL MOVE' COMMAND, IE. THE LOCATION С TABLE POINTERS FOR THE 'PRESENT LOCATION', THE 'DESTINATION', THE VALUE OF THE С С VELOCITY INDICATOR, AND THE VARIOUS С FUNCTION FLAGS. С С --- OUTPUT DATA : THE PROPER SEQUENCE OF CALLS TO THE NECESSARY С SUBROUTINES ('PRIMITIVES') TO CARRY OUT THE С 'ELEMENTAL MOVE' COMMAND. С С --- FUNCTION: FROM THE INFORMATION CONTAINED IN A SINGLE LINE С FROM THE PROGRAM MODULE, THIS SUBROUTINE, С WHICH IS THE THIRD LEVEL OF THE CONTROL HIERARCHY, С CALLS THE SUBROUTINES (PRIMITIVES) TO GENERATE A С TRAJECTORY BETWEEN THE TWO LOCATIONS SPECIFIED, С CAUSES THE ARM TO MOVE ALONG THIS TRAJECTORY AT A GIVEN VELOCITY, AND TESTS ON THE FUNCTION С FLAGS AND CALLS SUBROUTINES IN ACCORD WITH С С THE VALUES DETECTED. С

<pre>SUBROUTINE EMOVE(KK) IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64),OUTBUF(64) COMMON/GRIP/HAND COMMON/LMOD/LTAB(90,4,7),PRES,DEST COMMON/OUT/JPOS(8) COMMON/EM/ELE(6) COMMON/EM/ELE(6) COMMON/OFFS/OFF(3) COMMON/OFFS/OFF(3) COMMON/CORT/AC(6),AXEP,AYEP,AZEP COMMON/END/PNT EQUIVALENCE(NPO,INBUF(33)) EQUIVALENCE(EABORT,INBUF(28))</pre>
A CALL TO 'SERVO(-1)' IS MADE TO RESET ALL OF THE OUTPUT CHANNEL LEVELS TO ZERO.
CALL SERVO(-1)
THE COORDINATE OFFSET VALUES THAT ARE USED IN THE SENSOR SUBROUTINE CALLS ARE SET EQUAL TO ZERO.
DO 70 J=1,3 OFF(J)=0
TESTS ON THE FLAG 'KK' AND IF SET, JUMPS THE APPROACH PATH CALCULATION.
IF(KK.EQ.1)GOTO 220
TESTS THE FLAG TO SEE IF THE ARM STOPPED AT THE PRESENT LOCATION IF IT DID (LTAB(ELE(1),2,7)=1), THEN CONTINUE. IF IT DID NOT STOP(LTAB(ELE(1),2,7)=0), THEN JUMP OVER THE APPROACH PATH CALCULATION (IT IS ASSUMED THAT THERE IS NO APPROACH PATH FOR THOSE LOCATIONS THAT THE ARM DOES NOT STOP AT).
IF(LTAB(ELE(1),2,7).EQ.0)GOTO 220
THE FOLLOWING SUBROUTINE ('STLINE') GENERATES A STRAIGHT LINE PATH FROM ITS PRESENT LOCATION TO A POINT A DELTA X, DELTA Y, DELTA Z DISTANCE AWAY (THE DELTAS ARE LISTED AS ARGUMENTS). HERE IT IS USED TO GENERATE THE SPECIFIED APPROACH PATH FOR THE 'PRESENT LOCATION' POINT.
CALL STLINE(LTAB(ELE(1),3,4),LTAB(ELE(1),3,5),LTAB(ELE(1),3,6),1)
'EABORT' IS THE EQUIVALENT VALUE OF SWITCH 28 WHICH IS USED TO ABORT THE EXECUTION OF THE PROGRAM AND RETURN TO THE SUBROUTINE 'SAMPLE'. THIS VALUE IS CHECKED CONSTANTLY IN THE SUBROUTINE 'SERVO' AND AFTER EVERY SUBROUTINE CALL THAT RESULTS IN A CALL TO 'SERVO' (IE. EVERY TIME THE ARM IS COMMANDED TO MOVE)>
IF(EABORT.LT2000)GOTO 40
THE FUNCTON FLAG IS CHECKED TO SEE IF IT IS A 'GRASP PROXIMITY' (ELE(6)=3). IF IT IS, THEN CALL 'GRASP' TO CLOSE THE FINGERS FOR A SEARCH.

C C C C

C C C C

70 C C C

C C C C C C C

C C C C C C C

C C C C C C C

C C C C 220 IF(ELE(6).NE.3)GOTO 230 CALL GRASP(1)

С

C C

С

C 230

C C

С

С

С

С

С

C C

С

С

C 301

C C

С

С

С

С

С

С

C C

С

С

C C

С

С

C C

C C

С

С

С

С

С

C

C 300

- IF THE FUNCTION 'STRAIGHT LINE' IS CALLED FOR (ELE(6)=9), THEN BRANCH TO THE SUBROUTINE CALLS 'POS' AND 'STLINE'.
  - IF(ELE(6).EQ.9)GOTO 301
- THE ARGUMENT 'KK' IS CHECKED TO SEE IF THE TRAJECTORY IS TO BE A STRAIGHT LINE FROM THE PRESENT LOCATION OF THE ARM TO THE DESTINATION CALLED FOR IN PROGRAM LINE 'LL' (KK=1), OR IF IT IS TO BE LINEAR INTERPOLATION PATH BETWEEN THE TWO LOCATIONS SPECIFIED IN THE PROGRAM LINE 'LL' (KK=0).

IF(KK.NE.1)GOTO 300

- TO GENERATE A STRAIGHT LINE TRAJECTORY FROM THE PRESENT LOCATION OF THE ARM, THE SUBROUTINE 'POS' IS CALLED TO READ IN THE PRESENT JOINT POSITION VALUES TO BE USED BY 'STLINE'.
  - CALL POS
- THIS SUBROUTINE ('STLINE(DX,DY,DZ,I)') GENERATES AND EXECUTES A STRAIGHT LINE TRAJECTORY BETWEEN TWO LOCATION POINTS. IF THE ARGUMENT 'I' IS SET EQUAL TO ZERO, THEN THE STRAIGHT LINE IS GENERATED BETWEEN THE PRESENT LOCATION OF THE ARM (WHICH MAY OR MAY NOT BE DEFINED IN THE 'LOCATION TABLE MODULE') AND THE START OF THE APPROACH PATH OF THE 'DESTINATION' POINT LISTED IN THE 'ELEMENTAL MOVE' COMMAND (LINE 'LL' OF THE PROGRAM MODULE). IF 'I' IS SET EQUAL TO ONE, THEN THE STRAIGHT LINE TRAJECTORY IS FROM THE PRESENT LOCATION OF THE ARM TO A LOCATION POINT 'DX', 'DY', 'DZ' AWAY.

CALL STLINE(0,0,0,0)

IF A STRAIGHT LINE TRAJECTORY HAS BEEN USED THEN THE INTERPOLATION CALCULATION IS SKIPPED.

GOTO 325

IF A STRAIGHT LINE IS NOT GENERATED, THEN THE INTERPOLATION ROUTINE IS USED. HERE, 'CALD' IS CALLED TO CALCULATE THE STRAIGHT LINE DISTANCE (IN CENTIMETERS) BETWEEN THE PRESENT LOCATION OF THE ARM AND THE START OF THE APPROACH PATH FOR THE DESTINATION POINT. 'POL' IS THEN CALLED TO CALCULATE THE CORRECT DELTAS FOR EACH JOINT TO BE USED BY 'ACC' TO CAUSE THE JOINT POSITION COMMANDS TO BE INCREMENTED BY THESE DELTAS AT PERIODIC TIMES TO GENERATE THE SPECIFIED VELOCITY AND ACCELERATION AND DECCELERATION WHERE REQUIRED.

CALL CALD CALL POL

- CALL ACC
- C C
- THIS SWITCH IS EXPLAINED ABOVE.

C 325 C

С

С

С

С

С

С

C C

С

С

C C

С

С

С

С

С

С

С

С

С

С

IF(EABORT.LT.-2000)GOTO 40

C AT THIS POINT IN THE EXECUTION, THE ARM HAS ALREADY ACCOMPLISHED ITS C TRAJECTORY MOTION BY THE ABOVE SUBROUTINE CALLS. C IT NOW REMAINS TO MOVE THROUGH THE FINAL APPROACH PATH IF ONE IS C CALLED FOR, AND TO DETERMINE WHAT FUNCTIONS ARE TO BE C ACCOMPLISHED. FIRST, IT IS DETERMINED IF THE ARM C WILL STOP AT THE END OF THIS TRAJECTORY (LTAB(ELE(2),2,1)=1). C IF NOT, THEN RETURN TO THE CALLING PROGRAM.

- 400 IF(LTAB(ELE(2),2,7).EQ.0)GOTO 40
- С THE COMMON VARIABLE 'PNT' IS SET EQUAL TO ONE. THIS FLAG IS С USED BY THE SUBROUTINE 'SERVO'. WHEN IT IS SET TO ONE, С 'SERVO' WILL MAINTAIN CONTROL UNTIL THE POSITION OF ALL OF THE С JOINTS IS WITHIN SOME SPECIFIED MINIMUM DISTANCE OF THE С COMMANDED POSITION. THEREFORE, THE CONTROL PROGRAM DOES NOT С INITIATE THE NEXT STEP UNTIL THE ARM HAS ARRIVED AT THIS С END POINT OF THE TRAJECTORY.

PNT=1 CALL SERVO(0)

С THE VARIABLE 'FUN' IS SET EQUAL TO THE VALUE OF THE FUNCTION FLAG ('ELE(6)') PLUS ONE, TO BE USED TO COMMAND A MULTIPLE 'GOTO' С С STATEMENT TO THE APPROPRIATE CODE TO CARRY OUT THE SPECIFIED С =2 'GRASP' FUNCTION. ('FUN'=1,NO FUNCTION; =3 'RELEASE' С =4 'GRASP PROXIMITY' =5 'RELEASE PROXIMITY' =6 'DETECT' С =7 'BALANCE' =8 'UNSTACK' =9 'PTOUCH').

> FUN=1+ELE(6) GOTO(20,20,20,3,4,20,20,7,8,20,20)FUN

- C IF THERE IS AN APPROACH PATH, IT IS GENERATED AND EXECUTED BY C THIS CALL TO 'STLINE'. C
- 20 CALL STLINE(-LTAB(ELE(2),3,4),-LTAB(ELE(2),3,5),-LTAB(ELE(2),3,6),1) IF(EABORT.LT.-2000)GOTO 40
  - THIS MULTIPLE 'GOTO' STATEMENT CAUSES THE BRANCHING TO THE APPROPRIATE CODE TO CARRY OUT THE FUNCTION SPECIFIED.

GOTO(110,1,2,3,4,5,6,7,8,110,10)FUN

THIS IS THE CODE FOR A 'GRASP PROXIMITY' FUNCTION. THE HAND IS MOVED DOWN THE APPROACH PATH TO WITHIN SIX CENTIMETERS OF THE DESTINATION POINT BY A CALL TO 'STLINE'. IT HAS TO FIRST STOP ABOVE THE OBJECT TO USE ITS PROXIMITY SENSORS TO DETECT IT. IT DETERMINES THAT THE OBJECT IS UNDER, AT LEAST, ONE OF THE SENSORS BY A CALL TO 'DETECT' WHICH MOVES THE HAND UNTIL ONE OF THE SENSORS REACHES A THRESHOLD VALUE. THE HAND IS THEN MOVED IN THE DIRECTION TO EQUALIZE THE TWO SENSOR INPUTS BY A CALL TO 'BAL'. NOW THAT THE HAND IS CENTERED OVER THE OBJECT, THE FINGERS ARE OPENED BY A CALL TO 'RELEAS'. THE HAND DESCENDS THE REMAINING SIX CENTIMETERS BY A CALL TO 'STLINE', AND THE

```
FINGERS ARE CLOSED ON THE OBJECT BY A CALL TO 'GRASP'.
                                                                  IF THE
С
С
        FINGER POSITION INDICATOR ('HAND') IS LESS THAN 7200, THEN THE
С
        FINGERS ARE CLOSED TOO FAR. TO BE HOLDING AN OBJECT.
                                                             IF THIS IS
С
        THE CASE THEN THE HAND IS RAISED BACK UP SIX CENTIMETERS
С
        BY A CALL TO 'STLINE' AND THE SEARCH BEGUN AGAIN.
С
3
        NZ = 600 - LTAB(ELE(2), 3, 6)
        CALL STLINE(-LTAB(ELE(2),3,4),-LTAB(ELE(2),3,5),NZ,1)
480
        IF(EABORT.LT.-2000)GOTO 40
        CALL DETECT
        IF(EABORT.LT.-2000)GOTO 40
        CALL BAL
        IF(EABORT.LT.-2000)GOTO 40
        CALL RELEAS(0)
        IF(EABORT.LT.-2000)GOTO 40
        CALL STLINE(0, 0, -600, 1)
        IF(EABORT.LT.-2000)GOTO 40
        CALL GRASP(0)
        IF(EABORT.LT.-2000)GOTO 40
        IF(HAND.GT.7200)GOTO 110
        CALL STLINE(0,0,600,1)
        GOTO 480
С
    THE FOLLOWING CODE PERFORMS THE 'RELEASE PROXIMITY' FUNCTION.
С
С
        FIRST, THE HAND IS MOVED TO A POSITION ONE CENTIMETER ABOVE
С
        AND FIVE CENTIMETERS TO THE SIDE (SINCE THE PROXIMITY SENSORS
        ARE LOCATED ON THE OUTSIDE OF RATHER THICK FINGERS, THIS SIDEWAYS
С
С
        MOTION IS NECESSARY TO BRING ONE OF THE SENSORS TO A POSITION
С
        WHERE IT WOULD BE OVER THE EXPECTED LOCATION OF THE UNDERLYING
С
        OBJECT) OF THE DESTINATION POINT BY A CALL TO 'STLINE'.
                                                                   THE
С
        HAND IS MOVED SIDEWAYS UNTIL ONE OF THE SENSORS HAS REACHED THE
С
        THRESHOLD LEVEL BY A CALL TO 'DETECT'.
                                                 THE CALL TO 'BAL' CAUSES
С
        THE HAND TO MOVE IN THE DIRECTION OF THE SENSOR THAT WAS AT
С
        THRESHOLD UNTIL THE SENSOR VALUE DECREASES BELOW A CERTAIN
С
        VALUE, INDICATING THAT THE EDGE OF THE UNDERLYING
С
        OBJECT HAS BEEN REACHED.
                                 THE HAND IS THEN MOVED THE ADDITIONAL
С
        DISTANCE OF THE THICKNESS OF THE FINGER TO CAUSE THE SIDE OF THE
С
        OBJECT IN THE HAND TO LINE UP FLUSH WITH THE SIDE OF THE
С
        UNDERLYING OBJECT.
                            THE CALL TO 'STLINE' CAUSES THE HAND TO
С
        MOVE DOWN THE REMAINING ONE CENTIMETER AND THE FINGERS ARE
С
        OPENED AND THE OBJECT RELEASED BY THE CALL TO 'RELEAS'.
С
4
        NZ=100-LTAB(ELE(2),3,6)
        NY=500-LTAB(ELE(2),3,5)
        CALL STLINE(-LTAB(ELE(2),3,4),NY,NZ,1)
        IF(EABORT.LT.-2000)GOTO 40
        CALL DETECT
        IF(EABORT.LT.-2000)GOTO 40
        CALL BAL
        IF(EABORT.LT.-2000)GOTO 40
        CALL STLINE(0,0,-100,1)
        IF(EABORT.LT.-2000)GOTO 40
        CALL RELEAS(0)
        GOTO 110
```

THE 'GRASP' FUNCTON IS ACCOMPLISHED BY A CALL TO 'GRASP'.

С С С CALL GRASP(0) 1 GOTO 110 С С THE 'RELEASE' FUNCTION IS ACCOMPLISHED BY A CALL TO 'RELEAS'. С 2 CALL RELEAS(0) GOTO 110 С С THE 'DETECT' FUNCTION IS ACCOMPLISHED BY A CALL TO 'DETECT'. С 5 CALL DETECT GOTO 110 С С THE 'BALANCE' FUNCTION IS ACCOMPLISHED BY A CALL TO 'BAL'. С 6 CALL BAL GOTO 110 С THE FOLLOWING CODE IS USED TO GENERATE THE 'UNSTACK' FUNCTION. С С THE FINGERS ARE CLOSED BY A CALL TO 'GRASP' TO MAKE CERTAIN С THAT THE SENSOR TO DETECT THE TOP OF THE STACK IS OVER THE С EXPECTED LOCATION OF THE STACK. THE CALL TO 'PTOUCH' CAUSES С THE HAND TO DESCEND WHILE CONSTANTLY MONITORING THE SENSOR С INPUT TO SEE IF THE THRESHOLD VALUE HAS BEEN REACHED. WHEN С THE THRESHOLD IS REACHED THE HAND STOPS. THE CALL TO 'STLINE' С IS USED TO MOVE THE HAND BACK UP ONE CENTIMETER TO MAKE С CERTAIN THAT THE HAND DOES NOT COLLIDE WITH THE TOP OF THE С STACK DURING THE SEARCH OPERATION. THE HAND IS CENTERED OVER С THE TOP OF THE STACK BY A CALL TO 'BAL'. THE CALL TO 'RELEAS' OPENS THE FINGERS AND THE CALL TO 'STLINE' CAUSES THE HAND С С TO DESCEND AROUND THE OBJECT. THE FINGERS CLOSE ON THE OBJECT С DUE TO THE CALL TO 'GRASP'. THE HAND IS RETURNED TO ITS INITIAL С STARTING POINT BY A CALL TO 'STLINE' . С 7 CALL GRASP(0) IF(EABORT.LT.-2000)GOTO 40 CALL PTOUCH IF(EABORT.LT.-2000)GOTO 40 CALL BAL IF(EABORT.LT.-2000)GOTO 40 CALL RELEAS(0) IF(EABORT.LT.-2000)GOTO 40 CALL STLINE(0, 0, -600, 1)IF(EABORT.LT.-2000)GOTO 40 CALL GRASP(0) IF(EABORT.LT.-2000)GOTO 40 OFF(3) = OFF(3) - 600CALL STLINE(-OFF(1), -OFF(2), -OFF(3), 1) GOTO 435 С С THE 'EDGE' COMMAND С 10 RP = 1740 CALL EDGE(0) CALL WAIT(32)

738		IF(RP.NE.2)GOTO 738 OFF(2)=OFF(2)-INBUF(36) CALL STLINE(0,0,-INBUF(36),1) CALL EDGE(RP) CALL STLINE(0,0,500,1) OFF(3)=OFF(3)+500 CALL STLINE(-OFF(1),-OFF(2),-OFF(3),1) IF(INBUF(31).GT2000)GOTO 435 IF(RP.EQ.2)GOTO 435 RP=2 GOTO 740
C C	THE	'TOUCH' FUNCTION IS ACCOMPLISHED BY A CALL TO 'PTOUCH'.
C 8 110		CALL PTOUCH IF(EABORT.LT2000)GOTO 40
000000	THE	FOLLOWING CODE RE-DEFINES THE 'DESTINATION' OF THE ELEMENTAL MOVE' COMMAND AS THE PRESENT LOCATION OF THE ARM AND ENTERS THE PRESENT JOINT POSITION VALUES INTO THE LOCATION TABLE UNDER THIS (ELE(2)) DESTINATION NAME.
420		DO 420 J=1,6 AC(J)=JPOS(J) LTAB(ELE(2),1,J)=JPOS(J)
0000	THE	START OF THE APPROACH PATH MUST BE CALCULATED FROM THIS RE-DEFINED LOCATION AND ITS JOINT POSITION VALUES ENTERED UNDER THIS LOCATION NAME IN THE LOCATION TABLE.
430		AX=LTAB(ELE(2),3,4)/100. AY=LTAB(ELE(2),3,5)/100. AZ=LTAB(ELE(2),3,6)/100. CALL COOR(AX,AY,AZ,0,0) DO 430 J=1,6 LTAB(ELE(2),4,J)=JPOS(J) JPOS(J)=LTAB(ELE(2),1,J)
00000	IF	A VOLTAGE LEVEL IS TO BE SENT OUT ON A SPECIFIED CHANNEL (THIS ALLOWS THE ARM TO BE INTERLOCKED WITH AN EXTERNAL DEVICE) THEN THE CHANNEL NUMBER IS DECODED AND A SIGNAL SENT OUT.
435		SEN=ELE(4)/100 IF(SEN.EQ.0)GOTO 440 CALL SERVO(SEN)
000000	IF 1	THE ARM IS TO WAIT AT ITS PRESENT LOCATION UNTIL AN INPUT CHANNEL RECEIVES A VOLTAGE LEVEL (THIS ALLOWS THE ARM TO BE SYNCHRONIZED WITH AN EXTERNAL DEVICE) THEN THE INPUT CHANNEL NUMBER IS DECODED AND THE CONTROL SYSTEM WAITS UNTIL THIS CHANNEL RECEIVES A VOLTAGE LEVEL BEFORE CONTINUING.
440 40		WA=ELE(4)-SEN*100 IF(WA.EQ.0)GOTO 40 CALL WAIT(WA) RETURN



DI-24

C --- SUBROUTINE : STLINE C С = A STRAIGHT LINE TRAJECTORY IS TO BE --- ARGUMENTS : DX, DY, DZ C GENERATED FROM THE PRESENT LOCATION OF THE ARM TO A POSITION A DELTA 'X'(DX), C DELTA 'Y' (DY), DELTA 'Z' (DZ) DISTANCE С С AWAY. C Ι IF(I=0)THEN THE STRAIGHT LINE IS TO BE С GENERATED FROM THE PRESENT LOCATION С TO THE DESTINATION POINT (ELE(2)) С SPECIFIED IN THE 'ELEMENTAL MOVE' С COMMAND. С IF(I=1)THEN THE STRAIGHT LINE TRAJECTORY С IS TO BE GENERATED FROM THE PRESENT С POSITION OF THE ARM TO A POINT 'DX' 'DY', 'DZ' DISTANCE AWAY AS SPECIFIED С С BY THE ARGUMENTS OF THE SUBROUTINE С CALL. С С --- CALLED BY : EMOVE С С --- CALLS SUBROUTINES : COOR SQRT SERVO С С --- INPUT DATA : DX,DY,DZ,I = THE ARGUMENTS AS DESCRIBED ABOVE. С JPOS(1-6)= THE VALUE OF THE JOINT POSITION С INDICATORS. С ELE(2)= THE DESTINATION POINTER VALUE FOR С THE PRESENT 'ELEMENTAL MOVE' С COMMAND. С INBUF(36) = THE VALUE OF A POTENTIOMETER С WHICH IS USED TO CONTROL THE SPEED С OF THE STRAIGHT LINE TRAJECTORY. C С THE JOINT POSITION COMMAND VALUES --- OUTPUT DATA : JPOS(1-6) C SENT TO 'SERVO' TO CAUSE THE HAND С TO MOVE ALONG THE CALCULATED STRAIGHT С LINE TRAJECTORY. С С --- FUNCTION: TO GENERATE A STRAIGHT LINE TRAJECTORY FROM THE PRESENT C POSITION OF THE HAND TO A SPECIFIED LOCATION. C SUBROUTINE STLINE(DX, DY, DZ, I) IMPLICIT INTEGER(B-R) COMMON/ARMBUF/INBUF(64), OUTBUF(64) COMMON/LMOD/LTAB(90,4,7), PRES, DEST COMMON/OUT/JPOS(8) COMMON/CORT/AC(6), AXEP, AYEP, AZEP COMMON/EM/ELE(6) EQUIVALENCE(EABORT, INBUF(28)) DIMENSION ADD(6), COTAB(50,6) С С PLACE THE CURRENT JOINT POSITION VALUES IN THE COMMON VARIABLE С THE POSITION OF THE ARM DESCRIBED BY THESE 'AC(1-6)'. С VALUES WILL BE USED AS THE STARTING POINT OF THE С THE SUBROUTINE 'COOR' WILL CALCULATE TRAJECTORY. С THE CORRECT JOINT POSITION VALUES OF NEW POSITIONS THAT

C C C		ARE SPECIFIED BY DELTA 'X', 'Y', 'Z' DISTANCES AWAY FROM THIS REFERENCE POSITION ('AC(1-6)').
15 C		DO 15 J=1,6 AC(J)=JPOS(J)
C C C	THE	ARGUMENT 'I' IS TESTED IN ORDER TO BRANCH TO THE PROPER CODE.
c		IF(I.EQ.0)GOTO 10
с с с с с с с	FOR	(I=1), THE END POINT OF THIS STRAIGHT LINE TRAJECTORY IS DEFINED AS A POINT 'DX', 'DY', 'DZ' DISTANCE FROM THE PRESENT POSITION. THESE DELTA DISTANCES ARE CONVERTED TO CENTIMETERS BY DIVIDING BY 100 AND THEN STORED IN THE VARIABLES 'AX', 'AY', 'AZ'.
С		AX=DX/100. AY=DY/100. AZ=DZ/100.
C C C	ONCE	E THE VALUES 'AX', 'AY', 'AZ' HAVE BEEN DETERMINED, THEN BRANCH TO STATEMENT 20.
С		GOTO 20
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	FOR	(I=0), THE END POINT OF THIS STRAIGHT LINE TRAJECTORY IS DEFINED BY THE DESTINATION POINTER ('ELE(2)') FOR THE PRESENT 'ELEMENTAL MOVE' COMMAND. THE DELTA 'X', 'Y', 'Z' DISTANCE OF THIS DESTINATION FROM THE PRESENT LOCATION IS CALCULATED BY, FIRST, CALCULATING THE 'X,Y,Z' COORDINATES OF THE PRESENT LOCATION BY A CALL TO 'COOR'. THE 'X,Y,Z' COORDINATES OF THE BEGINNING OF THE APPROACH PATH ARE OBTAINED FROM THE LOCATION TABLE MODULE (IE. THE COORDINATES (LTAB(ELE(2),2,1-3)) OF THE END POINT OF THE DESTINATION ARE ADDED TO THE DELTA OFFSETS (LTAB(ELE(2),3,4-6)) OF THE START OF THE APPROACH PATH FROM THIS END POINT, THUS, OBTAINING THE COORDINATES 'X,Y,Z' OF THE START OF THE APPROACH PATH). THE DIFFERENCE BETWEEN THESE VALUES AND THE COORDINATES FOR THE PRESENT LOCATION ARE STORED IN 'AX', 'AY', 'AZ'.
10 C		CALL COOR(0.,0.,0.,0,1) AX=(LTAB(ELE(2),2,1)+LTAB(ELE(2),3,4))/100AXEP AY=(LTAB(ELE(2),2,2)+LTAB(ELE(2),3,5))/100AYEP AZ=(LTAB(ELE(2),2,3)+LTAB(ELE(2),3,6))/100AZEP
C	THE	DISTANCE OF THE STRAIGHT LINE PATH IS CALCULATED.
20 C		DV=SQRT(AX**2+AY**2+AZ**2)
	IF 1	THE DISTANCE OF THE TRAJECTORY IS ZERO, THEN NO FURTHER COMPUTATIONS ARE MADE AND THE CONTROL IS RETURNED TO THE CALLING PROGRAM.
C		IF(DV.EQ.0)GOTO 40
C	THE	STRAIGHT LINE TRAJECTORY IS TO BE 'DV' CENTIMETERS LONG. THIS

TRAJECTORY WILL BE GENERATED BY FIRST, CALCULATING A NUMBER OF INTERMEDIATE LOCATIONS THAT LIE ALONG THIS STRAIGHT LINE AND THEN CALCULATING THE ADDITIONAL POINTS BY INTERPOLATING BETWEEN THESE INTERMEDIATE LOCATIONS. THE INTERMEDIATE LOCATIONS WILL LIE APPROXIMATELY TWO CENTIMETERS APART ALONG THE STRAIGHT LINE. THE NUMBER OF THESE INTERMEDIATE LOCATIONS IS CALCULATED BY DIVIDING THE LENGTH OF THE TRAJECTORY ('DV') BY TWO. THIS VALUE IS INCREMENTED BY ONE TO MAKE CERTAIN THAT THE NUMBER OF POINTS IS A NON-ZERO VALUE IF THE TRAJECTORY IS LESS THAN TWO CENTIMETERS LONG.

NDV = DV/2 + 1

С

С

С

C C

С

С

С

C C

С

C C

С

С

С

С

110

С

C

C

C

C

C

C

C

C

C

140

THE DELTA 'X,Y,Z' COORDINATE VALUES BETWEEN EACH OF THE INTERMEDIATE LOCATIONS IS CALCULATED AND STORED IN 'ANX', 'ANY', 'ANZ'.

A N X = A X / N D V A N Y = A Y / N D VA N Z = A Z / N D V

C THE JOINT POSITION VALUES OF THE INTERMEDIATE LOCATIONS ARE CALCULATED C BY CALLS TO 'COOR' AND ARE STORED IN SEQUENCE IN THE TABLE C 'COTAB(50,6)'.

KD = NDV + 1 DO 110 J = 1, KD KLL = J - 1 ATX = KLL \* ANX ATY = KLL \* ANY ATZ = KLL \* ANY CALL COOR (ATX, ATY, ATZ, 0, 0) DO 110 KB = 1, 6 COTAB(J, KB) = JPOS(KB)

C THE VALUE OF THE POTENTIOMETER (INBUF(36)) IS READ IN AND USED TO C DEFINE THE NUMBER OF ADDITIONAL INTERPOLATION POINTS ('PC') TO BE C CALCULATED BETWEEN EACH PAIR OF INTERMEDIATE LOCATIONS.

> PC=10-INBUF(36)/30 ASP=PC

C A LOOP IS SET UP TO PROVIDE THE INTERPOLATED JOINT POSITION COMMANDS C FOR ALL 'NDV' OF THE INTERMEDIATE LOCATIONS. C

DO 150 P=1,NDV

FOR EACH INTERMEDIATE LOCATION, THE DELTA JOINT VALUES FOR THE SPECIFIED NUMBER ('ASP') OF INTERPOLATION POINTS IS CALCULATED AND STORED IN 'ADD(1-6)'.

DO 140 MP=1,6 ADD(MP)=(COTAB(P+1,MP)-COTAB(P,MP))/ASP

THIS LOOP CAUSES THE ARM TO MOVE FROM ONE INTERMEDIATE LOCATION TO THE NEXT BY INCREMENTING THE JOINT POSITION COMMANDS BY THE PROPER DELTA INTERPOLATION VALUE ('ADD(1-6)') EACH TIME.

C	
	DO 150 LM=1,PC
	DO 160 JB=1,6
160	JPOS(JB) = COTAB(P, JB) + LM # ADD(JB)
	CALL SERVO(0)
	IF(EABORT.LT2000)GOTO 40
150	CONTINUE
40	RETURN
	END





DI-30

C --- SUBROUTINE : WAIT C = THE INPUT CHANNEL NUMBER THAT IS TO C --- ARGUMENTS : CH SAMPLED FOR A VOLTAGE LEVEL. С С --- CALLED BY : EXPRO EMOVE С C С --- CALLS SUBROUTINES : ARMIN C С --- INPUT DATA : CH = THE ARGUMENT AS EXPLAINED ABOVE. C С --- OUTPUT DATA : С C --- FUNCTION: SUSPENDS OPERATION OF THE CONTROL SYSTEM UNTIL A SPECIFIED INPUT CHANNEL DROPS TO A ZERO VOLTAGE С С LEVEL OR THE ABORT SWITCH IS THROWN. С SUBROUTINE WAIT(CH) IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64), OUTBUF(64) EQUIVALENCE(EABORT.INBUF(28)) С THE INPUT CHANNELS ARE READ IN, AND THE VALUE OF THE SPECIFIED С С CHANNEL ('CH') IS TESTED TO SEE IF IT IS A POSITIVE OR NEGATIVE VALUE, INDICATING THAT THE PROGRAM IS TO WAIT UNTIL THE С С SPECIFIED INPUT CHANNEL RECEIVES A HIGH С OR A ZERO VOLTAGE LEVEL, RESPECTIVELY. С 20 CALL ARMIN IF(EABORT.LT.-2000)GOTO 40 IF(CH.LT.O)GOTO 25 С THE VALUE OF THE SPECIFIED INPUT С С CHANNEL IS TESTED. AS LONG AS THERE IS ZERO VOLTAGE ON THIS С CHANNEL, THE SUBROUTINE WILL CONTINUE SAMPLING IT. WHEN THE С VOLTAGE LEVEL GOES ABOVE ZERO, CONTROL IS RETURNED TO THE CALLING С PROGRAM. С IF(INBUF(CH).GT.-2000)GOTO 20 GOTO 40 С С THE VALUE OF THE SPECIFIED INPUT С CHANNEL IS TESTED. AS LONG AS THERE IS A VOLTAGE LEVEL ON THIS С CHANNEL, THE SUBROUTINE WILL CONTINUE SAMPLING IT. WHEN THE С VOLTAGE LEVEL DROPS TO ZERO, CONTROL IS RETURNED TO THE CALLING С PROGRAM. С 25 IF(INBUF(-CH).LT.-2000)GOTO 20 40 RETURN END



DI-32

C --- SUBROUTINE : CALD C --- ARGUMENTS : С С С --- CALLED BY : EMOVE С С --- CALLS SUBROUTINES : COOR SQRT С С = THE PRESENT JOINT POSITION VALUES. --- INPUT DATA : JPOS(1-6) С ELE(2) = THE VALUE OF THE DESTINATON POINTER С TO THE LOCATION TABLE. С THE 'X' COORDINATE VALUE FOR THE HAND AXEP С FOR THE SPECIFIED JOINT VALUES (AC(1-6)) C [FROM 'COOR']. C C = THE 'Y' COORDINATE VALUE FOR THE HAND AYEP FOR THE SPECIFIED JOINT VALUES (AC(1-6)) C [FROM 'COOR']. С THE 'Z' COORDINATE VALUE FOR THE HAND AZEP С FOR THE SPECIFIED JOINT VALUES (AC(1-6)) С [FROM 'COOR']. С C --- OUTPUT DATA : AC(1-6) = THE JOINT POSITION VALUES TO BE USED С BY THE COORDINATE TRANSFORMATION С ROUTINE ('COOR'). С = THE DISTANCE IN CENTIMETERS BETWEEN ADIST C THE PRESENT LOCATION OF THE ARM AND С THE SPECIFIED DESTINATION С POINT (ELE(2)). С С --- FUNCTION: CALCULATES THE DISTANCE (IN CENTIMETERS) FROM THE PRESENT С LOCATION OF THE END POINT OF THE HAND TO ITS POSITION С AT THE DESTINATION POSITION. С SUBROUTINE CALD IMPLICIT INTEGER(B-R) COMMON/LMOD/LTAB(90,4,7), PRES, DEST COMMON/OUT/JPOS(8) COMMON/EM/ELE(6) COMMON/DIST/ADIST COMMON/CORT/AC(6), AXEP, AYEP, AZEP С С STORE THE JOINT POSITION VALUES IN THE VARIABLE (AC(1-6)) С SO THAT THE 'X', 'Y', 'Z' VALUES FOR THIS POINT CAN BE С CALCULATED BY THE COORDINATE TRANSFORMATION ROUTINE. С DO 20 J=1,6 20 AC(J) = JPOS(J)С C THE CALL TO 'COOR(X,Y,Z,D,J)' IS MADE WITH 'J'=1 TO INDICATE С THAT ONLY THE 'X', 'Y', 'Z' VALUES ARE TO BE RETURNED (IE. THE С JOINT VALUES ARE NOT TO BE CALCULATED). С CALL COOR(0.,0.,0.,0,1) С С THE 'X,Y,Z' VALUES OF THE PRESENT LOCATION OF THE ARM ARE STORED С IN THE VARIABLES 'APX', 'APY', AND 'APZ'.

С		
		APX = AXEP
		APY = AYEP
		A P Z = A Z E P
С		
č	CAL	CULATE THE "X.Y.Z." VALUES OF THE DESTINATION POINT (ELE(2)) BY
č	0	PLACING ITS JOINT POSTTON VALUES IN THE COMMON VARIABLE
č		AC(1-6) AND CALLING 'COOR'
c		
0		DO 21 J-1 6
21		$\Delta C(1) = I T \Delta B(F   F(2)   4 , I)$
2 1		CALL COOP(0, 0, 0, 1)
C		
c	ጥሀፍ	DISTANCE DETWEEN THESE THO DOINTS IS CALCULATED AND STORE IN
c	Inc	THE COMMON VARIABLE LADISTI
C		THE COMMON VARIABLE ADIST.
U		
		ADX=APX-AXEP
		ADI=API-AIEP
		ADZ = APZ - AZEP
		ADIST=SQRT(ADX**2+ADY**2+ADZ**2)
40		RETURN
		END





DI-36

С	 SUBROUTINE : POL
C	 ARGUMENTS :
C C C	 CALLED BY : EMOVE
C	 CALLS SUBROUTINES : ARMIN
	 INPUT DATA : INBUF(26) = THE VALUE OF A POTENTIOMETER USED TO SPECIFY THE VELOCITY OF THIS TRAJECTORY BY DEFINING THE NUMBER OF INTERPOLATION POINTS TO BE USED PER UNIT DISTANCE
C C C	ADIST = THE DISTANCE BETWEEN THE TWO END POINTS OF THE TRAJECTORY IN CENTIMETERS [FROM 'CALD'].
C C	ELE(1) = THE LOCATION TABLE POINTER FOR THE PRESENT POSITION OF THE ARM.
C C	ELE(2) = THE LOCATION TABLE POINTER FOR THE DESTINATION OF THIS TRAJECTORY.
C C	JPOS(1-6) = THE JOINT POSITION VALUES OF THE LOCATION OF THE ARM.
C C C	LTAB(ELE(2),4,1-6) = THE JOINT POSITION VALUES OF THE START OF THE APPROACH PATH FOR THE SPECIFIED DESTINATION POINT.
C C	LTAB(ELE(1),2,7) = THE FLAG THAT INDICATES IF THE ARM HAS STOPPED AT THE PRESENT LOCATION.
C	LTAB(ELE(2),2,7)= THE FLAG THAT INDICATES IF THE ARM IS TO STOP AT THE DESTINATION POINT.
	 OUTPUT DATA : NACV = THIS IS THE NUMBER OF COMMANDED JOINT POSITION OUTPUTS FOR THE ACCELERATION (OR DECCELERATION) PORTION OF THE TRAJECTORY.
C C C	NVPT = THIS IS THE NUMBER OF COMMANDED JOINT POSITION OUTPUTS FOR THE CONSTANT VELOCITY PORTION OF THE TRAJECTORY
C C C	KJ = A FLAG THAT CODES THE INFORMATION OF WHETHER AN ACCELERATION OR DECCELERATION PROFILE IS TO BE USED
с с с с с с с с с с с с с с	ACDIF(1-6) = THE DELTA JOINT POSITION VALUES THAT WOULD CAUSE THE ARM TO MOVE 1/400 OF A CENTIMETER ALONG THE INTERPOLATED TRAJECTORY. USED AS THE ACCELERATION FACTOR FOR THE ACCELERATION PORTION OF THE TRAJECTORY.
00000000000	AVDIF(1-6) = THE DELTA JOINT POSITION VALUES THAT WOULD CAUSE THE ARM TO MOVE 'NACV' TIMES 1/400 CENTIMETERS ALONG THE CONSTANT VELOCITY PORTION OF THE TRAJECTORY. THUS, PROVIDING THE PROPER SIZE STEP REQUIRED FOR THE ARM TO MOVE AT THE SPECIFIED VELOCITY.
C C C	 FUNCTION: GENERATES THE DELTA JOINT POSITION VALUES AND SPECIFIES THE NUMBER OF THEM REQUIRED TO CAUSE THE ARM TO MOVE THROUGH THE TRAJECTORY AT THE CORRECT VELOCITY. THE

ACTUAL EXECUTION IS ACCOMPLISHED BY THE SUBROUTINE 'ACC' WHICH USES THIS INFORMATION FROM 'POL'.

SUBROUTINE POL IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64),OUTBUF(64) COMMON/LMOD/LTAB(90,4,7),PRES,DEST COMMON/OUT/JPOS(8) COMMON/INT/NACV,NVPT,KJ COMMON/DELT/ACDIF(6),AVDIF(6) COMMON/DIST/ADIST COMMON/EM/ELE(6) EQUIVALENCE(EABORT,INBUF(28))

С THE POTENTIOMETER VALUE THAT WILL CONTROL THE VELOCITY IS READ С IN ON 'INBUF(26)'. IT IS NORMALIZED TO A VALUE BETWEEN С ONE AND TEN AND MULTIPLIED BY THE SPECIFIED VELOCITY 'ELE(3)' С THE VALUE 'NACV' IS SET FOR THIS PARTICULAR TRAJECTORY. С EQUAL TO THIS NUMBER DIVIDED BY 5. THIS NUMBER SPECIFIES HOW С MANY INCREMENTAL STEPS ('ACDIF(1-6)') ARE TO BE SENT OUT AT A TIME TO THE SERVOS IN ORDER TO CAUSE THE ARM TO MOVE AT THE С С CORRECT VELOCITY. С

```
CALL ARMIN
NACV=((-INBUF(26)-2100)/100+1)*ELE(3)
NACV=NACV/10
```

THE VALUE 'ANTRJP' IS SET EQUAL TO 100 TIMES THE TOTAL DISTANCE OF THE TRAJECTORY IN CENTIMETERS. THE DIFFERENTIAL JOINT VALUES FROM THE PRESENT LOCATION TO THE DESTINATION ('LTAB(ELE(2),4,1-6)') ARE DIVIDE BY 'ANTRJP'. THIS CREATES THE DELTA JOINT VALUES THAT THAT WOULD CAUSE A MOVEMENT OF THE ARM OF 1/100 OF A CENTIMETER.

```
ANTRJP=ADIST*100.
DO 20 H=1,6
ACDIF(H)=(LTAB(ELE(2),4,H)-JPOS(H))/ANTRJP
```

С THE POSITION LTAB(J,2,7), CARRIES A FLAG THAT INDICATES IF THE ARM С IS TO STOP AT THAT LOCATION. IF IT IS A ONE THEN THE ARM STOPS, С THEREFORE, AN ACCELERATION PROFILE IS NEEDED FOR THAT POINT. С IF IT IS ZERO, IT DOES NOT STOP AND NO ACCELERATION PROFILE IS С THE VALUE 'KJ' IS SET EQUAL TO THE SUM OF THE FLAGS TO BE USED. С OF THE PRESENT LOCATION AND THE DESTINATION PLUS ONE. THE С VALUE 'KJ' IS THEN USED TO POINT TO THE APPROPRIATE CODE С FOR THE CORRECT ACCELERATION PROFILES.

> KJ=2\*LTAB(ELE(2),2,7)+LTAB(ELE(1),2,7)+1 GOTO (110,111,111,112)KJ

THIS IS THE CONDITION FOR NO ACCELERATION OR DECCELERATION PROFILES.

C C 110

С

С

С

С

С

С

C C

С

С

С

С

С

20

С

) NACCP=0 GOTO 115

C C C

THIS IS THE CONDITION FOR EITHER AN ACCELERATION OR A DECCELERATION PROFILE. 'NACCP' IS THE TOTAL NUMBER OF INCREMENTAL STEPS

- ('ACDIF(1-6)') THAT THE ARM WILL MOVE THROUGH DURING THE ACCELERATION OR DECCELERATION. THEREFORE, 'NACCP' IS A MEASURE OF HOW MUCH OF THE TRAJECTORY WILL BE USED FOR THE ACCELERATION OR DECCELERATION REGION.
- 111 NACCP=(NACV\*\*2+NACV)/2 GOTO 115

С

C C

С

С

C C

С

C C

С

С

THIS IS THE CONDITION FOR BOTH AN ACCELERATION AND A DECCELERATION REGION FOR THIS TRAJECTORY, THEREFORE, THERE WILL BE TWICE AS MANY INCREMENTAL STEPS ('ACDIF(1-6)') INVOLVED IN THESE REGIONS.

## 112 NACCP=NACV \*\* 2+NACV

С THE NUMBER OF INCREMENTAL STEPS USED IN THE ACCELERATION-DECCELERATION С PROFILES IS SUBTRACTED FROM THE TOTAL NUMBER OF STEPS IN THE С TRAJECTORY TO YIELD THE VALUE 'ANVELP'. THIS NUMBER IS DIVIDED BY 'NACV' (THE NUMBER OF STEPS TO BE SENT TO THE SERVOS AT ONE С С TIME IN ORDER TO CAUSE THE ARM TO MOVE AT THE CORRECT VELOCITY) С TO GIVE THE NUMBER 'NVPT' (THE NUMBER OF TIMES THAT THE DELTAS 'AVDIF(1-6)' ARE TO BE SENT TO THE SERVOS FOR THE CONSTANT С С VELOCITY PORTION OF THE TRAJECTORY.

115	ANVELP=ANTRJP-NACCP
	NVPT = ANVELP / NACV
	IF(NVPT.NE.O)GOTO 47
	N V P T = 1
47	AMV = ANVELP/NVPT
	DO 200 J=1,6
200	AVDIF(J) = ACDIF(J) * AMV
С	WRITE(6,320)NACV,NACCP,ANTRJP,ANVELP,AMV
320	FORMAT(2X,2(1X,16),3(1X,F10.4))
С	WRITE(6,321)ADIST,ELE(3),INBUF(26)
321	FORMAT(2X, F10.4, 2X, 15, 2X, 16)
40	RETURN
	END



С		SUBROUTINE : ACC
C		ARGUMENTS :
C		CALLED BY : EMOVE
C		CALLS SUBROUTINES : SERVO
		INPUT DATA : NACV = THIS IS THE NUMBER OF COMMANDED JOINT POSITION OUTPUTS FOR THE ACCELERATION (OR DECCELERATION) PORTION
C C		NVPT = THIS IS THE NUMBER OF COMMANDED JOINT POSITION OUTPUTS FOR THE CONSTANT
C C C		VELOCITY PORTION OF THE TRAJECTORY. KJ = A FLAG THAT CODES THE INFORMATION OF WHETHER AN ACCELERATION OR DECCELERATION
CCCCCC		ACDIF(1-6) = THE DELTA JOINT POSITION VALUES THAT WOULD CAUSE THE ARM TO MOVE 1/200 OF A CENTIMETER ALONG THE INTERPOLATED TRAJECTORY. USED AS THE ACCELERATION FACTOR FOR THE ACCELERATION PORTION OF
		AVDIF(1-6) = THE DELTA JOINT POSITION VALUES THAT WOULD CAUSE THE ARM TO MOVE 'NACV' TIMES 1/200 CENTIMETERS ALONG THE CONSTANT VELOCITY PORTION OF THE TRAJECTORY. THUS, PROVIDING THE PROPER SIZE STEP REQUIRED FOR THE ARM TO MOVE AT THE SPECIFIED VELOCITY.
00000		OUTPUT DATA : JPOS(1-6) = THE COMMANDED JOINT POSITION VALUES TO THE SERVOS THAT WILL MOVE THE ARM THROUGH THE PROPER TRAJECTORY IN SPACE.
		FUNCTION: CALCULATES AND OUTPUTS TO 'SERVO' THE CORRECT JOINT POSITION COMMANDS TO CAUSE THE ARM TO MOVE THROUGH ITS SPECIFIED TRAJECTORY USING ACCELERATION AND DECELERATION ROUTINES WHERE NECESSARY.
0		SUBROUTINE ACC IMPLICIT INTEGER(B-Z) COMMON/EM/ELE(6) COMMON/LMOD/LTAB(90,4,7),PRES,DEST COMMON/ARMBUF/INBUF(64),OUTBUF(64) COMMON/OUT/JPOS(8) COMMON/INT/NACV,NVPT,KJ COMMON/INT/NACV,NVPT,KJ COMMON/DELT/ACDIF(6),AVDIF(6) EQUIVALENCE(EABORT,INBUF(28)) DIMENSION AJPOS(6)
с с с с	Τŀ	HE JOINT POSITION VALUES ARE CONVERTED TO FLOATING POINT VALUES, SO THAT THEY CAN BE INCREMENTED BY VALUES LESS THAN ONE IF NECESSARY.

С DO 10 K=1,6 10 AJPOS(K) = JPOS(K)С С THE FLAG 'KJ' (WHOSE VALUE IS DETERMINED BY WHETHER OR NOT С ACCELERATION AND/OR DECCELERATION PROFILES ARE TO BE USED) С IS USED TO POINT TO THE APPROPRIATE CODE TO BE EXECUTED. С GOTO (11, 12, 11, 12)KJ С THIS IS THE CODE THAT CAUSES AN ACCELERATION TO BE PROVIDED AT THE С С BEGINNING OF THE TRAJECTORY. THE ACCELERATION LASTS FOR 'NACV' С OUTPUTS TO THE SERVOS. EACH TIME THE JOINT POSITION COMMANDED С OUTPUT IS INCREMENTED BY A DELTA THAT IS 'ACDIF(J)' LARGER THAN С THE LAST ONE, THEREBY PROVIDING AN ACCELERATION UP TO С THE SPECIFIED VELOCITY. С 12 DO 400 LD=1,NACV DO 401 J=1,6 AJPOS(J) = AJPOS(J) + LD \* ACDIF(J)401 JPOS(J) = AJPOS(J)CALL SERVO(0) IF(EABORT.LT.-2000)GOTO 40 400 CONTINUE С С THIS IS THE SECTION OF THE CODE THAT PROVIDES THE CONSTANT С VELOCITY PORTION OF THE TRAJECTORY. THE JOINT POSITION COMMANDED VALUES ARE INCREMENTED BY THE DELTA VALUES 'AVDIF(1-6)' FOR С С 'NVPT' TIMES TO CAUSE THE ARM TO MOVE AT A CONSTANT VELOCITY С THROUGH THIS PORTION OF THE TRAJECTORY. С DO 500 LD=1,NVPT 11 DO 501 J=1,6 AJPOS(J) = AJPOS(J) + AVDIF(J)501 JPOS(J) = AJPOS(J)CALL SERVO(0) IF(EABORT.LT.-2000)GOTO 40 500 CONTINUE С С THE FLAG 'KJ' IS USED TO RETURN TO THE CALLING PROGRAM ('EMOVE') IF С NO DECCELERATION IS TO BE USED OR EXECUTE THE NEXT SECTION OF CODE С IF A DECCELERATION IS CALLED FOR. С GOTO (40,40,13,13)KJ С С THIS SECTION OF CODE CREATES A DECCELERATION PROFILE. THE С DECCELERATION LASTS FOR 'NACV' OUTPUTS TO THE SERVOS. С FOR EACH OUTPUT, THE JOINT POSITION COMMANDED VALUES ARE С INCREMENTED BY A DELTA THAT IS 'ACDIF(J)' SMALLER THAN THE LAST С ONE UNTIL THE DESTINATION POSITION HAS BEEN REACHED. С DO 600 LD=1,NACV 13 LLD = NACV + 1 - LDDO 601 J=1,6 AJPOS(J) = AJPOS(J) + LLD \* ACDIF(J)601 JPOS(J) = AJPOS(J)

CALL SERVO(0)
IF(EABORT.LT2000)GOTO 40
CONTINUE
WRITE(6,48)(LTAB(ELE(2),4,J),J=1,6),(JPOS(H),H=1,6)
FORMAT(2X,6(2X,16))
RETURN
END



DI-44

<ul> <li>ARGUMENTS :</li> <li>CALLED BY : EMOVE</li> <li>CALLS SUBROUTINES : COOR ARMIN SERVO</li> <li>INPUT DATA : JPOS(7) = THE PRESENT JOINT POSITION VALUES</li></ul>	2	S	UBROUTINE : DETECT
<ul> <li> CALLED BY : EMOVE</li> <li> CALLS SUBROUTINES : COOR ARMIN SERVO</li> <li> INPUT DATA : JPOS(7) = THE PRESENT JOINT POSITION VALUES P1 = THE PRESENT VALUE OF THE SIGNAL FROM THE PROXIMITY SENSOR ON ONE OF THE FINGERS [FROM 'ARMIN' ON INPUT CHANNEL NUMBER 49].</li> <li>P2 = THE PRESENT VALUE OF THE SIGNAL FROM THE PROXIMITY SENSOR ON THE OTHER FINGER [FROM 'ARMIN' ON INPUT CHANNEL NUMBER 48].</li> <li> OUTPUT DATA : JPOS(7) = THE COMMANDED JOINT POSITION VALUES THAT WILL CAUSE THE ARM TO MOVE ALONG A SEARCH PATH IN THE 'I' DIRECTION (FROM 'ARMIN' ON INPUT CHANNEL NUMBER 48].</li> <li> FUNCTION: TESTS THE PROXIMITY SENSORS FREDBACK FOR A LARGE ENOUGH SIGNAL TO INDICATE THAT THERE IS AN OBJECT IN FRONT OF AT LEAST ONE OF THE SENSORS. IF THIS THRESHOLD SIGNAL IS NOT DEFECTED BY EITHER SENSOR, THEN THE HAND IS MOVED IN A SEARCH PATTERN UNTIL THE THRESHOLD LEVEL IS DETECTED.</li> <li>SUBROUTINE DETECT IMPLICIT INTEGER(6+2) COMMON/ARMUF/INBUF(64), OUTBUF(64) COMMON/OFFS/OFF(3) EQUIVALENCE(P1, INBUF(28)) EQUIVALENCE(P1, INBUF(28)) EQUIVALENCE(P1, INBUF(28)) EQUIVALENCE(P1, INBUF(28)) EQUIVALENCE(P1, INBUF(49)), (F2, INBUF(48)) CALL ARMIN</li> <li>PLACE THE PRESENT JOINT POSITION VALUES IN THE MATRIX AC(6) TO BE USED BY THE COORDINATE TRANSPORMATION ('CCOR') CALL. DO 51 JJ=1,6 AC(JJ)=JPOS(JJ)</li> <li>SET THE COUNTER FOR MOVEMENT IN THE 'Y' DIRECTION EQUAL TO ZERO. AY=0.</li> <li>ZERO THE FLAG ('MIN') USED TO INDICATE THAT THE HAND SHOULD BE MOVING IN THE MINUS 'Y' DIRECTION. MIN=0</li> </ul>	2	A	RGUMENTS :
<ul> <li>CALLS SUBROUTINES : COOR ARMIN SERVO</li> <li>INPUT DATA : JPOS(7) = THE PRESENT JOINT POSITION VALUES P1 = THE PRESENT VALUE OF THE SIGNAL FROM THE PROXIMITY SENSOR ON ONE OF THE FINCERS [FROM 'ARMIN' ON INPUT CHANNEL NUMBER 49].</li> <li>THE PRESENT VALUE OF THE SIGNAL FROM THE PROXIMITY SENSOR ON THE OTHER FINCER [FROM 'ARMIN' ON INPUT CHANNEL NUMBER 48].</li> <li>OUTPUT DATA : JPOS(7) = THE COMMANDED JOINT POSITION VALUES ALONG A SEARCH PATH IN THE 'Y' DIRECTION (FROM 'COOK'].</li> <li>FUNCTION: TESTS THE PROXIMITY SENSORS FEEDBACK FOR A LARGE ENOUGH SIGNAL TO INDICATE THAT THERE IS AN OBJECT IN FRONT OF AT LEAST ONE OF THE SENSORS. IF THIS THRESHOLD SIGNAL IS MOVED IN A SEARCH PATTERN UNTIL THE THRESHOLD LEVEL IS DETECTED.</li> <li>SUBROUTINE DETECT IMPLICIT INTEGER(E-Z) COMMON/ARMUF/ANEUF/AUEP,AZEF COMMON/OUT/AC(6),AXEP,AYEP,AZEF COMMON/OTAC(6),AXEP,AYEP,AZEF COMMON/OTACG(6),AXEP,AYEP,AZEF COMMON/OTACG(6),AXEP,AYEP,AZEF COMMON/ACRESCEDEDS ITION VALUES IN THE MATRIX AC(6) TO BE USED BY THE COORDINATE TRANSPORMATION ('COOR') CALL. DO 51 JJ=1,6 AC(JJ)=JPOS(JJ)</li> <li>SET THE COUNTER FOR MOVEMENT IN THE 'Y' DIRECTION EQUAL TO ZERO. AY=0.</li> <li>ZERO THE FLAG ('MIN') USED TO INDICATE THAT THE HAND SHOULD BE MOVING IN THE MINUS 'Y' DIRECTION. MIN=0</li> </ul>		C.	ALLED BY : EMOVE
INPUT DATA : JPOS(7) = THE PRESENT JOINT POSITION VALUES P1 = THE PRESENT VALUE OF THE SIGNAL FROM THE PROXIMITY SENSOR ON ONE OF THE FINGERS [FROM 'ARMIN' ON INPUT CHANNEL NUMBER 49]. P2 = THE PRESENT VALUE OF THE SIGNAL FROM THE PROXIMITY SENSOR ON THE OTHER FINGER [FROM 'ARMIN' ON INPUT CHANNEL NUMBER 48]. OUTPUT DATA : JPOS(7) = THE COMMANDED JOINT POSITION VALUES THAT WILL CAUSE THE ART TO MOVE ALONG A SEARCH PATH IN THE 'Y' DIRECTION [FROM 'COOR']. FUNCTION: TESTS THE PROXIMITY SENSORS FEEDBACK FOR A LARGE ENOUGH SIGNAL TO INDICATE THAT THERE IS AN OBJECT IN FROM TOF AT LEAST ONE OF THE SENSORS. IF THIS THRESHOLD SIGNAL IS NOT DETECTED BY EITHER SENSOR, THEN THE HAND IS MOVED IN A SEARCH PATTERN UNTIL THE THRESHOLD LEVEL IS DETECTED. SUBROUTINE DETECT IMPLICIT INTEGER(B-Z) COMMON/CORT/AC(6), AXEP, AYEP, AZEF COMMON/CORT/AC(6), TINBUF(28)) EQUIVALENCE(PAIDNT POSITION VALUES IN THE MATRIX AC(6) TO BE USED BY THE COORDINATE TRANSFORMATION ('COOR') CALL. D0 51 JJ=1,6 AC(JJ)=JPOS(JJ) SET THE COUNTER FOR MOVEMENT IN THE 'Y' DIRECTION EQUAL TO ZERO. AY=0. ZERO THE FLAG ('MIN') USED TO INDICATE THAT THE HAND SHOULD BE MOVING IN THE MINUS 'Y' DIRECTION. MIN=0		C.	ALLS SUBROUTINES : COOR ARMIN SERVO
<ul> <li>P2 = THE PRESENT VALUE OF THE SIGNAL FROM THE PROXIMITY SENSOR ON THE OTHER FINGER [FROM 'ARMIN' ON INPUT CHANNEL NUMBER 46].</li> <li> OUTPUT DATA : JPOS(7) = THE COMMANDED JOINT POSITION VALUES THAT WILL CAUSE THE ARM TO MOVE ALONG A SEARCH PATH IN THE 'I' DIRECTION [FROM 'COOR'].</li> <li> FUNCTION: TESTS THE PROXIMITY SENSORS FEEDBACK FOR A LARGE ENOUGH SIGNAL TO INDICATE THAT THERE IS AN OBJECT IN FRONT OF AT LEAST ONE OF THE SENSORS. IF THIS THRESHOLD SIGNAL IS MOVED IN A SEARCH PATTERN UNTIL THE THRESHOLD SIGNAL IS NOT DETECTED BY EITHER SENSOR, THEN THE HAND LEVEL IS DETECTED.</li> <li>SUBROUTINE DETECT IMPLICIT INTEGER(B-Z) COMMON/ORT/ARMBUF/INBUF(64), OUTBUF(64) COMMON/ORT/AC(6) COMMON/ORT/AC(6), AXEP, AYEP, AZEF COMMON/OFFS/OFF(3) EQUIVALENCE(P1, INBUF(28)) EQUIVALENCE(P1, INBUF(28)) CALL ARMIN</li> <li>PLACE THE PRESENT JOINT POSITION VALUES IN THE MATRIX AC(6) TO BE USED BY THE COORDINATE TRANSFORMATION ('COOR') CALL. DO 51 JJ=1,6 AC(JJ)=JPOS(JJ)</li> <li>SET THE COUNTER FOR MOVEMENT IN THE 'Y' DIRECTION EQUAL TO ZERO. AY=0.</li> <li>ZERO THE FLAG ('MIN') USED TO INDICATE THAT THE HAND SHOULD BE MOVING IN THE MINUS 'Y' DIRECTION.</li> <li>MIN=0</li> </ul>		II	NPUT DATA : JPOS(7) = THE PRESENT JOINT POSITION VALUES P1 = THE PRESENT VALUE OF THE SIGNAL FROM THE PROXIMITY SENSOR ON ONE OF THE FINGERS [FROM 'ARMIN' ON INPUT CHANNEL NUMBER 49].
<ul> <li>OUTPUT DATA : JPOS(7)</li> <li>= THE COMMANDED JOINT POSITION VALUES THAT WILL CAUSE THE ARM TO MOVE ALONG A SEARCH PATH IN THE 'Y' DIRECTION (FROM 'COOR').</li> <li> FUNCTION: TESTS THE PROXIMITY SENSORS FEEDBACK FOR A LARGE ENOUGH SIGNAL TO INDICATE THAT THERE IS AN OBJECT IN FRONT OF AT LEAST ONE OF THE SENSORS. IF THIS THRESHOLD SIGNAL IS NOT DETECTED BY EITHER SENSOR, THEN THE HAND IS MOVED IN A SEARCH PATTERN UNTIL THE THRESHOLD LEVEL IS DETECTED.</li> <li>SUBROUTINE DETECT IMPLICIT INTEGER(B-2) COMMON/ORT/AC(6), AXEP, AYEP, AZEF COMMON/ORT/AC(6), AXEP, AYEP, AZEF COMMON/ORT/AC(6), AXEP, AYEP, AZEF COMMON/OFFS/OFF(3) EQUIVALENCE(P1, INBUF(28)) CALL ARMIN</li> <li>PLACE THE PRESENT JOINT POSITION VALUES IN THE MATRIX AC(6) TO BE USED BY THE COORDINATE TRANSFORMATION ('COOR') CALL.</li> <li>DO 51 JJ=1,6 AC(JJ)=JPOS(JJ)</li> <li>SET THE COUNTER FOR MOVEMENT IN THE 'Y' DIRECTION EQUAL TO ZERO. AY=0.</li> <li>ZERO THE FLAG ('MIN') USED TO INDICATE THAT THE HAND SHOULD BE MOVING IN THE MINUS 'Y' DIRECTION.</li> <li>MIN=0</li> </ul>			P2 = THE PRESENT VALUE OF THE SIGNAL FROM THE PROXIMITY SENSOR ON THE OTHER FINGER [FROM 'ARMIN' ON INPUT CHANNEL NUMBER 48].
<ul> <li>FUNCTION: TESTS THE PROXIMITY SENSORS FEEDBACK FOR A LARGE ENOUGH SIGNAL TO INDICATE THAT THERE IS AN OBJECT IN FRONT OF AT LEAST ONE OF THE SENSORS. IF THIS THRESHOLD SIGNAL IS NOT DETECTED BY EITHER SENSOR, THEN THE HAND LEVEL IS DETECTED.</li> <li>SUBROUTINE DETECT IMPLICIT INTEGER(B-Z) COMMON/ARMEUF/INEUF(64), OUTBUF(64) COMMON/OUT/JPOS(8) COMMON/CORT/AC(6), AXEP, AYEP, AZEF COMMON/OFFS/OFF(3) EQUIVALENCE(EABORT, INBUF(28)) EQUIVALENCE(P1, INBUF(49)), (P2, INBUF(48)) CALL ARMIN</li> <li>PLACE THE PRESENT JOINT POSITION VALUES IN THE MATRIX AC(6) TO BE USED BY THE COORDINATE TRANSFORMATION ('COOR') CALL.</li> <li>D 51 JJ=1,6 AC(JJ)=JPOS(JJ)</li> <li>SET THE COUNTER FOR MOVEMENT IN THE 'Y' DIRECTION EQUAL TO ZERO. AY=0.</li> <li>ZERO THE FLAG ('MIN') USED TO INDICATE THAT THE HAND SHOULD BE MOVING IN THE MINUS 'Y' DIRECTION.</li> <li>MIN=0</li> </ul>		01	UTPUT DATA : JPOS(7) = THE COMMANDED JOINT POSITION VALUES THAT WILL CAUSE THE ARM TO MOVE ALONG A SEARCH PATH IN THE 'Y' DIRECTION [FROM 'COOR'].
SUBROUTINE DETECT IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64),OUTBUF(64) COMMON/OUT/JPOS(8) COMMON/CORT/AC(6),AXEP,AYEP,AZEP COMMON/OFFS/OFF(3) EQUIVALENCE(EABORT,INBUF(28)) EQUIVALENCE(EABORT,INBUF(28)) CALL ARMIN PLACE THE PRESENT JOINT POSITION VALUES IN THE MATRIX AC(6) TO BE USED BY THE COORDINATE TRANSFORMATION ('COOR') CALL. DO 51 JJ=1,6 AC(JJ)=JPOS(JJ) SET THE COUNTER FOR MOVEMENT IN THE 'Y' DIRECTION EQUAL TO ZERO. AY=0. ZERO THE FLAG ('MIN') USED TO INDICATE THAT THE HAND SHOULD BE MOVING IN THE MINUS 'Y' DIRECTION. MIN=0		F	UNCTION: TESTS THE PROXIMITY SENSORS FEEDBACK FOR A LARGE ENOUGH SIGNAL TO INDICATE THAT THERE IS AN OBJECT IN FRONT OF AT LEAST ONE OF THE SENSORS. IF THIS THRESHOLD SIGNAL IS NOT DETECTED BY EITHER SENSOR, THEN THE HAND IS MOVED IN A SEARCH PATTERN UNTIL THE THRESHOLD LEVEL IS DETECTED.
<pre>PLACE THE PRESENT JOINT POSITION VALUES IN THE MATRIX AC(6) TO BE USED BY THE COORDINATE TRANSFORMATION ('COOR') CALL. DO 51 JJ=1,6 AC(JJ)=JPOS(JJ) SET THE COUNTER FOR MOVEMENT IN THE 'Y' DIRECTION EQUAL TO ZERO. AY=0. ZERO THE FLAG ('MIN') USED TO INDICATE THAT THE HAND SHOULD BE MOVING IN THE MINUS 'Y' DIRECTION. MIN=0</pre>			SUBROUTINE DETECT IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64),OUTBUF(64) COMMON/OUT/JPOS(8) COMMON/CORT/AC(6),AXEP,AYEP,AZEF COMMON/OFFS/OFF(3) EQUIVALENCE(EABORT,INBUF(28)) EQUIVALENCE(P1,INBUF(28)),(P2,INBUF(48)) CALL ARMIN
DO 51 JJ=1,6 AC(JJ)=JPOS(JJ) SET THE COUNTER FOR MOVEMENT IN THE 'Y' DIRECTION EQUAL TO ZERO. AY=0. ZERO THE FLAG ('MIN') USED TO INDICATE THAT THE HAND SHOULD BE MOVING IN THE MINUS 'Y' DIRECTION. MIN=0		PLA	CE THE PRESENT JOINT POSITION VALUES IN THE MATRIX AC(6) TO BE USED BY THE COORDINATE TRANSFORMATION ('COOR') CALL.
SET THE COUNTER FOR MOVEMENT IN THE 'Y' DIRECTION EQUAL TO ZERO. AY=0. ZERO THE FLAG ('MIN') USED TO INDICATE THAT THE HAND SHOULD BE MOVING IN THE MINUS 'Y' DIRECTION. MIN=0	51	I	DO 51 JJ=1,6 AC(JJ)=JPOS(JJ)
AY=0. ZERO THE FLAG ('MIN') USED TO INDICATE THAT THE HAND SHOULD BE MOVING IN THE MINUS 'Y' DIRECTION. MIN=0		SET	THE COUNTER FOR MOVEMENT IN THE 'Y' DIRECTION EQUAL TO ZERO.
ZERO THE FLAG ('MIN') USED TO INDICATE THAT THE HAND SHOULD BE MOVING IN THE MINUS 'Y' DIRECTION. MIN=0	-		A Y = 0.
60 MIN=0		ZER	O THE FLAG ('MIN') USED TO INDICATE THAT THE HAND SHOULD BE MOVING IN THE MINUS 'Y' DIRECTION.
	60 50	)	MIN=0

TEST EACH PROXIMITY SENSOR FOR THE THRESHOLD VALUE AND RETURN С С TO THE CALLING PROGRAM ('EMOVE') IF THIS VALUE IS DETECTED. С IF(P1.GT.2000)GOTO 45 20 IF(P2.GT.2000)GOTO 45 С IF MOVING IN THE '-Y' DIRECTION, THEN BRANCH TO THE SECTION OF CODE TO DECREMENT THE DELTA 'Y' COUNTER ('AY'). С С С IF(MIN.EQ.1)GOTO 30 С С ONCE THE HAND HAS MOVED 15 CENTIMETERS IN THE PLUS DIRECTION. С THEN BRANCH TO THE CODE TO MOVE THE HAND IN THE MINUS С DIRECTION. С IF(AY.GT.15.)GOTO 31 С С THIS SECTION OF CODE ASSIGNS THE DELTA MOTION ('AYSIGN') AS С A POSITIVE .2 CENTIMETER. С 25 MIN = 0AYSIGN = .2GOTO 50 С IF THE HAND HAS MOVED 15 CENTIMETERS IN THE MINUS DIRECTION FROM С С THE INITIAL LOCATION, THEN BRANCH TO THAT CODE TO REVERSE С THE DIRECTION OF MOTION TO THE '+Y' DIRECTION. С 30 IF(AY.LT.-15.)GOTO 25 С С THIS SECTION OF CODE ASSIGNS THE DELTA MOTION ('AYSIGN') AS С A NEGATIVE .2 CENTIMETER. THE FLAG ('MIN') INDICATING MOVEMENT IN THE NEGATIVE 'Y' DIRECTION IS SET EQUAL TO ONE. С С 31 MIN = 1AYSIGN = -.2С С HERE, THE DELTA MOTION IN THE 'Y' DIRECTION ('AYSIGN') IS ADDED С TO THE TOTAL DELTA 'Y' ('AY') FROM THE ORIGINAL STARTING POINT С TO DETERMINE WHAT THE NEW DELTA IS. С 50 AY = AY + AYSIGNС С THIS DELTA 'Y' OFFSET FROM THE STARTING POINT IS TRANSFORMED С INTO THE PROPER JOINT POSITION VALUES BY A CALL TO С THESE JOINT POSITION VALUES ARE THEN 'COOR'. С SENT TO THE SERVOS TO BE EXECUTED BY A CALL TO 'SERVO'. ΙN С THIS WAY THE HAND MOVES IN THE 'Y' DIRECTION ALONG A PATH С THAT EXTENDS 15 CENTIMETERS ON EITHER SIDE OF THE STARTING С POINT MOVING IN INCREMENTS OF .2 CENTIMETERS AND CHECKING FOR С THE THRESHOLD LEVEL FROM THE SENSORS. С CALL COOR(0., AY, 0., 0, 0) CALL SERVO(0) IF(EABORT.GT.-2000)GOTO 20

45	OFF(2)=OFF(2)+100#AY
40	RETURN
	END



C C		SUBROUTINE : BAL
C		ARGUMENTS :
C		CALLED BY : EMOVE
C		CALLS SUBROUTINES : COOR ARMIN SERVO
		INPUT DATA : JPOS(7) P1 = THE PRESENT JOINT POSITION VALUES = THE PRESENT VALUE OF THE SIGNAL FROM THE PROXIMITY SENSOR ON ONE OF THE FINGERS [FROM 'ARMIN' ON INPUT CHANNEL NUMBER 49].
		P2 = THE PRESENT VALUE OF THE SIGNAL FROM THE PROXIMITY SENSOR ON THE OTHER FINGER [FROM 'ARMIN' ON INPUT CHANNEL NUMBER 48].
		OUTPUT DATA : JPOS(7) = THE COMMANDED JOINT POSITION VALUES THAT WILL CAUSE THE ARM TO MOVE ALONG A SEARCH PATH IN THE 'Y' DIRECTION [FROM 'COOR'].
		FUNCTION: ASSUMES THAT AT LEAST ONE OF THE PROXIMITY SENSORS IS ABOVE THE THRESHOLD VALUE, IE. AN OBJECT HAS BEEN DETECTED). THIS ROUTINE THEN INCREMENTS THE HAND'S MOTION IN THE DIRECTION SO AS TO CAUSE THE TWO PROXIMITY SIGNALS TO BE EQUAL. IF BOTH SENSORS DO NOT REACH THE THRESHOLD VALUE, THIS ROUTINE CAUSES THE HAND TO MOVE UNTIL THE OBJECT DETECTED IS WITHIN THE GRASP OF THE HAND (IE. IT ALIGNS THE INSIDE EDGE OF ONE FINGER WITH THE OUTSIDE EDGE OF THE DETECTED OBJECT).
0		SUBROUTINE BAL IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64),OUTBUF(64) COMMON/OUT/JPOS(8) COMMON/CORT/AC(6),AXEP,AYEP,AZEP COMMON/OFFS/OFF(3) EQUIVALENCE(EABORT,INBUF(28)) EQUIVALENCE(P1,INBUF(28)),(P2,INBUF(48)) CALL ARMIN
C C C	PL	ACE THE PRESENT JOINT POSITION VALUES IN THE MATRIX AC(6) TO BE USED BY THE COORDINATE TRANSFORMATION ('COOR') CALL.
51 C		DO 51 JJ=1,6 AC(JJ)=JPOS(JJ)
C C	SEI	THE COUNTER FOR MOVEMENT IN THE 'Y' DIRECTION EQUAL TO ZERO.
С		A Y = 0.
C C	ΤH	E FLAGS ('M' AND 'P') TO INDICATE IF THE HAND IS BEING MOVED IN A MINUS OR PLUS 'Y' DIRECTION DURING THE BALANCE FUNCTION,

D	[-/	4	9

C ARE SET EQUAL TO ZERO.

M = 0

С

С

С

С

С

С

С

С

С

С

P = 0

- C THE DIFFERENCE BETWEEN THE VALUES OF THE TWO PROXIMITY SENSORS IS C CALCULATED AND STORED IN 'DS'.
- 30 DS=P1-P2
- C THE ALGEBRAIC SIGN OF 'DS' IS AN INDICATION OF WHICH OF THE TWO C SIGNALS IS THE LARGER AND IS USED TO DETERMINE WHICH C CODE SHOULD NOW BE EXECUTED. C
  - IF(DS.GT.0)GOTO 20
- C IF 'P2' IS THE LARGER SIGNAL, THEN THE HAND SHOULD MOVE IN THE C '-Y' DIRECTION, THEREFORE, THE DELTA 'Y' MOTION VALUE ('AYSIGN') C IS ASSIGNED THE VALUE OF -.05 CENTIMETERS. THE MINUS 'Y' C DIRECTION FLAG ('M') IS SET EQUAL TO ONE.

AYSIGN = -.05 M = 1

- С THE PLUS 'Y' DIRECTION FLAG ('P') IS TESTED. IF IT IS EQUAL TO С ONE, THIS MEANS THAT THE HAND WAS MOVING IN THE PLUS 'Y' С DIRECTION AND NOW THE SENSORS INDICATE IT SHOULD MOVE IN THE С MINUS 'Y' DIRECTION. FOR THIS SITUATION TO OCCUR, THE С SENSORS MUST HAVE PAST THROUGH A BALANCE POINT (IE. 'P1' WAS С THE LARGER, NOW 'P2' IS THE LARGER. BETWEEN THESE TWO С CONDITIONS, 'P1' MUST HAVE EQUALED 'P2'), THEREFORE, RETURN TO С THE CALLING PROGRAM ('EMOVE') BECAUSE THE BALANCE POINT HAS BEEN С OBTAINED. С
  - IF(P.EQ.1)GOTO 45
- C IF THE CONDITION OCCURS THAT 'P2' STARTS DECREASING C IN VALUE BEFORE THE 'BALANCE' CONDITION IS REACHED, THEN BRANCH TO THE SECTION OF CODE THE 'EDGE' DETECTION. SINCE 'P2' C WAS ABOVE THE THRESHOLD LEVEL AND IS NOW DECREASING, THE SENSOR C MUST BE PASSING ACROSS THE EDGE OF THE UNDERLYING OBJECT. C

IF(P2.LT.1500)GOTO 75 GOTO 50

- C IF 'P1' IS THE LARGER SIGNAL, THEN MOVE IN THE PLUS 'Y' DIRECTION C BY ASSIGNING A VALUE OF +.05 CENTIMETERS TO 'AYSIGN'. C
- 20 AYSIGN=.05
- C THE SAME TYPE OF TESTS MADE FOR THE MINUS 'Y' MOTION ABOVE C ARE ALSO MADE HERE FOR THE PLUS 'Y' MOTION. C

P=1 IF(M.EQ.1)GOTO 45 IF(P1.LT.1500)GOTO 80 С С THE ACTUAL COMMANDED MOTION OF THE ARM IS CALCULATED BY THE С FOLLOWING CODE. FIRST 'AY', THE TOTAL DELTA 'Y' MOTION FROM С THE STARTING POINT IS CALCULATED USING THE DELTA 'Y' VALUE ASSIGNED ABOVE. THEN A CALL TO 'COOR', THE COORDINATE TRANSFORMATION ROUTINE, CALCULATES THE CORRECT JOINT POSITION VALUES FOR THE LOCATION 'AY' DISTANCE AWAY FROM THE STARTING С С С С THEN A CALL TO 'SERVO' SENDS THESE VALUES OUT TO THE SERVO POINT. С SYSTEM OF THE ARM. 'ARMIN' IS CALLED TO BRING IN THE CURRENT С VALUES OF THE PROXIMITY SENSORS FOR ANOTHER TEST, STARTING С BACK AT STATEMENT 30. С 50 AY=AY+AYSIGN CALL COOR(0., AY, 0., 0, 0) CALL SERVO(0) IF(EABORT.LT.-2000)GOTO 40 GOTO 30 С IF AN EDGE IS DETECTED BY 'P2', THEN THE FOLLOWING CODE ADVANCES С С THE HAND AN ADDITIONAL DISTANCE IN THE '-Y' DIRECTION (WHICH С DISTANCE IS EQUAL TO THE THICKNESS OF THE FINGER THAT THE С SENSOR 'P2' IS ATTACHED TO ) TO PLACE THE INSIDE SURFACE OF С THE FINGER FLUSH WITH THE UNDERLYING DETECTED EDGE. С DO 77 GT=1,48 75 AY = AY = .05CALL COOR(0., AY, 0., 0, 0) 77 CALL SERVO(0) GOTO 45 С С IF 'P1' DETECTS AN EDGE, THIS CODE MOVES THE HAND IN THE '+Y' С DIRECTION BY AN AMOUNT EQUAL TO THE THICKNESS OF THE FINGER AS С ABOVE. С 80 DO 81 GGT=1,40 AY = AY + .05CALL COOR(0., AY, 0., 0, 0) 81 CALL SERVO(0) 45 OFF(2) = OFF(2) + 100 # AY40 RETURN END


C --- SUBROUTINE : GRASP С С --- ARGUMENTS : D IF D=0THIS IS THE QUICK CLOSE COMMAND. THE POSITION VALUE OF THE FINGERS IN С С THE CLOSED POSITION IS SENT TO THE С SERVOS. CONTROL IS IMMEDIATELY С RETURNED TO THE CALLING PROGRAM С WITHOUT WAITING FOR THE FINGERS TO С COMPLETE THE CLOSING OPERATION. С IF D=1HERE, THE FINGERS ARE CLOSED AN С INCREMENT AT A TIME UNTIL A DIFFERENCE С IS DETECTED BETWEEN THE COMMANDED С POSITION AND THE ACTUAL POSITION AS С READ IN FROM THE POSITION INDICATOR. С С --- CALLED BY : EMOVE С --- CALLS SUBROUTINES : ARMIN SERVO С С С = THE INPUT CHANNEL THAT CONTAINS --- INPUT DATA : INBUF(19) С THE PRESENT VALUE OF THE POSITION С INDICATOR FOR THE FINGERS. С = THE COMMANDED OUTPUT POSITION VALUE С --- OUTPUT DATA : JPOS(7) С FOR THE FINGERS. С JPOS(8) = THE DIGITAL (16 BITS) OUTPUT CHANNEL С THAT CONTROLS THE SETTING OF THE BRAKES ON ALL OF THE JOINTS. С С С --- FUNCTION: CAUSES THE FINGERS TO CLOSE UNTIL THEY EXERT A PREDEFINED С FORCE ON AN OBJECT, THEN IT SETS THE BRAKE ON THE С FINGERS (D=O). OR SENDS OUT THE POSITION COMMAND THAT WILL RESULT IN THE FINGERS CLOSING ALL OF THE WAY (D=1). С С SUBROUTINE GRASP(D) IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64),OUTBUF(64) COMMON/OUT/JPOS(8) EQUIVALENCE(EABORT, INBUF(28)) COMMON/GRIP/HAND С С READ IN THE PRESENT POSITION OF THE FINGERS AND SET THE OUTPUT С POSITION COMMAND FOR THE FINGERS (JPOS(7)) EQUAL TO THIS С VALUE. С CALL ARMIN JPOS(7) = 2\*INBUF(19) + 16383С С SEND OUT THE PROPER CODE NUMBER TO SET UP THE BIT PATTERN С ON OUTPUT CHANNEL 8 (JPOS(8)) TO RELEASE THE BRAKE ON THE С FINGERS. С JPOS(8) = 32767CALL SERVO(0) С С TEST 'D'. IF D=1, THEN SEND THE POSITION VALUE OF 6600 TO THE

00000000000		FINGER SERVO (THIS IS USED TO CLOSE THE FINGERS SO THAT THE SENSORS CAN BE USED IN SOME OF THE SEARCH ROUTINES. THE OUTPUTTING OF THIS VALUE TO THE SERVOS CAUSES THE FINGERS TO CLOSE COMPLETELY, HOWEVER, THIS ROUTINE DOES NOT WAIT FOR THIS ACTION TO BE FINISHED BEFORE RETURNING TO THE CALLING PROGRAM. AS A RESULT, THE FINGERS WILL STILL BE IN MOTION WHILE THE OTHER SUBROUTINES OF THE CONTROL SYSTEM ARE IN EXECUTION.). IF D=O THEN BRANCH TO STATEMENT 20.
C		IF(D.NE.1)GOTO 20 JPOS(7)=6600 CALL SERVO(0) GOTO 40
C C C	THE	COUNTER 'KB' WHICH IS USED IN THE DETECTION OF THE GRIPPING FORCE OF THE FINGERS IS SET EQUAL TO ZERO.
20		K B = 0
C C C	THE	JOINT POSITION COMMAND FOR THE FINGERS (JPOS(7)) IS DECREMENTED WHICH WILL CAUSE AN INCREMENTAL CLOSING WHEN SENT TO THE SERVO.
100		JPOS(7)=JPOS(7)-100 CALL SERVO(0)
	THE	INPUT CHANNELS ARE SAMPLED TO DETERMINE IF AN ABORT HAS BEEN CALLED, AND TO DETERMINE THE PRESENT VALUE OF THE POSITION OF THE FINGERS ('FINGER').
c		IF(EABORT.LT2000)GOTO 40 FINGER=2*INBUF(19)+16383
	THE	DIFFERENCE BETWEEN THE PRESENT POSITION ('FINGER') OF THE FINGERS AND THE COMMANDED (JPOS(7)) POSITION OF THE FINGERS IS CALCULATED AND STORED IN TST.
c		TST=FINGER-JPOS(7)
00000000	AS I	ONG AS THIS DIFFERENCE ('TST') IS LESS THAN 800, THEN WE CONTINUE TO DECREMENT THE COMMANDED POSITION VALUE, THUS CONTINUING TO CLOSE THE FINGERS. IF, HOWEVER, THE DIFFERENCE BECOMES GREATER THAN 800, WE THEN USE 'KB' AS A COUNTER AND SAMPLE THE PRESENT POSITION FOR .2 SEC (KB=50) TO MAKE CERTAIN THAT THE FINGERS ARE NO LONGER CLOSING. THIS INDICATES THAT THE FINGERS HAVE GRASPED AN OBJECT WITH A CERTAIN FORCE.
		IF(TST.LT.800)GOTO 20 KB=KB+1 IF(KB.LT.50)GOTO 100
C C C	ONCE	E AN OBJECT IS GRASPED, THE BRAKE ON THE FINGERS IS SET BY SETTING THE OUTPUT CHANNEL 8 ((POS(8)) EQUAL TO 32703.
310 C		JPOS(8)=32703 CALL SERVO(0)

THE PRESENT POSITION VALUE OF THE FINGERS IS READ IN AND THE COMMANDED POSITION VALUE (JPOS(7)) OF THE FINGERS SET EQUAL TO IT. THIS ZEROS THE SERVO ERROR, THEREFORE, THE ACTUATOR IS NO LONGER DRIVING THE FINGERS TO CLOSE, SINCE THE BRAKE WILL NOW HOLD THE FINGERS CLOSED ON THE OBJECT.

CALL ARMIN JPOS(7)=2\*INBUF(19)+16383

## THE ACTUAL POSITION VALUE OF THE FINGERS IS STORED IN THE COMMON VARIABLE 'HAND' SO THAT IT CAN BE ACCESSED BY OTHER SUBROUTINES IF NECESSARY.

HAND=JPOS(7) CALL SERVO(0) RETURN END

C C

С

С

С

С

C C

С

С

С

40

DI-55



DI-56

87 69 69 -- X -

--- SUBROUTINE : RELEAS C С С --- ARGUMENTS : С С --- CALLED BY : EMOVE С --- CALLS SUBROUTINES : ARMIN SERVO С С --- INPUT DATA : INBUF(19) = THE INPUT CHANNEL THAT CONTAINS С С THE PRESENT VALUE OF THE POSITION С INDICATOR FOR THE FINGERS. С С --- OUTPUT DATA : JPOS(7) = THE COMMANDED OUTPUT POSITION VALUE С FOR THE FINGERS. С JPOS(8) = THE DIGITAL (16 BITS) OUTPUT CHANNEL С THAT CONTROLS THE SETTING С OF THE BRAKES ON ALL OF THE JOINTS. С С --- FUNCTION: CAUSES THE FINGERS OF THE HAND TO FULLY OPEN. С SUBROUTINE RELEAS IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64),OUTBUF(64) COMMON/OUT/JPOS(8) EQUIVALENCE(EABORT, INBUF(28)) С С SEND OUT THE PROPER CODE NUMBER TO SET UP THE BIT PATTERN С ON OUTPUT CHANNEL 8 (JPOS(8)) TO RELEASE THE BRAKE ON THE С FINGERS. С JPOS(8) = 32767С С SEND THE POSITION VALUE OF 31000 TO THE SERVO. WHEN THE FINGERS С ARE SERVOED TO THIS POSITION THEY WILL BE FULLY OPENED. С JPOS(7) = 31000CALL SERVO(0) С С С THE INPUT CHANNELS ARE SAMPLED TO DETERMINE IF AN ABORT HAS BEEN С CALLED, AND TO DETERMINE THE PRESENT VALUE OF THE POSITION С OF THE FINGERS ('FINGER'). С 100 CALL ARMIN IF(EABORT.LT.-2000)GOTO 40 FINGER = 2\*INBUF(19) + 16383С С IF THE FINGERS HAVE NOT YET REACHED THE FULLY OPENED POSITION С THEN CONTINUING SAMPLING THEIR POSITION (GOTO STATEMENT 100). С IF(FINGER.LT.30400)GOTO 100 С С ONCE THE HAND IS FULLY OPENED, SET THE BRAKE (JPOS(8)), AND SET THE COMMANDED POSITION VALUE OF THE FINGERS EQUAL TO С С THEIR PRESENT POSITION. С JPOS(8) = 32703JPOS(7) = FINGERCALL SERVO(0) 40 RETURN DI-57 END



--- SUBROUTINE : PTOUCH C С С --- ARGUMENTS : С С --- CALLED BY : EMOVE С С --- CALLS SUBROUTINES : ARMIN SERVO COOR С С --- INPUT DATA : INBUF(48) = 'P2' THE VALUE OF ONE OF THE PROXIMITY С SENSORS. С JPOS(1-7)= THE JOINT POSITION VALUES AT THE С BEGINNING OF THE ROUTINE. С JPOS(1-7)= THE JOINT POSITION COMMANDS NECESSARY С TO MOVE THE ARM TO THE POSITION С DELTA 'Z' FROM THE STARTING POINT [FROM С 'COOR']. С С --- OUTPUT DATA : ADY = THE PRESENT DELTA 'Y' OFFSET VALUE FROM С THE INITIAL POSITION OF THE ARM. С = THE PRESENT DELTA 'Z' OFFSET VALUE FROM ADZ С THE INITIAL POSITION OF THE ARM. = THE JOINT POSITION COMMANDS TO BE С JPOS(1-7)С SENT TO THE SERVOS. С OFF(1-3)= THE TOTAL OFFSET IN THE X, THE Y, С AND THE Z DIRECTIONS FROM THE ORIGINAL С STARTING LOCATION. С С --- FUNCTION: CAUSES THE HAND TO DESCEND IN A STRAIGHT LINE IN THE 'Z' С DIRECTION WHILE TESTING THE VALUE OF THE SENSOR С FOR A THRESHOLD LEVEL EVERY .2 CENTIMETER. WHEN THE С THRESHOLD LEVEL IS DETECTED, THE HAND IS С STOPPED AT THAT LOCATION AND CONTROL IS RETURNED TO THE С CALLING PROGRAM. С SUBROUTINE PTOUCH IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64), OUTBUF(64) COMMON/OFFS/OFF(3) COMMON/OUT/JPOS(8) COMMON/CORT/AC(6), AXEP, AYEP, AZEP EQUIVALENCE(EABORT, INBUF(28)) EQUIVALENCE(P1, INBUF(49)), (P2, INBUF(48)) С С SET THE DELTA 'Y' (ADY) AND THE DELTA 'Z' VALUE EQUAL TO ZERO. С ADY = 0. ADZ = 0. С С PLACE THE PRESENT JOINT POSITION VALUES IN THE COMMON С VARIABLE 'AC(1-6)' FOR USE BY 'COOR'. С DO 20 J=1.6 20 AC(J) = JPOS(J)С С MOVE THE HAND 3.0 CENTIMETERS IN THE '+Y' DIRECTION TO С POSITION THE SENSOR ON THE OUTSIDE EDGE OF THE FINGER

C C	OVER THE EXPECTED CENTER OF THE STACK.
30 C	DO 30 J=1,12 ADY=ADY+.25 CALL COOR(0.,ADY,0.,0,0) CALL SERVO(0)
C C C	TEST THE VALUE OF THE PROXIMITY SENSOR TO DETERMINE IF THE TOP OF THE STACK HAS BEEN DETECTED.
50 C	IF(P2.GT.1500)GOTO 35
C C C	MOVE THE HAND ANOTHER .2 CENTIMETERS IN THE '-Z' DIRECTION, THEN TEST THE SENSOR VALUE AGAIN.
36	ADZ=ADZ2 CALL COOR(0.,ADY,ADZ,0,0) CALL SERVO(0) IF(EABORT.LT2000)GOTO 40 GOTO 50
С	ONCE THE TOD OF THE STACK HAS DEEN DETECTED. MOVE THE HAND DOWN
C C C	SLOWLY UNTIL THE THRESHOLD LEVEL IS DETECTED.
35	ADZ=ADZ03 IF(P2.GT.4000)GOTO 45 GOTO 36
C C C	UPDATE THE TOTAL OFFSET VALUES BY THE AMOUNTS MOVED DURING THIS SUBROUTINE CALL.
45 40	OFF(2)=100*ADY+OFF(2) OFF(3)=100*ADZ+OFF(3) RETURN END





DI-62

C --- SUBROUTINE : COOR С С --- ARGUMENTS : AX = THE 'X' COORDINATE VALUE С THE 'Y' COORDINATE VALUE. ΑY = С ΑZ = THE 'Z' COORDINATE VALUE. С DA THE FLAG TO INDICATE WHETHER THE С 'AX, AY, AZ' VALUES ARE ABSOLUTE COORDINATE С POSITIONS (DA=1), OR DELTA COORDINATE OFFSETS С FROM THE PRESENT POSITION OF THE ARM (DA=0). С NA = THE FLAG TO INDICATE WHETHER THE JOINT С COORDINATE VALUES ARE TO BE CALCULATED (NA=0). С OR NOT (NA=1). С С --- CALLED BY : JOY LOCTAB ARRLOC EMOVE STLINE CALD DETECT С BAL PTOUCH С С --- CALLS SUBROUTINES : C --- INPUT DATA : AX, AY, AZ, DA, NA С AS EXPLAINED ABOVE С = THE VALUES OF THE SIX JOINT COORDINATES AC(1-6)С USED AS A REFERENCE POINT FOR THIS С TRANSFORMATION. С A04,A05,A06 = THE VALUES OF THE OFFSETS FOR THE FOURTH, С FIFTH, AND SIXTH JOINTS (FROM 'JOY'). С С --- OUTPUT DATA : AXEP, AYEP, AZEP = THE NEW 'X, Y, Z' COORDINATE POSITION С CALCULATED FROM THE REFERENCE С POINT (AC(1-6)) AND THE INPUT 'X,Y,Z' С VALUES (AX,AY,AZ). С = THE JOINT POSITION VALUES THAT JPOS(1-6)С ARE CALCULATED FROM THE REFERENCE С POINT (AC(1-6)) AND THE INPUT 'X,Y,Z' С VALUES (AX, AY, AZ). С С --- FUNCTION: TRANSFORMS THE 'X,Y,Z' COORDINATE VALUES FOR A POSITION С IN SPACE INTO THE CORRESPONDING JOINT COORDINATE VALUES, С AND VISE VERSA. (THIS IS ONLY A THREE AXIS TRANSFORMATION, С NOT THE ENTIRE SIX AXIS TRANSFORMATION. THE FOURTH. С FIFTH AND SIXTH AXIS PLANOGRAPH THE MOTIONS С OF THE FIRST THREE.) С SUBROUTINE COOR(AX, AY, AZ, DA, NA) IMPLICIT INTEGER(D-R) COMMON/XYZO/A04,A05,A06 COMMON/CORT/AC(6), AXEP, AYEP, AZEP COMMON/OUT/JPOS(8) COMMON/ARMBUF/INBUF(64), OUTBUF(64) DIMENSION AOM(6) С С TEST IF AX, AY, AZ ARE TO BE DELTA OR ABSOLUTE COORDINATES. С IF(DA)5,5,6 С С IF ABSOLUTE, SET 'AXEP', 'AYEP', 'AZEP' EQUAL TO THEM AND BRANCH С TO STATEMENT 10 TO CALCULATE THE CORRESPONDING JOINT POSITION C VALUES.

```
С
6
         A X E P = A X
         A Y E P = A Y
         AZEP = AZ
         GOTO 10
С
С
    IF AX, AY, AZ ARE DELTA COORDINATE OFFSETS, CALCULATE COORDINATES
С
         OF PRESENT POSITION (PRESENT POSITION JOINT INDICATOR
С
         VALUES ARE IN 'AC(1-6)').
С
5
         AR=(34552.-AC(3))/358.7
         AT1 = (15018. - AC(6)) / 5182.
         AT2=(17821.-AC(2))/5190.
         ARR=AR*COS(AT2)
         AB = SQRT(275.56 + ARR * * 2)
         AA = ATAN(ARR / 16.6)
         AG = AT1 + AA - 1.5708
C********
         AAZ = AR * SIN(AT2)
         AAX = AB * COS(AG)
         AAY=AB*SIN(AG)
C********
С
С
    ADD PRESENT POSITION X,Y,Z COORDINATE VALUES TO THE COMMANDED
С
         DELTA COORDINATE OFFSET VALUES.
С
         A X E P = A A X + A X
         A Y E P = A A Y + A Y
         AZEP = AAZ + AZ
С
С
    IF JOINT POSITIONS NOT TO BE CALCULATED (NA=1), THEN RETURN TO THE
С
         CALLING PROGRAM.
С
         IF(NA.EQ.1)GOTO 40
C*********
С
С
    CALCULATE THE JOINT POSITION VALUES THAT CORRESPOND TO THE POSITION
С
         IN SPACE DESIGNATED BY THE COORDINATES 'AXEP', 'AYEP', 'AZEP'.
С
10
         ARRPS=AXEP**2+AYEP**2-275.56
         IF(ARRPS)1323,1323,1324
         WRITE(6,1325)ARRPS
1323
         FORMAT(2X'ERROR** ARRPS=',F10.3)
1325
         READ(6, 1326)KKR
1326
         FORMAT(I3)
1324
         ARRP=SQRT(ARRPS)
         IF(AXEP)202,201,200
202
         IF(AYEP)203,204,204
203
         AT1P = ATAN(AYEP/AXEP) - 1.5708 - ATAN(ARRP/16.6)
         GOTO 205
204
         AT1P = ATAN(AYEP/AXEP) - 1.5708 - ATAN(ARRP/16.6)
         IF(AT1P.GT.-1.60)GOTO 205
         AT1P = ATAN(AYEP/AXEP) + 4.7124 - ATAN(ARRP/16.6)
         IF(AT1P.LT.2.54)GOTO 205
         WRITE(6,220)
220
        FORMAT(2X'THIS IS FORBIDDEN!!')
```

```
GOTO 40
201
         AXEP = .0001
200
         AT1P = ATAN(AYEP/AXEP) + 1.5708 - ATAN(ARRP/16.6)
205
         ARP=SQRT(ARRPS+AZEP**2)
         AT2P = ATAN(AZEP/ARRP)
C****
      ****
1000
         AOM(6) = 15018. - (AT1P*5182.)
         AOM(2) = 17821 - (AT2P*5190.)
         AOM(3) = 34552 \cdot - (ARP*358 \cdot 7)
         AOM(4) = 17437 + AO4
         AOM(5) = 1.202 * AOM(2) - 16461. + AO5
         AOM(1) = -.8837 * AOM(6) + 35380 + AO6
С
С
    TEST TO MAKE CERTAIN THAT ALL THE NEW JOINT VALUES
С
         (JPOS(1-6)) ARE WITHIN THEIR ALLOWABLE LIMITS.
С
720
         DO 265 JB=1,6
         IF(AOM(JB).GT.30000.)GOTO 266
         IF(AOM(JB).LT.2000.)GOTO 267
         JPOS(JB) = AOM(JB)
         GOTO 265
266
         JPOS(JB) = 30000
         GOTO 265
267
         JPOS(JB) = 2000
265
         CONTINUE
40
         RETURN
         END
```



--- SUBROUTINE : SERVO С С С --- ARGUMENTS : SD IF SD=-1 ZERO THE EIGHT OUTPUT CHANNELS С FOR THE 'SEND' FUNCTION COMMAND. С IF SD=0 SEND OUT TO THE SERVOS, THE SEVEN С JOINT POSITION COMMANDS AND THE VALUE С IN JPOS(8) FOR CONTROLLING THE BRAKES. С IF 'SD' IS A NON-ZERO VALUE, IT IS THE SD= С OUTPUT CHANNEL NUMBER ON WHICH A VOLTAGE С LEVEL IS TO BE SENT AS REQUESTED BY THE С 'SEND' FUNCTION. С С --- CALLED BY : EMOVE RELEAS STLINE BAL GRASP DETECT С PTOUCH ACC JOY С С --- CALLS SUBROUTINES : ARMOUT ARMIN С С --- INPUT DATA : SD = THE ARGUMENT AS EXPLAINED ABOVE. PNT = THE FLAG IN COMMON MEMORY THAT IF IT IS SET EQUAL TO ONE CAUSES THIS SUBROUTINE 'SERVO' TO MAINTAIN CONTROL UNTIL THE ACTUAL POSITION OF THE JOINTS IS WITHIN SOME MINIMUM DISTANCE OF THE COMMANDED JOINT POSITIONS. С С --- OUTPUT DATA : OUTBUF(1)-OUTBUF(8) = THE SEVEN COMMANDED JOINT С POSITION VALUES, AND THE С 15-BIT DIGITAL CHANNEL FOR С CONTROLLING THE BRAKES. С OUTBUF(9)-OUTBUF(16)= THE EIGHT OUTPUT CHANNELS THAT С CAN BE USED BY THE 'SEND' С FUNCTION COMMAND. THIS IS USED С FOR THE INTERLOCKING OF THE ARM С EXTERNAL DEVICES. С С --- FUNCTION: USES THE ARGUMENT TO DETERMINE WHICH OUTPUTS SHOULD BE С SENT TO THE ROBOT WORK STATION. ALL OUTPUTS FROM С THE CONTROL SYSTEM ARE MADE THROUGH THIS CALL. THESE С INCLUDE THE JOINT POSITION COMMANDS, THE CONTROL OF С ALL OF THE JOINT BRAKES, AND THE VOLTAGE LEVEL SIGNALS С ON THE SPECIFIED OUTPUT CHANNELS. С SUBROUTINE SERVO(SD) IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64), OUTBUF(64) COMMON/END/PNT COMMON/OUT/JPOS(8) DIMENSION ERRT(12), ERR(6), INP(6) EQUIVALENCE(EABORT, INBUF(28)) DATA ERRT/700,700,1500,700,1000,700,200,100,360,200,280,100/ С С THE FLAG 'PNT' IS TESTED TO SEE WHICH GROUP OF DELTA JOINT VALUES С FROM 'ERRT' IS TO BE USED. IF 'PNT' IS EQUAL TO ZERO, THEN С THE ONLY REQUIREMENT ON THE ACTUAL POSITION OF ALL С OF THE JOINTS IS THAT DIFFERENCE BETWEEN THEIR PRESENT POSITION С AND THEIR NEXT COMMANDED POSITION NOT BE GREATER THAN THE

С DISTANCE THAT THEY CAN MOVE IN THAT NEXT INCREMENT. IF 'PNT' IS EQUAL TO ONE, THEN THIS SUBROUTINE WILL LOOP, SENDING THE SAME С COMMANDED POSITION VALUES UNTIL THE ACTUAL POSITION OF С THE JOINTS IS WITHIN SOME MINIMUM DISTANCE OF THESE VALUES С С (THESE MINIMUM VALUES ARE IN 'ERRT(7-12)'). С KS = 0IF(PNT.EQ.0)GOTO 55 PNT = 0KS = 655 CALL ARMIN KP = 0С С WHEN THE ACTUAL POSITION VALUES OF THE JOINTS ARE READ IN, С A CORRECTION FACTOR IS USED TO COMPENSATE FOR THE ERRORS INTRODUCED IN THE CONVERSION ELECTRONICS IN THE INTERFACE С С AND THE HARDWARE SERVO SYSTEM. С INP(1) = INBUF(5) \* 2. + 16361INP(2) = INBUF(8) \* 1.9758 + 16394INP(3) = INBUF(11) \* 2.002 + 16369INP(4) = INBUF(13) \* 2.033 + 16370INP(5)=INBUF(15)\*1.9808+16270 INP(6) = INBUF(17) \* 1.994 + 16349DO 710 KKK=1,6 ERR(KKK) = INP(KKK) - OUTBUF(KKK)KM = KS + KKKIF(ERR(KKK).GT.ERRT(KM))GOTO 58 IF(ERR(KKK).LT.-ERRT(KM))GOTO 58 710 CONTINUE GOTO 77 58 KP = 177 IF(EABORT.LT.-2000)GOTO 40 С С A CALL IS MADE TO 'ARMIN' FOR SWITCH 34. IF THIS SWITCH IS UP, THE ARM WILL STOP AT ITS PRESENT POSITION AND REMAIN С С THERE UNTIL THE SWITCH IS FLIPPED DOWN. IF(INBUF(34).LT.-2000)GOTO 55 С С THE VARIABLE 'SD' IS USED TO BRANCH TO THE APPROPRIATE CODE С IF(SD)10,20,30 С С FOR 'SD'=-1, ZERO ALL OF THE OUTPUT CHANNELS USED BY THE 'SEND' С FUNCTION COMMAND. С 10 DO 15 K=9,16 OUTBUF(K) = 1638315 GOTO 35 С С FOR 'SD'=0, OUTPUT THE SEVEN JOINT POSITION COMMANDS AND С THE VALUE (JPOS(8)) FOR CONTROLLING THE BRAKES. С 20 DO 25 JK=1,8 OUTBUF(JK)=JPOS(JK) 25 CALL ARMOUT(8)

GOTO 45

С

00000

FOR 'SD'= SOME NUMBER BETWEEN ONE AND EIGHT, SET 'CH' EQUAL TO THIS NUMBER PLUS EIGHT AND OUTPUT A +5 VOLT SIGNAL ON THIS CHANNEL. HERE, THE NUMBER 'SD' WILL HAVE BEEN SPECIFIED BY THE 'SEND' FUNCTION COMMAND.

30	CH = 8 + SD	
	OUTBUF(CH) = 8192	
35	CALL ARMOUT(16)	
45	IF(KP.NE.O)GOTO 55	
40	RETURN	
	END	

•	.TITLE A .IDENT /	ARMOUT FOR 'RMR01/	LOW L	EVEL	ARM	OUTF	UT					
2 2	CALLING	SEQUENCE I	s:									
9 . 9 . 9	CALL ARM	10UT(COUNT, WH	[BUFF ERE [	ER]) BUFFE THERE	R] I	S OP	TION	AL				
3	.GLOBL	VAL	NOI	; THE ; ARM	001 001	45 I MUST	S TO SLO	O FAS	ST, . √N, ` ΓΗΔΤ	ARMIN VAL I	I AN Is A	ID
ARMOUT				, "OI	DIC	, 1151		00 1	IIIAI	•		
	мот	VAL. RO										
	MOVB	@R5,R4		;GET :IN	THE THE	NUM CALL	IBER .ING	OF AI SEQUE	RGUM ENCE	ENTS		
	MOV	@2(R5),R3		;GET ;SEN	THE	NUM THE	IBER E ARM	OF P(	TNIC	S TO		
	MOV	#OUTBUF,R2		; ASS ; FOR	UME ARM	OUTE	BUF I SPUT	S USI	ED			
	DEC	R 4										
	BEQ	1\$		;THE ;SO	NUM USE	IBER OUTE	OF A BUF,	RGUMI OTHEI	ENTS RWIS:	WAS E	ONE	2
	MOV	4(R5),R2		USE	THE	ARF	RAYS	PECIE	FIED			
1\$:	MOV	#167772.R4		POI	NT T	O TH	IE AR	M INT	<b>FERF</b>	ACE		
	MOV	#-1.0R4		AND	RES	SET I	Т					
2\$:	DEC	RO		,								
- + •	BPL	2\$										
	MOV	VAL. RO		:11/	45 I	S TO	O FA	ST. S	so. '	TIMEC	TUC	
	MOV	$(R_2) + 0R_4$		:011	PUT	FROM	1 THE	BUFF	FER			
	DEC	R3		;COU ;TO	NT I SENI	OWN TO	ON N THE	UMBEI	ROF	POIN	ITS	
	BGT	2\$		: THE	N SE	ND T	HEM					
	MOV	#-1.0R4		:RES	ET A	FTEF	2					
		<i>"</i> , , , , , , , , , , , , , , , , , , ,		; THE	WRJ	TE (	6-MA	Y = 74	)			
				: THI	S CA	USES	LES	s cui	R R E N '	т		
				DRA:	TNC	N TF	IE PO	WER S	SUPP	LIES	ΤN	THE
				; D / A	CON	IVERT	TER					
	RTS	R5		:THE	N GC	HOM	1E					
;				,								
* 9 9	IMPLICIT INTEGER(A-Z) COMMON/ARMBUF/INBUF(64),OUTBUF(64)											
;	.CSECT A	ARMBUF										
UTBUF = .	+200											
. = . +400	.CSECT											
	. END											

.TITLE ARMIN FOR LOW LEVEL ARM INPUT .IDENT /RMR01/

; ARMIN AND ARMOUT HAVE SIMILAR DOCUMENTATION. THE TWO PROGRAMS ; SHOULD BE READ TOGETHER AS SOME DOCUMENTATION EXISTS IN ; ONE AND NOT THE OTHER.

.CSECT

;

1

THE ARM IS CONTROLLED BY A DR11-C INTERFACE TO THE PDP-11/45 UNIBUS. ALTHOUGH ALL THE INTERRUPT FACILITY AVAILABLE WITH THE DR11-C IS INTACT, NO INTERRUPTS ARE USED WITH THIS VERSION OF THE ARM SOFTWARE. THE GENERAL PHILOSOPHY OF THE SOFTWARE IS SUCH THAT DATA TRANSFER TO AND FROM THE ARM WILL OCCURE WHENEVER A PROGRAM WANTS AND/OR HAS THE TIME.

; THE DR11-C HAS A UNIBUS ADDRESS OF 167770 ; THIS IS THE CONTROL REGISTER. 167772 IS THE TRANSMIT REGISTER ; AND 167774 IS THE RECEIVE REGISTER. THE A/D CONVERTER ; IS RESET WHENEVER IT SEES BIT 15 SET. AT LOCATION 24, THE A/D CONVERTER ; IS RESET. ; ALL 64 CHANNELS ARE READ INTO THE COMMON BLOCK NAMED ARMBUF ; THIS IS FORTRAN COMPATIBLE COMMON. ALSO THE SUBROUTINE LINKAGE ; IS COMPATIBLE.

VAL::	.WORD	25	;TIME OUT VALUE ;IS SET AT 10 WHICH CAUSES THIS ;ROUTINE TO WAIT (SEE LOOP 1\$) ;LONG ENOUGH FOR THE A/D CONVERTER ;TO SETTLE DOWN BETWEEN READS.
ARMIN::			'
	MOV	VAL,RO	;THE 11/45 RUNS TOO FAST ;SO WE WILL USE RO TO ;TIMEOUT BETWEEN READS.
	MOV	#167772,R2	LOAD THE CSR OUTPUT REG
	MOV	#-1,(R2)+	WITH A RESET AND POINT
			;TO THE INPUT SIDE
	MOV	#64.,R4	;COUNT UP TO 64 POINTS
	MOV	#INBUF,R3	; POINT TO THE FIRST WORD
1\$:	DEC	RO	;COUNT DOWN FOR 11/45 TIMEOUT
	BPL	1\$	
	MOV	VAL, RO	
	MOV	$e_{R2}, (R3) +$	;LOAD THE INBUF WITH 64 POINTS
	DEC	R4	
	BGT	1\$	
	RTS	R5	;THEN RETURN
2	TNDLTOT		
;	COMMON	ARMBUF/INBUF(64)	),OUTBUF(64)
;			
; WHEN	CSED WIT	H FORTRN, COMPILI ARMBUF	WITH THE FON SWITCH
INBUF=. OUTBUF=	.+200		
. = . + 400			
	.CSECT		
	.END		

## Program Module (Module #2)

PROGS	-	Reads in editor commands and calls	
		appropriate subroutine.	DII-2

## Editor Commands

INSERT	-	Causes elemental move commands to be entered	
		in program table.	DII-6
PRINT	-	Causes the program table to be printed out	
		as elemental move commands.	DII-10
DELETE	-	Deletes specified lines from program table.	DII-14
AVOID	-	Creates avoidance paths by inserting additional	
		location points.	DII-18
LOOP	-	Creates the additional lines in an indexed	
		repeat pattern.	DTT-22

## Additional Support Subroutines

INDEX	-	Codes indexed location names into their location table pointers.	DII-26
LOCPT	-	Codes non-indexed location names into their location table pointers.	DII-30
LINE	-	Codes elemental move command into a line in program table.	DII-34
PTNAME	-	Decodes location table pointer into its location name.	DII-40
PLINE	-	Prints out decoded line from program table as elemental move commands.	DII-44
NEXT	-	Advances through input character string to next piece of information.	DII-48
LIMIT	-	Decodes into integer from the lines specified in the editor commands.	DII-52
ADJUST	-	Verifies continuity in the specified motion in the program.	DII-56



DII-2

```
C
 --- SUBROUTINE : PROGS
С
С
  --- ARGUMENTS :
С
С
 --- CALLED BY : OPRO
С
С
  --- CALLS SUBROUTINES : INDEX
                                   INSERT
                                           DELETE
                                                    PRINT
                                                            RECORD
С
                           AVOID
                                   ARMIN
С
С
  --- INPUT DATA : PROG(105,6) = THE PROGRAM MODULE THAT IS TO BE MODIFIED
С
                               = THE ASCII CHARACTER STRING THAT CONTAINS
                    CS(50)
С
                                  THE 'EDITOR' COMMANDS.
С
С
  --- OUTPUT DATA : PROG(105,6)= THE EDITED PROGRAM MODULE.
С
С
  --- FUNCTION: EDITS AN OLD PROGRAM FROM THE DISC, OR ENTERS A
С
                 NEW PROGRAM THROUGH THE USE OF THE PROPER
С
                 EDITOR COMMANDS.
С
        SUBROUTINE PROGS
        IMPLICIT INTEGER(B-Z)
        COMMON/PMOD/PROG(105,6), ENDP, BRNCH(6), M
        COMMON/IND/IN(30), FL(6), NAME(3), NPT(3,20)
        COMMON/CMD/CS(50), PN, PLN
        COMMON/ARMBUF/INBUF(64), OUTBUF(64)
        EQUIVALENCE(RET, INBUF(30))
С
С
    THE SPECIFIED PROGRAM MODULE IS READ IN FROM THE DISC BY THE CALL
        TO 'RDMOD' IN 'EXPRO'. THE INDEXED NAMES ARE STORED IN THE
С
С
        CHARACTER STRING IN(30).
С
500
        M = 0
        DO 204 J=101,105
        DO 204 L=1,6
        M = M + 1
204
        IN(M) = PROG(J,L)
        PLN = 1
С
С
    THE CALL TO 'INDEX' PRINTS THE PRESENT INDEXED LOCATION NAMES
С
        AND ALLOWS THE ENTERING OF NEW INDEXED NAMES.
С
        CALL INDEX(0)
        WRITE(6,125)
125
        FORMAT(8X'EDITOR IS NOW AVAILABLE FOR PROGRAM ENTRY',/)
С
С
    THE CURRENT INDEXED NAMES ARE STORED IN THE LAST
С
        FIVE LINES OF THE PROGRAM MODULE.
С
        M = 0
        DO 210 J=101,105
        DO 210 L=1,6
        M = M + 1
210
        PROG(J,L) = IN(M)
С
С
    THE COMMAND FROM THE TERMINAL IS READ INTO THE
С
        CHARACTER STRING CS(50) AND TESTED TO SEE IF THE FIRST
```

с с с с с	LETTER IS THE ASCII CODE NUMBER FOR I(INSERT),D(DELETE),P(PRINT), R(RECORD),OR A(AVOID). THE PROPER SUBROUTINE IS CALLED FOR THE IDENTIFIED CODE LETTER. IF NO VALID LETTER IS FOUND, THE MESSAGE 'ILLEGAL COMMAND' IS PRINTED AND THE PROGRAM WAITS FOR THE NEXT COMMAND.
99 200	READ(6,200)(CS(N),N=1,50) FORMAT(50(A1)) CALL ARMIN IF(RET.GT2000)GOTO 40
77	PN=1 IF(CS(PN).NE.8265)GOTO 220
220	IF(CS(PN).NE.8260)GOTO 221 CALL DELETE
221	IF(CS(PN).NE.8272)GOTO 222 CALL PRINT GOTO 77
222	IF(CS(PN).NE.8274)GOTO 223 CALL RECORD(0,1) GOTO 405
223	IF(CS(PN).NE.8270)GOTO 224 GOTO 500
224	IF(CS(PN).NE.8257)GOTO 255 CALL AVOID GOTO 99
255	IF(RET.GT2000)GOTO 40
100	WRITE(6,101)
101	FORMAT(8X'ILLEGAL COMMAND') GOTO 99
405	WRITE(6,225)
225	FORMAT(8X,'PROGRAM HAS BEEN STORED ON DISC') GOTO 99
40	RETURN END







```
--- SUBROUTINE : INSERT
С
С
С
 --- ARGUMENTS :
С
С
  --- CALLED BY : PROGS
С
С
  --- CALLS SUBROUTINES : NEXT LIMIT PLINE
                                                LOOP LOCPT
                                                              LINE ADJUST
С
С
  --- INPUT DATA : CS(50)
                               = THE CHARACTER STRING THAT CONTAINS THE
С
                                  INPUT COMMAND STATEMENT.
С
                    BEG
                                 THE LINE NUMBER IN THE PROGRAM MODULE
                               =
С
                                  WHERE THE INSERTION OCCURS [LIMIT].
С
                    PLN
                               = THE PRESENT PROGRAM LINE NUMBER,
С
                                  HERE, SET EQUAL TO 'BEG'.
С
                    ΒN
                               = THE LOCATION TABLE POINTER FOR THE
C
                                  FIRST LOCATION IN THE PROGRAM MODULE,
С
                                  ENTERED BY 'START' COMMAND [LOCPT].
С
                    PROG(PLN, 6) = THE DECODED NEW LINE IN THE PROGRAM
С
                                 MODULE [LINE].
С
С
  --- OUTPUT DATA : PROG(105, 6) =
                                     THE UPDATED PROGRAM MODULE
С
С
  --- FUNCTION: TO INSERT NEW LINES AT THE SPECIFIED PROGRAM LINE,
С
                 SLIDING BACK THE REST OF THE PROGRAM TO
С
                 ACCOMMODATE THESE ADDITIONAL LINES.
С
        SUBROUTINE INSERT
        IMPLICIT INTEGER(B-Z)
        COMMON/PMOD/PROG(105,6), ENDP, BRNCH(6), M
        COMMON/PTN/BN.EN
        COMMON/BED/BEG, FIN, DIF, ERR
        COMMON/CMD/CS(50), PN, PLN
        DIMENSION TEMP(100,6)
        ERR = 0
С
С
    STORE PRESENT PROGRAM MODULE (PROG(105,6))IN A TEMPORARY MATRIX
С
        CALLED TEMP(100,6).
С
        DO 50 K=1,100
        DO 50 F=1,6
50
        TEMP(K, F) = PROG(K, F)
С
С
    IDENTIFY AND DECODE THE PROGRAM LINE NUMBER WHERE THE
С
        INSERTION IS TO OCCUR.
С
500
        CALL NEXT
        IF(PN.GT.50)GOTO 27
        CALL LIMIT
        IF(ERR.EQ.1)GOTO 100
        PLN=BEG
27
        STAR=PLN
        GOTO 160
С
С
    ERROR MESSAGE TO BE PRINTED OUT IF A INCORRECT COMMAND IS
С
        ENTERED IN THIS SUBROUTINE.
С
```

100 WRITE(6,101) 101 FORMAT(8X, 'ILLEGAL FORMAT FOR \*\*\* INSERT (J) \*\*\*') GOTO 40 С С PRINT OUT ON THE TERMINAL THE PRESENT PROGRAM LINE (PLN). С 160 CALL PLINE(PLN) С С READ IN A NEW LINE (CS(50)) AND TEST ON THE FIRST CHARACTER, С RETURN TO CALLING PROGRAM IF IT IS AN EDITOR COMMAND (INSERT, NAME, AVOID, DELETE, PRINT, OR RECORD). ٠C 170 READ(6, 171)(CS(L), L=1, 50)171 FORMAT(50(A1)) PN = 1IF(CS(PN).EQ.8265)GOTO 400 IF(CS(PN).EQ.8270)GOTO 400 IF(CS(PN).EQ.8257)GOTO 400 IF(CS(PN).EQ.8260)GOTO 400 IF(CS(PN).EQ.8272)GOTO 400 IF(CS(PN).EQ.8274)GOTO 400 С С TEST FOR A 'LOOP' COMMAND. С IF(CS(PN).NE.8268)GOTO 182 CALL LOOP PLN = PLN + 1GOTO 170 С TEST FOR A 'START' COMMAND, IE. THE ENTERING OF THE FIRST С С LOCATION POINT IN THE PROGRAM MODULE. С 182 IF(CS(PN).NE.8275)GOTO 183 CALL NEXT CALL LOCPT(1) PROG(1,1) = BNSTAR=1PLN = 1GOTO 170 С С TEST FOR A 'GOTO' ELEMENTAL MOVE COMMAND, CALL 'LINE' TO С RECORD AND DECODE THE CORRECT VALUES FOR THE PROGRAM MODULE. С 183 IF(CS(PN).NE.8263)GOTO 100 CALL LINE PLN = PLN + 1GOTO 170 С С PUSH BACK THE REST OF THE PROGRAM LINES TO ACCOMMODATE THE С NEWLY INSERTED LINES, AND STORE UPDATED PROGRAM IN THE С PROGRAM MODULE PROG(105,6). С 400 IF(PLN.NE.1)GOTO 401 GOTO 40 401 END=PLN-STAR PT = 101 - PLNIF(PLN.NE.1)GOTO 60

	PROG(1,2)=TEMP(1,1) FND-1
	PT=99
60	DO 450 MB=1,PT
	FD = 101 - MB
	DIF = FD - END
	DO 450 MT=1,6
450	PROG(FD,MT)=TEMP(DIF,MT)
451	CALL ADJUST
	PLN=STAR
40	RETURN
	END



RE TURN

C --- SUBROUTINE : PRINT С С --- ARGUMENTS : С С --- CALLED BY : PROGS С --- CALLS SUBROUTINES : NEXT LIMIT PLINE С С С --- INPUT DATA : CS(50) = CHARACTER STRING THAT CONTAINS THE С EDITOR COMMAND TO PRINT A LINE(S) С PLN = THE NUMBER OF THE PRESENT PROGRAM LINE С (MAY NOT BE THE LINE SPECIFIED IN THE С 'PRINT' COMMAND). С BEG = THE NUMBER (IF SPECIFIED IN THE PRINT С COMMAND) OF THE FIRST LINE TO BE С PRINTED [FROM 'LIMIT']. С = THE NUMBER OF LINES TO BE PRINTED STARTING DIF С FROM LINE 'BEG' (IF MORE THAN ONE LINE С HAS BEEN SPECIFIED IN THE COMMAND). С С --- OUTPUT DATA : PLN THE NUMBER OF THE PROGRAM LINE TO BE = С PRINTED OUT ON THE TERMINAL (SENT С TO THE SUBROUTINE 'PLINE'). С --- FUNCTION: DECODES THE PRINT COMMAND TO DETERMINE HOW MANY LINES ARE С С TO BE PRINTED AND WHAT ARE THEIR LINE NUMBERS IN THE С PROGRAM MODULE. С SUBROUTINE PRINT IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64), OUTBUF(64) COMMON/BED/BEG, FIN, DIF, ERR COMMON/CMD/CS(50), PN, PLN ERR=0С TEST TO SEE IF THE LINES HAVE BEEN SPECIFIED IN THE 'PRINT' С COMMAND (IE. IS THEIR ANY CHARACTERS AFTER THE WORD С С 'PRINT' IN THE CHARACTER STRING CS(50)). IF SO, THEN С GO TO STATEMENT 20. С 60 CALL NEXT IF(PN.LT.51)GOTO 20 С С IF NO LINE NUMBERS ARE SPECIFIED IN THE 'PRINT' С COMMAND THEN THE NUMBER OF LINES TO BE PRINTED (DIF) IS SET С EQUAL TO ONE . С PLN = PLN - 1DIF = 1GOTO 70 С С THIS IS THE ERROR MESSAGE DISPLAYED ON THE TERMINAL IF AN INCORRECT С FORMAT IS USED. С 100 WRITE(6,101) FORMAT(8X'FORMAT ERROR IN \*\*\* PRINT (J-K) \*\*\* STATEMENT') 101

GOTO 40 С С IF LINES ARE SPECIFIED IN THE 'PRINT' COMMAND SET PLN EQUAL С TO THE FIRST LINE TO BE PRINTED (IE. SET PLN EQUAL TO С BEG FROM 'LIMIT') AND CALCULATE THE NUMBER OF LINES TO BE С PRINTED 'DIF' [FROM 'LIMIT']. С 20 CALL LIMIT IF(ERR.EQ.1)GOTO 100 PLN = BEG - 1С С EACH TIME THROUGH THIS LOOP A LINE FROM THE PROGRAM MODULE IS С PRINTED OUT (BY A CALL TO 'PLINE') AND THE LINE NUMBER 'PLN' С IS INCREMENTED. С 70 DO 50 K=1,DIF PLN = PLN + 150 CALL PLINE(PLN) С С THE NEXT COMMAND IS READ INTO CS(50) FROM THE TERMINAL AND THE С FIRST LETTER OF THE COMMAND WORD TESTED TO SEE IF IT IS С A D(DELETE), I(INSERT), N(NAME), P(PRINT), R(RECORD), С A(AVOID). IF ONE OF THESE EDITOR COMMANDS, THEN С RETURN TO THE CALLING PROGRAM 'PROGS'. С 65 READ(6, 66)(CS(RN), RN = 1, 50)66 FORMAT(50(A1))С С IF THE CALLING SWITCH (SWITCH 30) IS RESET, THEN RETURN TO С CALLING PROGRAM. С CALL ARMIN IF(INBUF(30).GT.-2000)GOTO 40 PN = 1IF(CS(PN).EQ.8260)GOTO 40 IF(CS(PN).EQ.8265)GOTO 40 IF(CS(PN).EQ.8270)GOTO 40 IF(CS(PN).EQ.8272)GOTO 40 IF(CS(PN).EQ.8274)GOTO 40 IF(CS(PN).EQ.8257)GOTO 40 С С TEST IF A MINUS SIGN WAS ENTERED INDICATING THE PREVIOUS LINE IS С TO BE PRINTED. THIS IS DONE BY SUBTRACTING ONE FROM THE С PRESENT LINE NUMBER PLN. С IF(CS(PN).NE.8237)GOTO 51 PLN = PLN - 1GOTO 31 С С TEST TO SEE IF ONLY A CARRIAGE RETURN WAS ENTERED INDICATING THAT С THE NEXT LINE OF THE PROGRAM MODULE IS TO BE PRINTED. THIS С IS DONE BY ADDING ONE TO THE PRESENT PROGRAM LINE NUMBER AND С CALLING 'PLINE'. С 51 IF(CS(PN).NE.8224)GOTO 100 PLN = PLN + 1

31	CALL	PLINE(PLN)
	GOTO	65
40	RETUR	N
	END	



С --- SUBROUTINE : DELETE С --- ARGUMENTS : С С --- CALLED BY : PROGS С С С --- CALLS SUBROUTINES : NEXT LIMIT PLINE ADJUST С С --- INPUT DATA : PROG(105,6) = THE PRESENT PROGRAM MODULE С CS(50)= THE CHARACTER STRING THAT CONTAINS С THE 'DELETE' COMMAND. С = THE NUMBER OF THE FIRST LINE TO BE BEG С DELETED [FROM 'LIMIT']. С DIF = THE NUMBER OF LINES TO BE DELETED AS С SPECIFIED IN THE 'DELETE' COMMAND [FROM С 'LIMIT']. С FIN = THE NUMBER OF THE LAST LINE TO BE DELETED С [FROM 'LIMIT']. С PN = A POINTER THAT INDICATES THE POSITION С IN THE CHARACTER STRING CS(50) OF THE NEXT С PIECE OF INFORMATION [FROM NEXT]. С С --- OUTPUT DATA : PROG(105,6) =THE MODIFIED PROGRAM MODULE AFTER С THE SPECIFIED LINES HAVE BEEN DELETED AND THE REST OF THE PROGRAM CLOSED С С UP AROUND THE DELETED LINES. С PLN THE POINTER TO THE PRESENT PROGRAM = С LINE. С С --- FUNCTION: DELETES THE SPECIFIED LINES FROM THE PROGRAM, PRINTS C OUT THE DELETED LINES ON THE TERMINAL, AND CLOSES С UP THE PROGRAM MODULE AROUND THE DELETED LINES. С SUBROUTINE DELETE IMPLICIT INTEGER(B-Z) COMMON/PMOD/PROG(105,6), ENDP, BRNCH(6), M COMMON/BED/BEG, FIN, DIF, ERR COMMON/CMD/CS(50), PN, PLN ERR=0С С ADVANCE THROUGH THE CHARACTER STRING CS(50) UNTIL THE NUMBER OF THE С FIRST LINE OF THE PROGRAM TO BE DELETED IS REACHED BY С CALLING 'NEXT'. C CALL NEXT IF(PN.LT.51)GOTO 20 С С ERROR MESSAGE THAT IS PRINTED OUT IF AN INCORRECT С FORMAT IS DETECTED IN THE 'DELETE' COMMAND. С 100 WRITE(6.101)FORMAT(8X'FORMAT ERROR IN \*\*\* DELETE (J-K)\*\*\* STATEMENT') 101 GOTO 40 С С THE FIRST LINE SPECIFIED TO BE DELETED IS DECODED BY A CALL TO С 'LIMIT' AND RETURNED IN THE VARIABLE 'BEG'. THE NUMBER

С OF LINES TO BE DELETED IS ALSO DETERMINED BY 'LIMIT' AND С RETURNED IN THE VARIABLE 'DIF'. С 20 CALL LIMIT IF(ERR.EQ.1)GOTO 100 С С AN INTERMEDIATE VARIABLE 'NEN' IS CREATED TO BE USED IN С THE CLOSING UP PROCEDURE WHERE THE REMAINDER OF THE PROGRAM С LINES ARE SLID FORWARD TO CLOSE THE GAP CREATED BY THE С DELETION OF THE SPECIFIED LINES. С NEN = 100 - DIFIF(BEG.NE.1)GOTO 70 С С THE STARTING LOCATION OF THE PROGRAM IS SAVED IN THE VARIABLE 'TEM' С TO BE REINSERTED IN THE PROGRAM MODULE AFTER ALL OF С THE ADJUSTMENTS HAVE BEEN MADE. С TEM = PROG(1, 1)С С THE FOLLOWING 'DO LOOP' DELETES THE SPECIFIED LINES AND CLOSES С UP THE PROGRAM AT THE SAME TIME BY MOVING ALL OF THE PROGRAM С LINES FORWARD 'DIF' NUMBER OF LINES, STARTING WITH LINE С NUMBER 'BEG' + 'DIF'. С 70 DO 50 K=BEG,NEN JMP = K + DIFIF(K.GT.FIN)GOTO 30 PLN = KС EACH LINE, AS IT IS DELETED, IS PRINTED OUT ON THE TERMINAL С С BY A CALL TO 'PLINE'. С CALL PLINE(PLN) 30 DO 50 F=1,6 50 PROG(K, F) = PROG(JMP, F)IF(BEG.NE.1)GOTO 71 PROG(1, 1) = TEMС С ANY INCOMPLETE LINES THAT MIGHT HAVE BEEN CREATED ARE С ELIMINATED BY THE SUBROUTINE 'ADJUST'. С 71 CALL ADJUST 40 RETURN END




C		SUBROUTINE : AVOID												
000000000000000000000000000000000000000		ARGUMENTS :												
		CALLED BY : PROGS												
		CALLS SUBROUTINES : NEXT LOCPT ADJUST												
		<pre>INPUT DATA : PROG(105,6) CS(50) = THE PRESENT PROGRAM MODULE. THE CHARACTER STRING THAT CONTAINS THE PROPER SEQUENCE OF LOCATIONS TO BE USED IN THE AVOIDANCE PATH. THE LOCATION TABLE POINTER FOR EACH LOCATION SPECIFIED IN THE CHARACTER STRING CS(50) [FROM 'LOCPT']. THE MODIFIED PROGRAM MODULE WITH ALL OF THE ADDITIONAL LINES REQUIRED TO CREATE THE AVOIDANCE PATHS THROUGH THE SPECIFIED LOCATIONS.</pre>												
		<pre>FUNCTION: IF A TRAJECTORY FROM LOCATION 'A' TO LOCATION'B' IS TO PASS THROUGH ADDITIONAL INTERMEDIATE LOCATIONS, THIS SUBROUTINE INSERTS THOSE ADDITIONAL LOCATIONS IN THE CORRECT SEQUENCE FOR EVERY OCCURRENCE OF 'A-B' OR 'B-A' IN THE PROGRAM MODULE BY MEANS OF A SINGLE 'AVOID' COMMAND. SUBROUTINE AVOID IMPLICIT INTEGER(B-Z) COMMON/PMOD/PROG(105,6),ENDP,BRNCH(6),M COMMON/PTN/BN,EN COMMON/CMD/CS(50),PN,PLN COMMON/TEMPOR/TEMP(100,6),DET(10),NDET(10)</pre>												
C C C C C C C C C C C C C C C C C C C	A	FLAG ('REV') IS SET EQUAL TO ZERO. IT WILL BE USED TO INDICATE IF THE PROGRAM MODULE HAS BEEN CORRECTED FOR THE AVOIDANCE PATH IN THE REVERSE SEQUENCE ALSO. REV=0												
	THI	E FOLLOWING LOOP DETERMINES THE NUMBER OF LOCATION POINTS IN THE AVOIDANCE PATH (AS SPECIFIED IN THE CHARACTER STRING CS(50)) AND DECODES THEM INTO THEIR PROPER LOCATION TABLE POINTERS BY CALLING 'LOCPT'. DO 30 JK=1,10 CALL NEXT IF(PN.GT.50)GOTO 20 CALL LOCPT(1) DET(JK)=BN GOTO 77 JK=JK-1												
C C C	T	HE FOLLOWING LOOP SEQUENTIALLY TESTS EVERY LINE IN THE PROGRAM MODULE FOR THE PRESENCE OF BOTH OF THE END POINTS OF THE AVOIDANCE PATH. IF BOTH IN THE SAME LINE, THEN BRANCH												

```
С
        TO CODE TO INSERT ADDITIONAL LINES.
С
77
        DO 25 JB=1,100
        IF(PROG(JB, 1).EQ.DET(1))GOTO 22
        GOTO 25
22
        IF(PROG(JB,2).EQ.DET(JK))GOTO 50
25
        CONTINUE
        GOTO 35
С
С
    THE FOLLOWING LOOP STORES THE PROGRAM MODULE IN A TEMPORARY
С
        TABLE WHICH ACTS AS A SCRATCH PAD UNTIL ALL OF THE REQUIRED
С
        MODIFICATIONS HAVE BEEN MADE.
С
50
        DO 75 K=1,100
        DO 75 F = 1, 6
75
        TEMP(K, F) = PROG(K, F)
С
    THIS LOOP INSERTS THE ADDITIONAL LINES FOR THE AVOIDANCE PATH,
С
С
        ZEROS THE FUNCTION FLAGS FOR THESE INTERMEDIATE LOCATIONS AND
С
        SETS THE VELOCITY (PROG(NV,3)) EQUAL TO 50 CM/SEC.
С
        VE = PROG(JB, 3)
        DO 76 FT=2,JK
        NV = JB + FT - 2
        DO 79 RD=3,6
        PROG(NV, RD) = 0
79
        PROG(NV, 3) = VE
76
        PROG(NV, 2) = DET(FT)
С
    THE REMAINDER OF THE PROGRAM IS NOW ADDED ON TO THE NEWLY INSERTED
С
С
        LINES.
С
        END = NV - JB
        PT = 101 - NV
        DO 450 MB=1,PT
        FD = 101 - MB
        DIF = FD - END
        DO 450 MT=1,6
450
        PROG(FD,MT)=TEMP(DIF,MT)
С
С
    THE SUBROUTINE 'ADJUST' IS CALLED TO INSURE THAT
С
        ALL OF THE LOCATIONS ARE IN THE PROPER SEQUENCE.
С
        CALL ADJUST
С
С
    RETURN TO THE LOOP TO CONTINUE TESTING THE PROGRAM MODULE
С
        FOR ANY OTHER PLACES WHERE THE AVOIDANCE PATH IS TO BE USED.
С
        GOTO 77
С
С
    IF THE REVERSE FLAG ('REV') HAS NOT BEEN SET EQUAL TO ONE, THEN
С
        SET IT EQUAL TO ONE AND REVERSE THE SEQUENCE OF THE LOCATION
С
        POINTS IN THE AVOIDANCE PATH (DET(10)), AND GO BACK AND
С
        TEST THE PROGRAM MODULE FOR ANY PLACES WHERE THE REVERSE
С
        PATH IS TO BE USED.
                              AFTER ALL OF THESE MODIFICATIONS
С
        HAVE BEEN DONE, THE REVERSE FLAG WILL BE TESTED AGAIN,
```

C C C	FOUND E PROGRAM	QUAL •	ΤO	ONE	AND	CONTROL	WILL	RETURN	ΤO	THE	CALLING
35	IF(REV. REV=1 DO 60 L	EQ.1) L=1,J	GOT К	0 40	)						
60	NDET(LL)=DET(LL) DO 61 LL=1,JK OL=JK+1-LL										
61	DET(LL) GOTO 77	= NDE T	(01	,)							
40	RETURN END										



```
C --- SUBROUTINE : LOOP
С
С
 --- ARGUMENTS :
С
С
 --- CALLED BY : INSERT
С
С
 --- CALLS SUBROUTINES : LINE
С
С
 --- INPUT DATA : CS(50)
                                  = THE CHARACTER STRING THAT CONTAINS
С
                                    AN ELEMENTAL MOVE ('GOTO') COMMAND.
С
                    PLN
                                  = THE NUMBER OF THE PRESENT LINE IN THE
С
                                    PROGRAM MODULE.
С
                    BN
                                  = LOCATION TABLE POINTER FOR AN ENTERED
С
                                    LOCATION (IF INDEXED NAME THIS IS
С
                                    THE FIRST POINTER OF THE INDEXED
С
                                    SEQUENCE [FROM LINE].
С
                    EN
                                  = THE LOCATION TABLE POINTER FOR THE LAST
С
                                    LOCATION SPECIFIED BY THE INDEXED
С
                                    SEQUENCE [FROM LINE].
С
                    PROG(105,6)
                                 = THE PROGRAM MODULE.
С
 --- OUTPUT DATA : PROG(105,6)
С
                                    = THE MODIFIED PROGRAM MODULE
С
                                      WITH THE ADDITIONAL LINES GENERATED
С
                                      BY THE 'LOOP' COMMAND.
                                     THE NUMBER OF THE LAST LINE ENTERED
С
                     PLN
                                    c
С
                                      IN THE PROGRAM MODULE BY THE 'LOOP'
С
                                      COMMAND.
С
  --- FUNCTION: TO ALLOW ENTRY OF A REPEATED SEQUENCE OF ELEMENTAL
С
С
                 MOVES WHERE ONLY THE LOCATIONS ARE
С
                 DIFFERENT AND ARE DESIGNATED BY INDEXED NAMES.
С
        SUBROUTINE LOOP
        IMPLICIT INTEGER (B-Z)
        COMMON/PMOD/PROG(105,6), ENDP, BRNCH(6), M
        COMMON/PTN/BN, EN
        COMMON/CMD/CS(50), PN, PLN
        DIMENSION STR(50)
        K = 1
С
С
    ZERO THE ARRAY STR(50)
С
        DO 55 H=1,50
55
        STR(H)=0
С
С
    STORE THE FIRST PROGRAM LINE NUMBER OF THE 'LOOP' SEQUENCE
С
        IN THE VARIABLE 'BEGIN'.
С
        BEGIN=PLN
С
С
    READ IN A COMMAND FROM THE TERMINAL.
С
99
        READ(6, 90)(CS(J), J=1, 50)
90
        FORMAT(50(A1))
        PN = 1
C
```

С IF THE COMMAND IS A 'FINISH' STATEMENT THEN BRANCH TO С STATEMENT 20 TO GENERATE THE ADDITIONAL REPEATED LINES. С IF(CS(PN).EQ.8262)GOTO 20 С С IF THE COMMAND IS A 'GOTO' STATEMENT, THEN BRANCH TO STATEMENT С 30 TO DECODE IT. С IF(CS(PN).EQ.8263)GOTO 30 С С IF THE COMMAND IS NEITHER OF THE ABOVE, THEN PRINT OUT THE С FOLLOWING ERROR MESSAGE ON THE TERMINAL AND RETURN TO THE С CALLING PROGRAM. С 100 WRITE(6.101) 101 FORMAT(8X'ERROR IN \*\*\*LOOP\*\*\* INSTRUCTION') PLN=BEGIN GOTO 40 С CALL THE SUBROUTINE 'LINE' TO DECODE THE 'GOTO' STATEMENT INTO С С THE CORRECT LOCATION TABLE POINTERS AND FUNCTION FLAGS С AND STORE THEM IN THE PROPER LINE IN THE PROGRAM С MODULE. С 30 CALL LINE С IF A RANGE OF INDEXED LOCATIONS WAS NOT GIVEN FOR THIS 'GOTO' С С STATEMENT (IE. ONLY ONE LOCATION WAS SPECIFIED, RESULTING С IN 'BN' BEING EQUAL TO 'EN') THEN BRANCH TO STATEMENT С 31 WHICH WILL HAVE THE EFFECT OF SETTING THE CORRESPONDING С VALUE OF THIS LINE IN 'STR(50)' EQUAL TO ZERO. С IF(EN.EQ.BN)GOTO 31 С С IF A RANGE OF INDEXED LOCATIONS WAS GIVEN, THEN THE LOCATION С TABLE POINTERS FOR THE STARTING (BN) AND ENDING (EN) INDEX С SPECIFIED ARE USED TO CALCULATE THE NUMBER OF REPEATS THROUGH С THE LOOP 'SDIF=EN-BN'. С SDIF = EN - BNDIF=IABS(SDIF) С С THE SIGN OF THE DIRECTION THROUGH THE INDEXED NAME (IE, IS THE INDEX С INCREASING OR DECREASING) IS STORED AT THE APPROPRIATE POSITION С IN THE MATRIX 'STR(50'. С STR(K) =SDIF/DIF С С THE PROGRAM MODULE LINE INDICATOR (PLN) IS INCREMENTED. THEN С BRANCH TO STATEMENT 99 TO READ IN ANOTHER COMMAND. С 31 K = K + 1PLN = PLN + 1GOTO 99 С С THIS SECTION OF CODE GENERATES THE ADDITIONAL REPEATED LINES,

INCREMENTING (OR DECREMENTING) THE INDEXED LOCATIONS FOR EACH REPEAT. CALCULATE THE NUMBER OF LINES TO BE REPEATED AND STORE IN 'LINES'. LINES=PLN-BEGIN REPEAT THE NUMBER OF LINES('LINES') IN THE REPEATING GROUP 'DIF' TIMES, INCREMENTING THE INDEXED VALUES BY THE APPROPRIATE AMOUNT (STR(KM)\*LB) EACH TIME. DO 21 LB=1,DIF DO 21 KM=1,LINES ORIG=BEGIN+KM-1 NXT=BEGIN+LINES\*LB+KM-1 DO 22 JK=1,6 PROG(NXT,JK)=PROG(ORIG,JK) PROG(NXT,2)=PROG(NXT,2)+STR(KM)\*LB SET THE PROGRAM LINE INDICATOR ('PLN') TO THE LAST LINE ENTERED IN

#### SET THE PROGRAM LINE INDICATOR ('PLN') TO THE LAST LINE ENTERED IN THE 'LOOP' SEQUENCE AND RETURN TO THE CALLING PROGRAM.

40 PLN=NXT END

С

С

C C

C 20

C C

С

С

С

22

21

C C

С

С



--- SUBROUTINE : INDEX С С С --- ARGUMENTS : I = IF I=1 DO NOT PRINT OUT INDEXED NAMES ON С TERMINAL AND DO NOT ALLOW THE ENTRY С OF NEW INDEXED NAMES. С IF I=0PRINT OUT INDEXED NAMES ON THE С TERMINAL AND ALLOW THE ENTRY OF С NEW INDEXED NAMES. С --- CALLED BY : PROGS С LOCTAB С С --- CALLS SUBROUTINES : С С --- INPUT DATA : IN(30) = THE CHARACTER STRING THAT CONTAINS THE С ASCII FORMATTED INDEXED LOCATION NAMES. С С --- OUTPUT DATA : NPT(3,20) = THE ARRAY THAT CONTAINS THE LOCATION С TABLE POINTERS FOR ALL OF THE POSSIBLE С INDEXED NAME LOCATIONS. C FL(6) = THE POSITION IN THE STRING IN(30) С OF THE FIRST AND LAST LETTER OF EACH С INDEXED NAME. С = THE FIRST LETTER OF EACH INDEXED NAME. NAME(3) С С --- FUNCTION: INITIALIZES THE ARRAY NPT(3,20) WHICH IS USED TO DECODE С AN INDEXED NAME AND ITS INDEX INTO ITS CORRECT LOCATION С TABLE POINTER. STORES THE INDEXED NAMES IN THE STRING С IN(30) AS WELL AS DECODING PERTINENT INFORMATION INTO С VARIABLES IN A COMMON BLOCK FOR USE BY OTHER PROGRAMS С FOR IDENTIFICATION PURPOSES. С С SUBROUTINE INDEX(I) IMPLICIT INTEGER(B-Z) COMMON/IND/IN(30), FL(6), NAME(3), NPT(3,20) С С INITIALIZE THE ARRAY NPT(3,20) SO THAT IT CONTAINS ALL OF THE С CORRECT LOCATION TABLE POINTERS FOR ALL POSSIBLE С INDEXED NAMES. С DO 10 G=1,20 NPT(1,G)=GNPT(2,G) = G + 2010 NPT(3,G) = G + 40С С TEST FLAG (I), IF I=O THEN PRINT OUT THE INDEXED NAMES FROM IN(30), С AND REQUEST IF NEW INDEXED NAMES ARE TO BE ENTERED. С IF(I.EQ.1)GOTO 120 WRITE(6,199) 300 FORMAT(8x'THESE ARE THE CURRENT INDEXED LOCATIONS') 199 WRITE(6,200)(IN(J), J=1,30) 200 FORMAT(2X, 30(A1))WRITE(6,201) 201 FORMAT(8X'DO YOU WANT TO ENTER NEW INDEXED NAMES ?') READ(6,202)JA

202	FORMAT(A1) IF(JA.EQ.1HY)GOTO 70 IF(JA.EQ.1HN)GOTO 120 WRITE(6 125)
125 C	FORMAT(8X'YOU DID NOT ANSWER THE QUESTION, PLEASE TRY AGAIN',//) GOTO 300
C C	IF NEW INDEXED NAMES ARE TO BE ENTERED, READ THEM INTO IN(30).
70 100	WRITE(6,100) FORMAT(8X'ENTER INDEXED NAMES',/ 1 8X'EG. PALLET CUTTER STACK') READ(6,102)(IN(J),J=1,30)
102 120 C	FORMAT(30(A1)) J=0 K=0
C C C C C C	ADVANCE THROUGH THE STRING IN(30), NOTING THE POSITION IN THE STRING WHERE EACH INDEXED NAME BEGINS AND ENDS AND STORING THESE POSITION VALUES IN FL(6). ALSO, STORE THE FIRST LETTER OF EACH INDEXED NAME IN NAME(3).
20	J=J+1 IF(J.GT.30)GOTO 40 IF(IN(J).EQ.8224)GOTO 20 K=K+1 FL(K)=J D=(K+1)/2 NAME(D)=IN(J)
15	J=J+1 IF(J.GT.30)GOTO 40 IF(IN(J).NE.8224)GOTO 15 K=K+1 FL(K)=J-1 GOTO 20
40	RETURN END





RETURN

```
C --- SUBROUTINE : LOCPT
С
С
                       = FLAG USED TO INDICATE IF A LOCATION NAME
  --- ARGUMENTS : D
С
                         IS TO BE ENTERED FROM THE TERMINAL (D=0).
С
                         OR IF THE LOCATION NAME IS COMING FROM
С
                         THE CALLING PROGRAM (D=1)>
С
С
 --- CALLED BY : AVOID LIMIT
                                 LINE
                                        NWTAB
С
С
 --- CALLS SUBROUTINES :
С
С
 --- INPUT DATA : CS(50)
                               = THE CHARACTER STRING THAT CONTAINS THE
С
                                 ASCII FORMAT OF THE LOCATION NAME.
С
                    PN
                               = THE POSITION IN THE ABOVE CHARACTER
С
                                 STRING OF THE FIRST LETTER OF THE
С
                                 LOCATION NAME.
С
                               = THE CHARACTER STRING THAT CONTAINS THE
                    IN(30)
С
                                 ENGLISH NAMES (IN ASCII FORMAT) OF THE
С
                                  INDEXED LOCATION POINTS.
С
                    NAME(3)
                               = THE FIRST LETTER OF THE INDEXED
С
                                 NAMES.
С
                               = THE MATRIX THAT CONTAINS THE LOCATION
                    NPT(3,20)
С
                                 TABLE POINTERS FOR ALL OF THE
С
                                 INDEXED POSITIONS.
С
С
 --- OUTPUT DATA : BN
                                   = THE LOCATION TABLE POINTER DECODED FROM
С
                                     THE ASCII FORMAT ENGLISH NAME OF THE
С
                                     LOCATION POINT.
С
                                   = THE LOCATION TABLE POINTER FOR THE
                     ΕN
С
                                     LAST INDEXED POSITION IF A SEQUENCE OF
С
                                     INDEXED LOCATIONS HAS BEEN ENTERED.
С
С
 --- FUNCTION: TO DECODE THE ENGLISH NAME OF A LOCATION INTO ITS
С
                CORRECT LOCATION TABLE POINTER. IF A SEQUENCE OF
С
                INDEXED LOCATIONS IS TO BE DECODED, THIS ROUTINE
С
                RETURNS THE LOCATION TABLE POINTERS OF
С
                THE FIRST AND LAST LOCATIONS IN THE SEQUENCE.
                                                                  THIS
С
                ROUTINE CAN ALSO BE USED TO DECODE AN ASCII FORMAT
С
                NUMBER FROM 1-100 INTO ITS INTEGER VALUES.
С
        SUBROUTINE LOCPT(D)
        IMPLICIT INTEGER (B-Z)
        COMMON/IND/IN(30), FL(6), NAME(3), NPT(3, 20)
        COMMON/PTN/BN, EN
        COMMON/CMD/CS(50), PN, PLN
        BN = 0
        EN = 0
С
С
    TEST FLAG TO SEE IF LOCATION NAME TO BE ENTERED THROUGH
С
        TERMINAL.
        IF(D.EQ.1)GOTO 75
С
С
    ACCEPT LOCATION NAME FROM TERMINAL.
С
500
        WRITE(6,300)
        FORMAT(2X'ENTER TRAJECTORY NAME')
300
```

READ(6, 200)(CS(J), J=1, 50)200 FORMAT(50(A1)) J = 010 J = J + 1IF(CS(J).EQ.8224)GOTO 10 PN = J75 J = P NС С TEST TO SEE IF FIRST CHARACTER IS A LETTER OR A NUMBER. IF A С LETTER BRANCH TO TEST IF INDEXED NAME. С ONE = CS(J)IF(ONE.GT.8256)GOTO 50 С С DECODE ASCII FORMAT NUMBERS INTO TWO DIGIT INTEGERS. С TWO = CS(J+1)BN = (10 # (ONE - 8240) + TWO - 8240) + 90J = J + 2GOTO 41 50 J = J + 1IF(J.GT.50)GOTO 60 IF(CS(J).NE.8224)GOTO 35 37 J = J + 1С С IF LETTERED NAME DOES NOT HAVE ANY INDEXING NUMBERS, BRANCH TO С STATEMENT 60. С IF(J.GT.50)GOTO 60 IF(CS(J).EQ.8224)GOTO 37 IF(CS(J).NE.8232)GOTO 60 35 IF(CS(J).NE.8232)GOTO 50 С С IF A OPEN PARENS IS DETECTED (INDICATING THE INDEXING NUMBERS), С THEN DECODE THE INDEXED NAME USED. С DO 20 K=1,3 20 IF(ONE.EQ.NAME(K))GOTO 7 100 WRITE(6,101) 101 FORMAT(2X'INDEXED NAME ERROR') GOTO 40 7 J = J + 1IF(J.LT.51)GOTO 33 102 WRITE(6,103) 103 FORMAT(2X'INCORRECT NAME') GOTO 40 С С DECODE THE INDEXING NUMBER USED WITH THE INDEXED NAME. С 33 IF(CS(J).EQ.8224)GOTO 7 ONE = CS(J)TWO=CS(J+1)F = (ONE - 8240) \* 10 + TWO - 8240BN = NPT(K, F)J = J + 280 IF(CS(J).EQ.8237)GOTO 82

IF(CS(J), NE. 8233)GOTO 100 EN = BNGOTO 41 С IF A SEQUENCE OF INDEXING NUMBERS FOR A PARTICULAR INDEXED С NAME IS GIVEN, DECODE THE LAST INDEXING NUMBER IN THE С SEQUENCE. 82 J = J + 3ONE = CS(J-2)TWO=CS(J-1)F = (ONE - 8240) \* 10 + TWO - 8240LOOK UP THE LOCATION TABLE POINTER FOR THE LAST INDEXING NUMBER FOR THE SPECIFIED INDEXED NAME. EG. FOR THE INDEXED NAME AND SEQUENCE NUMBERS - BOX(13-17) - THE INDEXED NAME IS 'BOX', THE FIRST INDEXING NUMBER IS '13', THE LAST INDEXING NUMBER IS '17'. IF 'BOX' WAS THE SECOND INDEXED NAME STORED IN 'IN(30)' THEN THE FIRST LOCATION TABLE POINTER WOULD BE FOUND AT 'NPT(2,13)', AND THE LAST LOCATION TABLE POINTER WOULD BE FOUND AT 'NPT(2,17)'. EN = NPT(K, F)GOTO 41 DECODE THE NON-INDEXED LETTERED NAME INTO THE CORRECT LOCATION С TABLE POINTER. 60 BN = ONE - 8196EN = BNJ = J - 141 PN = JIF(BN.LE.O)GOTO 102 IF(BN.GT.190)GOTO 102 40 RETURN END

С

С

С С

С С

С С

С

С С

С

С С

С



С --- SUBROUTINE : LINE С С --- ARGUMENTS : C С --- CALLED BY : INSERT LOOP С С --- CALLS SUBROUTINES : NEXT LOCPT С С --- INPUT DATA : CS(50) = THE CHARACTER STRING THAT CONTAINS THE С ELEMENTAL MOVE ('GOTO' STATEMENT) COMMAND. С PLN = THE NUMBER OF THE LINE IN THE PROGRAM С MODULE THAT THE ABOVE STATEMENT WILL BE С CODED INTO. С BN = THE INTEGER REPRESENTATION OF AN ASCII С CODED NUMBER IN THE CHARACTER STRING С CS(50), USED TO GENERATE LOCATION С TABLE POINTERS, VELOCITY VALUES, AND С CHANNELS FOR INTERLOCK (SEND AND WAIT) С SIGNALS [FROM 'LOCPT']. С --- OUTPUT DATA : PROG(PLN,6) = THE NEW LINE OF THE PROGRAM MODULE С THAT THE ELEMENTAL MOVE HAS BEEN С CODED INTO. С С --- FUNCTION: TAKES THE ENGLISH TEXT ELEMENTAL MOVE STATEMENT TYPED INTO THE TERMINAL, CODES IT INTO THE CORRECT С С POINTERS AND FLAGS, AND STORES THEM IN THEIR PROPER С POSITIONS IN THE SPECIFIED LINE IN THE С PROGRAM MODULE. С SUBROUTINE LINE IMPLICIT INTEGER(B-Z) COMMON/PMOD/PROG(105,6), ENDP, BRNCH(6), M COMMON/PTN/BN.EN COMMON/CMD/CS(50), PN, PLN COMMON/BED/BEG, FIN, DIF, ERR С С ZERO ALL OF THE VALUES IN LINE PLN, SET THE VELOCITY INDICATOR С EQUAL TO 50 CM/SEC AS A DEFAULT VALUE. С 25 DO 125 J=2,6 PROG(PLN, J)=0 125 PROG(PLN, 3) = 50С С ADVANCE THROUGH THE CHARACTER STRING UNTIL THE DESTINATION NAME С IS REACHED(BY A CALL TO 'NEXT'). С CALL NEXT IF(PN.LT.51)GOTO 41 С С THIS IS THE ERROR MESSAGE PRINTED IF ANY MISTAKE IN FORMAT С IS DETECTED. С 100 WRITE(6,101) FORMAT(8X'ERROR IN \*\*\* GOTO \*\*\*STATEMENT') 101 GOTO 42 С

```
С
    THE ASCII REPRESENTATION OF THE DESTINATION IS DECODED
С
        INTO THE CORRECT LOCATION TABLE POINTER BY A CALL TO 'LOCPT'.
С
        THIS POINTER IS THEN STORED IN THE PROGRAM MODULE.
С
41
        CALL LOCPT(1)
        PROG(PLN, 2) = BN
        BBN=BN
        E E N = E N
С
С
    ADVANCE THROUGH THE ASCII CHARACTER STRING UNTIL A FUNCTION
С
        COMMAND IS FOUND (BY A CALL TO 'NEXT').
С
15
        CALL NEXT
        IF(PN.GT.50)GOTO 42
С
С
    THIS IS A SERIES OF TESTS ON THE ASCII FORM OF THE FIRST LETTER OF THE
С
        FUNCTION COMMAND TO DETERMINE IF IT IS A G(GRASP), R(RELEASE),
С
        P(PROXIMITY), D(DETECT), B(BALANCE), U(UNSTACK), T(TOUCH),
С
        L(LINE), E(EDGE).
С
С
С
    'GRASP'
С
        IF(CS(PN).NE.8263)GOTO 60
        PROG(PLN, 6) = 1
        GOTO 80
С
С
    'RELEASE'
С
60
        IF(CS(PN).NE.8274)GOTO 61
        PROG(PLN, 6) = 2
80
        PN = PN + 1
С
С
    'PROXIMITY'
С
         IF(CS(PN).NE.8272)GOTO 81
         PROG(PLN, 6) = PROG(PLN, 6) + 2
82
81
         CALL NEXT
         IF(PN.GT.50)GOTO 42
С
С
    'PROXIMITY'
С
         IF(CS(PN).NE.8272)GOTO 85
         GOTO 82
С
С
    'DETECT'
С
61
         IF(CS(PN).NE.8260)GOTO 62
         PROG(PLN, 6) = 5
         GOTO 81
С
С
     'BALANCE'
С
62
         IF(CS(PN).NE.8258)GOTO 63
         PROG(PLN, 6) = 6
         GOTO 81
```

C C	'UNSTACK'
63	IF(CS(PN).NE.8277)GOTO 64 PROG(PLN,6)=7 GOTO 81
C C	'TOUCH'
64	IF(CS(PN).NE.8276)GOTO 65 PROG(PLN,6)=8 GOTO 81
C C	'LINE'
65	IF(CS(PN).NE.8268)GOTO 66 PROG(PLN,6)=9 GOTO 81
C	'EDGE'
66	IF(CS(PN).NE.8261)GOTO 85 PROG(PLN,6)=10 CALL NEXT CALL LIMIT PROG(PLN,5)=BEG GOTO 81
000000000000000000000000000000000000000	TEST FOR A 'VELOCITY' COMMAND, IF THERE IS ONE THEN DECODE THE ASCII FORM OF THE SPECIFIED VELOCITY (CM/SEC) BY A CALL TO 'LOCPT'. MULTIPLY THIS INTEGER NUMBER BY 10 AND STORE AT POSITION 3 IN THE LINE IN THE PROGRAM MODULE.
85	IF(CS(PN).NE.8278)GOTO 90 CALL NEXT IF(PN.GT.50)GOTO 100 CALL LOCPT(1) PROG(PLN,3)=(BN-90) CALL NEXT IF(PN.GT.50)GOTO 42
	TEST FOR A 'SEND' COMMAND. IF THERE IS ONE, DECODE THE ASCII FORM OF THE OUTPUT CHANNEL NUMBER THAT IS TO BE SET HIGH, MULTIPLY THIS INTEGER BY 100 AND STORE IN POSITION 4 OF THE SPECIFIED LINE OF THE PROGRAM MODULE.
90	IF(CS(PN).NE.8275)GOTO 91 CALL NEXT IF(PN.GT.50)GOTO 100 CALL LOCPT(1) PROG(PLN,4)=(BN-90)*100 CALL NEXT IF(PN.GT.50)GOTO 42
C C	TEST FOR A 'WAIT' COMMAND. IF THERE IS ONE, STORE THE NUMBER

С	OF THE INPUT CHANNEL THAT MUST GO HIGH FOR THE PROGRAM
C	TO CONTINUE.
91	IF(CS(PN).NE.8279)GOTO 100 CALL NEXT IF(PN.GT.50)GOTO 100 CALL LOCPT(1) PROG(PLN,4)=PROG(PLN,4)+BN-90
	CALL NEXT TF(PN.LT.51)GOTO 100
42	BN=BBN EN=EEN
40	R E T U R N E N D





C --- SUBROUTINE : PTNAME С C --- ARGUMENTS : NU = A LOCATION TABLE POINTER SPECIFIED BY С THE CALLING PROGRAM. С С --- CALLED BY : PLINE C С --- CALLS SUBROUTINES : С C --- INPUT DATA : FL(6) = THE LOCATIONS IN THE CHARACTER STRING С IN(30) OF THE FIRST AND LAST LETTER С OF THE INDEXED LOCATION NAMES. С = THE FIRST LETTERS OF THE INDEXED NAME(3) С LOCATION NAMES. С = THE ARRAY OF VALUES FOR THE POINTERS NPT(3, 20)С FOR THE INDEXED LOCATION NAMES. С C --- OUTPUT DATA : NM(15) = THE CHARACTER STRING THAT CONTAINS THE SEQUENCE OF LETTERS (IN ASCII С FORMAT) THAT MAKES UP THE NAME THAT С С CORRESPONDS TO THE LOCATION TABLE С POINTER 'NU'. С С --- FUNCTION: DECODES THE LOCATION TABLE POINTER 'NU' INTO THE С CORRESPONDING ASCII FORMATED NAME. С SUBROUTINE PTNAME(NU) IMPLICIT INTEGER(B-Z) COMMON/NAM/NM(15) COMMON/IND/IN(30), FL(6), NAME(3), NPT(3, 20) С С FILL THE CHARACTER STRING NM(15) WITH BLANKS. С DO 10 J=1,15 10 NM(J) = 8224С С TEST IF POINTER 'NU' IS A SINGLE LETTERED NAME OR С AN INDEXED LOCATION NAME. IF INDEXED NAME THEN BRANCH TO С STATEMENT NUMBER 60. С IF(NU.LT.61)GOTO 60 С DECODE THE LETTERED NAME LOCATION TABLE POINTER INTO ITS С С APPROPRIATE ASCII FORMAT LETTER. STORE THIS VALUE IN THE STRING С NM(30) AND RETURN TO THE CALLING PROGRAM. С NM(1) = NU + 8196GOTO 40 С С SEPARATE OUT THE TEN'S DIGIT AND THE UNIT'S DIGIT FROM С THE POINTER 'NU' FOR THE INDEXED NAME. С 60 DO 31 K=1,7 TEN = K - 1UNIT = NU - 10 # TENIF(UNIT.LT.10)GOTO 80

31 C		CONTINUE
	THI	S SECTION DECODES THE LOCATIONS IN THE STRING IN(30) OF THE FIRST AND LAST LETTER OF THE INDEXED NAME SPECIFED BY THE POINTER 'NU'. THEN STORES THE LETTERS OF THIS INDEXED NAME IN THE STRING NM(15).
80		J=2#((NU-1)/20)+1 BE=FL(J) EN=FL(J+1) DO 82 LJ=1,15 NN=BE+LJ-1 IF(NN.GT.EN)GOTO 83
82 C		NM(LJ)=IN(NN)
C C C	AN	OPEN PARENS IS NOW INSERTED IN THE STRING NM(15) AFTER THE INDEXED NAME.
83 C		NM(LJ)=8232
C C	THE	CORRECT INDEX NUMBER IS DECODED AND STORED IN NM(15).
-		NTEN=((TEN+1)*2)/(J+1)-1 IF(TEN.NE.(J+1))GOTO 85 NTEN=2
85 C		NM(LJ+1)=NTEN+8240 NM(LJ+2)=UNIT+8240
с с с с	A C	LOSE PARENS (IE THE ASCII FORMAT VALUE FOR A CLOSE PARENS) IS PLACED AFTER THE INDEX NUMBER IN NM(15) AND CONTROL RETURNS TO THE CALLING PROGRAM.
40		NM(LJ+3)=8233 RETURN END







```
C --- SUBROUTINE : PLINE
C
С
 --- ARGUMENTS : LN
                                    = THE NUMBER OF THE PARTICULAR LINE
С
                                      IN THE PROGRAM MODULE TO BE
С
                                      PRINTED OUT.
С
С
  --- CALLED BY : INSERT
                                      PRINT
                             DELETE
                                              SAMPLE
С
  --- CALLS SUBROUTINES : PTNAME
С
С
С
 --- INPUT DATA : PROG(105,6) = THE PROGRAM MODULE.
С
                     NM(15)
                                     THE ASCII FORMATTED
                                    =
С
                                      CHARACTER STRING THAT CONTAINS THE
С
                                      NAME OF THE LOCATION 'NU' [FROM 'PTNAME']
С
 --- OUTPUT DATA : THE DECODED LINE FROM THE PROGRAM MODULE PRINTED
С
С
                      OUT ON THE TERMINAL.
С
С
 --- FUNCTION: DECODES A SPECIFIED LINE FROM THE PROGRAM MODULE
С
                  INTO THE ENGLISH LANGUAGE CHARACTER STRING ORIGINALLY
С
                  USED TO ENTER IT, AND DISPLAYS IT ON A TERMINAL.
С
         SUBROUTINE PLINE(LN)
         IMPLICIT INTEGER(B-Z)
         COMMON/PMOD/PROG(105,6), ENDP, BRNCH(6), M
         COMMON/NAM/NM(15)
         COMMON/CMD/CS(50), PN, PLN
         DIMENSION FN(6,11)
         DATA FN/6# '
          'GR', 'AS', 'P', 3*'
         2
         3 'RE','LE','AS','E ',2*'
4 'GR','AS','P ','PR','OX','
                                        ,
         5 'RE','LE','AS','E ','PR','OX'
6 'DE','TE','CT',3*' ',
                                       1,
         7 'BA', 'LA', 'NC', 'E ', 2*'
                                       ۲,
         8 'UN', 'ST', 'AC', 'K ', 2*'
         9 'TO', 'UC', 'H ', 3*'
1 'LI', 'NE', 4*' ',
         1 'ED', 'GE', 4#'
                            1/
С
    IF THE FIRST LINE OF THE PROGRAM MODULE IS TO BE PRINTED OUT,
С
         THEN DECODE THE STARTING LOCATION BY A CALL TO 'PTNAME'
С
         WHICH RETURNS THE ASCII FORMATTED NAME IN THE STRING 'NM(15)'.
С
         THIS NAME IS THEN PRINTED OUT WITH THE WORD 'START'.
С
С
         IF(LN.NE.1)GOTO 10
         NU = PROG(1, 1)
         IF(NU.EQ.O)GOTO 40
         CALL PTNAME(NU)
         WRITE(6,200)(NM(J), J=1,15)
200
         FORMAT(6X, 'START', 1X, 15(A1))
С
С
    THE DESTINATION POINTER 'NU' IS DECODED BY 'PTNAME' AND RETURNED
С
         IN 'NM(15)'.
С
10
         NU = PROG(LN, 2)
```

IF(NU.EQ.O)GOTO 40 CALL PTNAME(NU)

C THE FLAG 'F' IS CALCULATED FROM THE FUNCTION FLAG OF THE C OF THE PROGRAM LINE AND IS USED TO SPECIFY THE PROPER LINE C OF THE MATRIX 'FN(6,11)' IN ORDER TO PRINT OUT THAT FUNCTION NAME. C

F = PROG(LN, 6) + 1

C IF AN OUTPUT SIGNAL IS TO BE SENT OUT ON A CHANNEL, THEN THE C CHANNEL NUMBER IS DECODED AND STORED IN 'SEN'. C

SEN=PROG(LN, 4)/100

C IF THE PROGRAM IS TO WAIT FOR A SIGNAL ON AN INPUT CHANNEL, THEN C THE INPUT CHANNEL NUMBER IS DECODED AND STORED IN 'WA'. C

WA = PROG(LN, 4) - SEN # 100

### C THE VELOCITY VALUE IN CM/SEC IS DECODED AND STORED IN 'VEL'.

VEL=PROG(LN,3)

# C THE DECODED PROGRAM LINE IS NOW PRINTED OUT ON THE TERMINAL.

IF(PROG(LN,5).EQ.0)GOTO 140

LE=PROG(LN,5) WRITE(6,300)LN,(NM(L),L=1,15),(FN(E,F),E=1,6),LE,VEL,SEN,WA 300 FORMAT('+'I5,' GOTO ',15(A1),1X,6(A2),T34,I2,T41,' VELOCITY(',I3, 1 ') SEND(',I2,') WAIT(',I2,')')

GOTO 40

END

## 140 WRITE(6,301)LN,(NM(L),L=1,15),(FN(E,F),E=1,6),VEL,SEN,WA 301 FORMAT('+',15,' GOTO ',15(A1),1X,6(A2),' VELOCITY(',I3,

- 1 ') SEND(',12,') WAIT(',12,')') 40 RETURN

%

С

С

С

С

С

С





C		S	UBRO	UTI	NE	:	NEX	Т															
00000		A	ARGUMENTS :																				
		C	ALLE	DВ	Υ:	P	RIN	Т	INSE	RT	DI	ELEI	ΓE	LIN	E								
C		C.	ALLS	SU	BRC	DUT	INE	s:															
000000		I	NPUŢ	DA	TA	: (	CS(	50)		=	THE	с сн	IARA	CTE	RS	TRI	NG	THAT	CO	ΝT	AINS	THI	Ξ
						1	PN		=	THI POS	E IN SITI (50)	COL IDIC IDIC	ATO IN	INPU R DH THE	UT ESI CH	INF GNA ARA	ORMA TING CTER	TIO TH ST	N. E 1 RII	PRES NG	ENT		
		01	UTPU	TD.	ΑΤΑ	:	PN				=	THE CS( THE	PC 50) NE	SIT TH XT	ION AT PIE	IN IND CE	DIC ICA OF	ATOR TES INFO	IN THE RMA	TI BI TI(	HE S EGIN DN.	TRI NIN(	NG G OF
0000		F	UNCT	ION	: A T C	DV HE HAI	ANC BE RAC	ES GIN TER	THE NING STR	POS OH IN(	SIT: F TH G CS	EON HEN S(50	IND IEXT ).	ICA PI	TOR ECE	'P OF	N' IN	UNTI FORM	L R ATI	EA( ON	CHES IN	THE	
48			SUB IMP COM GOT PN = IF(	ROU LIC MON 0 2 PN+ PN.	TIN IT /CM 1 GT.	IE I IN' 1D/0	NEX TEG CS(	T ER( 50) TO	B-Z) , PN, 40	PLI	1												
	Т	HI	S (P IT	N) IS	POS A E	SIT: BLAI	ION NK,	I N A N	THE OPE	CI N 1	HARI PARI	ACTE ENS,	CR S OF	TRI A	NG CLO	IS SE	C H E P A R	CKED ENS.	ΤO	SI	EE I	F	
c			IF( IF( IF(	CS( CS( CS(	PN) PN) PN)	.E( .E(	2.8 2.8 2.8	224 232 233	)GOT )GOT )GOT	0	41 50 50												
00000	I	F	THE BAC IN	PRE K T THE	SEN OS ST	IT ( STA' RII	CHA TEM NG	R A C E N T A N D	TER 48, TES	IS S'	NOI CEP AGA:	NE C TO IN.	)F T THE	HE NE	АВО ХТ	V E C H A	T H E R A C	N CY TER	CLE				
с			GOT	04	8																		
C C C C 4 1	0	NCI	E A CON FOR	BLA TIN BL	N K U E A N K	IS STI S,	DE EPP OP	TEC ING EN	TED, THR PARE	BI OU( NS,	RANC GH 7 , OI	CH T THE R CL	O T CHA OSE	HIS RAC PA	SE TER REN	CTI ST S.	O N R I N	OF C G TE	ODE STI	A 1 N G	ND		
			PN = IF( IF( IF(	PN+ PN. CS( CS(	1 GT. PN) PN)	50 .E(	) GO 2.8 2.8	TO 224 232	40 )GOT )GOT	0 1	+ 1 5 0												
000000	I	F	A CH OR BEG TO	ARA A C INN THE	CTE LOS ING CA	R E I I I I I I I I I I I I I I I I I I	IS PAR FT ING	DET ENS HE PR	ECTE THE NEXT OGRA	D N P M.	THAT T ECH	T IS IS A E OF	NO SSU IN	T A MED FOR	BL. TH. MAT	ANK AT ION	, O THI AN	PEN S IS D RE	PARI THI TURI	ENS NS	Ξ,		

IF(CS(PN).NE.8233)GOTO 40

- C IF EITHER A OPEN OR CLOSE PARENS IS DETECTED THEN ADVANCE TO THE C NEXT CHARACTER AND TEST FOR A BLANK. C
- 50 PN = PN + 1

С

С

IF(PN.GT.50)GOTO 40

## C IF A BLANK IS FOUND, CONTINUE STEPPING THROUGH THE STRING C UNTIL THE FIRST NON-BLANK CHARACTER IS DETECTED THEN RETURN C TO THE CALLING PROGRAM. C

IF(CS(PN).EQ.8224)GOTO 50 40 RETURN END




--- SUBROUTINE : LIMIT C С С --- ARGUMENTS : С С --- CALLED BY : INSERT DELETE PRINT С С --- CALLS SUBROUTINES : LOCPT NEXT С С --- INPUT DATA : CS(50) = THE CHARACTER STRING THAT CONTAINS A С NUMBER OR A RANGE OF NUMBERS TO BE С DECODED FROM ASCII INTO INTEGER FORM. С PN = THE POSITION IN THE STRING CS(50) OF С THE FIRST LINE NUMBER TO BE DECODED. С BN = THE INTEGER VALUE OF THE LINE NUMBER С DECODE FROM THE ASCII FORMAT BY A CALL С TO THE SUBROUTINE 'LOCPT'. С С --- OUTPUT DATA : BEG = THE VARIABLE IN THE COMMON BLOCK THAT С RETURNS THE INTEGER VALUE OF THE FIRST С PROGRAM MODULE LINE NUMBER SPECIFIED С IN THE EDITOR COMMAND. = THE VARIABLE IN THE COMMON BLOCK THAT С FIN RETURNS THE INTEGER VALUE OF THE LAST С С PROGRAM MODULE LINE NUMBER SPECIFIED С IN THE EDITOR COMMAND. С DIF = THE DIFFERENCE (THE NUMBER OF LINES) С BETWEEN 'BEG' AND 'FIN'. С С --- FUNCTION: TO RETURN THE BEGINNING AND ENDING PROGRAM MODULE LINE С NUMBERS THAT THE PARTICULAR EDITOR COMMAND SPECIFIES С FOR ITS OPERATION. С SUBROUTINE LIMIT IMPLICIT INTEGER(B-Z) COMMON/PTN/BN, EN COMMON/BED/BEG, FIN, DIF, ERR COMMON/CMD/CS(50), PN, PLN ERR=0С С TRANSLATE THE ASCII FORMAT BEGINNING LINE NUMBER INTO AN С INTEGER FORMAT AND STORE IN 'BEG' BY A CALL TO С 'LOCPT'. С CALL LOCPT(1) BEG=BN-90IF(BEG.LE.O)GOTO 100 IF(BEG.GT.100)GOTO 100 С С TEST FOR A DASH(-), CLOSE PARENS()), OR A BLANK( ) AND BRANCH С TO THE APPROPRIATE STATEMENT. С IF(CS(PN).EQ.8237)GOTO 30 IF(CS(PN).EQ.8233)GOTO 45 IF(CS(PN).EQ.8224)GOTO 45 100 WRITE(6,101) FORMAT(8X'FORMAT ERROR IN PROGRAM MODULE LINE NUMBER') 101

с		ERR=1 GOTO 40
C C C	IF	A CLOSE PARENS WAS DETECTED THEN THIS INDICATES ONLY ONE LINE WAS SPECIFIED THEREFORE SET 'FIN' EQUAL TO 'BEG' .
45 C		FIN=BEG GOTO 60
C C C C C	IF	A DASH WAS DETECTED, THIS INDICATES THAT AN ENDING NUMBER IS ALSO SPECIFIED THEREFORE ADVANCE TO THE NEXT NUMBER IN THE STRING CS(50) (BY A CALL TO 'NEXT') AND TRANSLATE IT INTO THE INTEGER FORMAT AND STORE IN 'FIN' (BY A CALL TO 'LOCPT')
30		PN=PN+1 IF(CS(PN).NE.8224)GOTO 31 CALL NEXT
31 C		CALL LOCPT(1) FIN=BN-90
С С С	TES	I TO MAKE CERTAIN THAT THE LINE NUMBERS ARE WITHIN THE ALLOWABLE RANGE.
60 C		IF(FIN.LE.0)GOTO 100 IF(FIN.GT.100)GOTO 100
C C C	CAL	CULATE THE NUMBER OF LINES SPECIFIED AND STORE IN THE COMMON VARIABLE 'DIF'.
40		DIF=FIN-BEG+1 RETURN END





--- SUBROUTINE : ADJUST С С С --- ARGUMENTS : С С --- CALLED BY : INSERT DELETE AVOID С С --- CALLS SUBROUTINES : С С --- INPUT DATA : PROG(105,6) = THE PRESENT PROGRAM MODULE. С С --- OUTPUT DATA : PROG(105,6) = THE VERIFIED PROGRAM MODULE. С С --- FUNCTION: MAKES CERTAIN THAT FOR EVERY LINE IN THE PROGRAM С MODULE, THE PRESENT LOCATION POINTER IS THE SAME С AS THE DESTINATION POINTER OF THE PREVIOUS LINE С THEREBY ASSURING CONTINUITY IN THE COMMANDED С POINT-TO-POINT MOTION. С SUBROUTINE ADJUST IMPLICIT INTEGER(B-Z) COMMON/PMOD/PROG(105,6), ENDP, BRNCH(6), M С С LOOP THROUGH THE PROGRAM MODULE, TESTING TO DETERMINE IF С EACH PROGRAM LINE HAS A DESTINATION POINTER. IF IT С DOES, THEN SET THAT LINE'S PRESENT LOCATION POINTER EQUAL С TO THE PREVIOUS LINE'S DESTINATION POINTER. IF THE PROGRAM С LINE DOES NOT HAVE A DESTINATION POINTER, THEN ZERO ITS С PRESENT LOCATION POINTER AND BRANCH TO STATEMENT 207. С 200 DO 201 M=2,100 IF(PROG(M,2).NE.0)GOTO 201 PROG(M, 1) = 0GOTO 207 201 PROG(M, 1) = PROG(M-1, 2)С С THIS LOOP ZEROS OUT THE REMAINDER OF THE PROGRAM MODULE TO ELIMINATE С ANY EXTRANEOUS DATA. С DO 208 RM=M,100 207 DO 208 MM=1,6 208 PROG(RM,MM) = 040 RETURN END



# Location Module (Module #3)

LOCTAB	-	Requests data to completely specify a	DITI O
		location point.	D111-2
ARRAY	-	Requests data to specify the dimensions of	
		the array of points to be entered.	DIII10
ARRLOC		Computes the coordinate values to specify	
		all of the locations in the array.	DIII-14
.10.Y	-	Uses input values from joystick to control	
001		robot's motions	DTTT-18
DOC		Calle in and acales the present joint	D
PU5	-	caris in and scares the present joint	DTTT O
		position values.	DIII-24

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### DIII-2

C --- SUBROUTINE : LOCTAB С С --- ARGUMENTS : С С --- CALLED BY : SAMPLE С С --- CALLS SUBROUTINES : ARMIN INDEX LOCPT ARRAY ARRLOC JOY POS С COOR С С --- INPUT DATA : INBUF(28) = WHEN THIS SWITCH IS UP, CAUSES THE С PROGRAM TO JUMP BACK TO THE PREVIOUS С DATA ENTRY REQUEST. С INBUF(29) = WHEN THIS SWITCH IS DOWN, CAUSES THE С CONTROL TO RETURN TO THE CALLING С PROGRAM. С = WHEN THIS SWITCH IS UP, THE ARM IS INBUF(32) С UNDER JOYSTICK CONTROL. = WHEN THIS SWITCH IS UP, THE LOCATION IS С INBUF(34) С TO BE ENTERED AS AN 'X,Y,Z' COORDINATE С POSITION. С --- OUTPUT DATA : LTAB(90,4,7) = THE UPDATED LOCATION TABLE MODULE. С С С --- FUNCTION: USES A QUESTION AND ANSWER SYSTEM TO OBTAIN THE С NECESSARY INFORMATION FOR THE DESCRIPTION OF A С LOCATION AND THE CONSTRUCTION OF THE LOCATION TABLE С MODULE. С SUBROUTINE LOCTAB IMPLICIT INTEGER(B-R) IMPLICIT INTEGER(T-Z) COMMON/ARMBUF/INBUF(64), OUTBUF(64) COMMON/LMOD/LTAB(90,4,7), PRES, DEST COMMON/OUT/JPOS(8) COMMON/ARR/B1, E1, J1, J2, AD1(3), AD2(3), DA COMMON/IND/IN(30), FL(6), NAME(3), NPT(3,20) COMMON/PTN/BN, EN COMMON/CORT/AC(6), AXEP, AYEP, AZEP EQUIVALENCE(EABORT, INBUF(28)) EQUIVALENCE(NRE, INBUF(29)), (JSTK, INBUF(32)), (XYZ, INBUF(34)) CALL ARMIN С MONITOR SWITCH 29 ('NRE') TO DETERMINE WHEN CONTROL SHOULD BE С С RETURNED TO CALLING PROGRAM. С 500 IF(NRE.GT.-2000)GOTO 40 С С INITIALIZE THE FLAG 'DA' AT ZERO. USED TO INDICATE WHEN AN ARRAY С OF LOCATION POINTS ARE TO BE STORED. С DA = 0С THE FOLLOWING CODE READS THE PRESENT INDEXED NAMES OUT OF THE С LOCATION TABLE MODULE, AND BY A CALL TO 'INDEX', PRINTS С THESE INDEXED NAMES ON THE TERMINAL AND PROVIDES THE OPERATOR С THE OPPORTUNITY TO CHANGE THESE NAMES. С

С M = 0DO 104 J=89,90 DO 104 K=1,4 DO 104 L=1,7 M = M + 1IF(M.EQ.31)GOTO 98 104 IN(M) = LTAB(J,K,L)98 CALL INDEX(0) С С THE FOLLOWING CODE PRINTS OUT THE FUNCTIONS OF THE VARIOUS CONTROL С SWITCHES AND ASKS THE OPERATOR IF A SINGLE LOCATION OR AN ARRAY С OF LOCATIONS IS TO BE ENTERED. С 303 WRITE(6,300) 300 FORMAT(8X'---SW 32 UP--- FOR JOYSTICK CONTROL'./ 1 8X'---SW 34 UP--- FOR XYZ ENTRY',/ 1 8X'---SW 32 & 34 DOWN---FOR MANUAL ENTRY',//) WRITE(6,201) 201 FORMAT(8X'\*\*\*TYPE +1\*\*\* TO RECORD AN ARRAY OF INDEXED LOCATIONS',/ 1 8X'\*\*\*TYPE [CR]\*\*\* TO RECORD LOCATIONS ONE AT A TIME') READ(6,202)DA 202 FORMAT(I3) CALL ARMIN IF(NRE.GT.-2000)GOTO 40 IF(EABORT.LT.-2000)GOTO 500 С С THE OPERATORS RESPONSE IS TESTED AND IF AN ARRAY OF POINTS IS С TO BE ENTERED, THEN THE SUBROUTINE 'ARRAY' IS CALLED. С IF(DA.EQ.0)GOTO 275 CALL ARRAY С С THE LOCATION TABLE POINTER FOR THE FIRST LOCATION TO BE ENTERED С IS STORED IN THE VARIABLE 'BN' ('B1' IS THE FIRST LOCATION OF С THE ARRAY DECODED AND RETURNED FROM THE CALL TO 'ARRAY'). С BN = B1GOTO 321 С С IF ONLY A SINGLE LOCATION IS TO BE ENTERED, THEN THE VALUE OF ITS С LOCATION TABLE POINTER IS DECODED BY A CALL TO 'LOCPT', С RETURNED IN THE VARIABLE 'BN' AND STORED IN BOTH 'B1' AND 'E1', THE VARIABLES THAT ARE THE FIRST AND LAST С С LOCATIONS TO BE ENTERED. С 275 CALL LOCPT(0) B1 = BNE1 = BNС С THE VALUE OF THE SWITCH FOR JOYSTICK CONTROL IS CHECKED AND IF UP. С THE SUBROUTINE 'JOY' IS CALLED TO TRANSFER CONTROL TO THE С JOYSTICK BOX. С 321 IF(JSTK.GT.-2000)GOTO 400 CALL JOY

GOTO 401

С С THE VALUE OF THE SWITCH FOR 'X, Y, Z' ENTRY IS CHECKED AND IF UP, THEN С THE 'X,Y,Z' COORDINATE VALUES FOR THE LOCATION ARE С REQUESTED. С 400 IF(XYZ.GT.-2000)GOTO 401 WRITE(6,304) 765 304 FORMAT(8X'ENTER X,Y,Z VALUES (DECIMAL CENTIMETERS)',/ 1 8X'OF THE LOCATION TO BE RECORDED') READ(6,305)A1X,A1Y,A1Z 305 FORMAT(3(F10.3)) CALL ARMIN IF(EABORT.LT.-2000)GOTO 303 С С THE OPERATOR IS NOW ASKED IF THESE COORDINATES ARE ABSOLUTE С VALUES OR DELTA OFFSETS FROM THE PREVIOUS VALUES FOR С THE PRESENT LOCATION OR FROM ANOTHER PREVIOUSLY ENTERED С LOCATION. С 766 WRITE(6,306) 306 FORMAT(8X'\*\*\*TYPE +1\*\*\*IF THESE ARE ABSOLUTE VALUES',/ 1 8X'\*\*\*TYPE [CR]\*\*\*IF OFFSETTING PRESENT LOCATION BY THESE AMOUNTS',/ 1 8X'\*\*\*TYPE -1\*\*\*IF THESE ARE OFFSETS FROM ANOTHER LOCATION') READ(6,307)RAD 307 FORMAT(I3) CALL ARMIN IF(EABORT.LT.-2000)GOTO 765 DD = RADIF(RAD.NE.-1)GOTO 176 С С IF OFFSET FROM ANOTHER PREVIOUSLY RECORDED LOCATION, HERE, THAT С LOCATION NAME IS ENTERED. С WRITE(6,308) FORMAT(8x'WHAT IS THE OTHER LOCATION YOU ARE OFFSETTING FROM ?') 308 RAD = 0. MNN = BNС THIS OTHER LOCATION NAME IS IDENTIFIED BY A CALL TO 'LOCPT', С AND THE VALUE OF ITS LOCATION TABLE POINTER RETURNED IN THE С С COMMON VARIABLE 'BN'. С CALL LOCPT(0) С С THE VALUE OF THE JOINT POSITIONS FOR THIS OTHER POINT ('BN') ARE С STORED IN THE COMMON VARIABLE 'AC(1-6)' TO BE USED BY THE С COORDINATE TRANSFORMATION ROUTINE 'COOR' AS THE REFERENCE POINT С FROM WHICH TO OFFSET THE NEW LOCATION BY THE DELTA COORDINATE С VALUES ('A1X', 'A1Y', 'A1Z'). С 176 DO 402 JX=1,6 402 AC(JX)=LTAB(BN, 1, JX) CALL COOR(A1X,A1Y,A1Z,RAD,O) IF(DD.NE.-1)GOTO 479 BN = MNN

0		GOTO 479
C C C C C C C C	THE	PRESENT VALUES OF THE JOINT POSITION INDICATORS ARE ENTERED AS THE JOINT POSITION VALUES FOR THIS DESIGNATED LOCATION BY A CALL TO 'POS' TO READ IN THESE VALUES.
401		CALL POS IF(EABORT.LT2000)GOTO 500
C C C C	THE	PRESENT JOINT POSITION INDICATOR VALUES FROM THE CALL TO 'POS' ARE ENTERED IN THE LOCATION TABLE FOR THIS DESIGNATED LOCATION.
479 415		DO 415 JX=1,6 AC(JX)=JPOS(JX) LTAB(BN,1,JX)=JPOS(JX) IF(DA.NE.1)GOTO 711 DA=0 CALL ARRLOC
C C C	IF 7	THE START OF THE APPROACH PATH IS TO BE A DELTA X,Y,Z AWAY FROM THE END POINT, THOSE DELTA VALUES ARE ENTERED HERE.
C 711 521 522		WRITE(6,521) FORMAT(8X'ENTER DELTA X,Y,Z (DECIMAL CM) TO START OF APPROACH PATH') READ(6,522)ADX,ADY,ADZ FORMAT(3(F7.3)) CALL ARMIN IF(EABORT.LT2000)GOTO 303 HX=ADX*100 HY=ADY*100 HZ=ADZ*100
C C C C	THE	OPERATOR NOW SUPPLIES THE INFORMATION AS TO WHETHER THE HAND COMES TO A STOP AT THIS LOCATION (FX=1) OR IT DOES NOT STOP HERE (FX=0).
630 109		WRITE(6,109) FORMAT(8X'***TYPE +1***IF HAND WILL STOP AT THIS LOCATION',/ 1 8X'***TYPE[CR]***IF HAND DOES NOT STOP HERE') BEAD(6, 110)FX
110		FORMAT(I3) CALL ARMIN IF(NRE.GT2000)GOTO 40 IF(EABORT.LT2000)GOTO 303 DO 620 J=B1,E1 LTAB(J,2,7)=FX LTAB(J,3,4)=HX LTAB(J,3,5)=HY
620 C	<b></b>	LTAB(J,3,6)=HZ
C C	146	TABLE ON THE TERMINAL OR ENTERING A NEW LOCATION IN THE TABLE.

	WRITE(6,111)	
111	FORMAT(8X'***TYPE [CR]*** FOR ANOTHER POINT',/ 1 8X'***TYPE +1*** TO DISPLAY TABLE THEN RETURN TO BEGINNING	۲)
112	READ(6,112)HH FORMAT(I3) CALL ARMIN	
	M=0	
C	THESE NEXT LOOPS SCAN THE LOCATION TABLE AND IE A DELTA OFFSET I	S
C	GIVEN TO THE START OF AN APPROACH PATH, THEN THE	
C	JOINT POSITION VALUES OF THE START OF THIS APPROACH PATH	
c	ENTERED IN THE TABLE ('LTAB(J,4,1-6)'). IF THERE IS NO	
С	APPROACH PATH, THEN THE JOINT POSITION VALUES OF	
C	THE END POINT ARE ALSO STORED IN 'LIAB(J,4,1-6). THE NAMES OF THE INDEXED LOCATIONS ARE STORED IN THE LAST TW	0
С	POSITONS IN THE LOCATION TABLE.	
C	DO $850 J = 1.86$	
	IF(LTAB(J,1,1).EQ.0)GOTO 850	
	AX = LTAB(J, 3, 4) / 100. AY = LTAB(J, 3, 5) / 100.	
	AZ = LTAB(J, 3, 6) / 100.	
830	DO $830 JB=1,6$ AC(JB)=LTAB(J,1,JB)	
	CALL COOR(0.,0.,0.,0,1)	
	LTAB(J, 2, 1) = AXEP*100 LTAB(J, 2, 2) = AYEP*100	
	LTAB(J,2,3)=AZEP*100	
	IF(AX.NE.O.)GOTO 2500	
	IF(AZ.NE.O.)GOTO 2500	
21100	DO 2400 KBL=1,6 TAP(T, H, KPL) - TAP(T, 1, KPL)	
2400	GOTO 850	
2500	CALL COOR(AX, AY, AZ, 0, 0)	
820	LTAB(J, 4, JA) = JPOS(JA)	
850	CONTINUE	
C	HERE THE NAMES OF THE INDEXED LOCATIONS ARE STORED IN THE LAST	
C	TWO POSITIONS OF THE TABLE.	
772	DO 704 J=89,90	
	DO 704 K=1,4	
	M=M+1	
704	IF(M.EQ.31)GOTO 798	
704 C	LTAB(J,K,L)=IN(M)	
C	IF 'HH' EQUAL TO ZERO (IE. A CARRIAGE RETURN WAS ENTERED), THEN	
c	IF 'HH'=1, THEN PRINT THE LOCATION TABLE OUT ON THE	
C	TERMINAL.	

798	IF(NRE.GT2000)GOTO 40 IF(HH.NE.1)GOTO 303 DO 120 KL=1,90 CALL ARMIN
	DO 120 NK=1,4 WRITE(6,1201)KL,(LTAB(KL,NK,J),J=1,7)
1201	FORMAT(8(2X,16))
120	CONTINUE
	GOTO 500
40	RETURN
	END





C		SUBROUTINE : ARRAY
00000		ARGUMENTS :
		CALLED BY : LOCTAB
C		CALLS SUBROUTINES :
000000		INPUT DATA : PA(30) = THE CHARACTER STRING FROM THE TERMINAL THAT CONTAINS THE INDEXED NAME AND THE STARTING AND ENDING INDEXED LOCATION VALUE FOR THIS PARTICULAR ARRAY [FROM THE TERMINAL].
C C		J1, J2 = THE DIMENSIONS OF THE ARRAY [FROM THE TERMINAL]
C C C		AD1(3) = THE DELTA 'X,Y,Z' DISTANCES (IN CENTIMETERS) BETWEEN THE LOCATION POINTS ALONG THE FIRST DIMENSION ('J1')
		OF THE ARRAY [FROM THE TERMINAL]. AD2(3) = THE DELTA 'X,Y,Z' DISTANCES BETWEEN THE LOCATION POINTS ALONG THE SECOND DIMENSION OF THE ARRAY [FROM THE TERMINAL].
000000000000000000000000000000000000000		OUTPUT DATA : J1, J2 AD1(3) AD2(3)= AS DESCRIBED ABOVE. = AS DESCRIBED ABOVE. = AS DESCRIBED ABOVE. = AS DESCRIBED ABOVE. = THE LOCATION TABLE POINTER FOR THE FIRST INDEXED LOCATION SPECIFIED IN THE ARRAY.E1= THE LOCATION TABLE POINTER FOR THE LAST INDEXED LOCATION SPECIFIED IN THE ARRAY.DA= A ·FLAG SET EQUAL TO ONE TO INDICATE THAT AN ARRAY OF LOCATION POINTS HAS BEEN ENTERED.
		FUNCTION: TO READ IN FROM THE TERMINAL THE NECCESARY INFORMATION TO CONSTRUCT THE CORRECT LOCATION TABLE VALUES FOR THE ARRAY OF LOCATIONS SPECIFIED. THE ACTUAL ENTERING OF THE VALUES INTO THE TABLE WILL BE DONE BY THE SUBROUTINE 'ARRPT'.
		SUBROUTINE ARRAY IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64),OUTBUF(64) COMMON/ARR/B1,E1,J1,J2,AD1(3),AD2(3),DA COMMON/IND/IN(30),FL(6),NAME(3),NPT(3,20) EQUIVALENCE(EABORT,INBUF(28)) DIMENSION PA(30)
CCCC	RI	EAD IN FROM THE TERMINAL, THE INDEXED NAME AND THE RANGE OF LOCATIONS, THE DIMENSIONS OF THE ARRAY, AND THE DELTA COORDINATE OFFSETS ALONG EACH DIMENSION.
50	0	WRITE(6,200)

```
200
        FORMAT(2X'ENTER LOCATION NAME AND INDEX NUMBERS',/
        1 2X'EG.
                        PALLET(01-20)')
        READ(6, 201)(PA(J), J=1, 30)
        FORMAT(30(A1))
201
        WRITE(6,202)
202
        FORMAT(2X'ENTER ARRAY DIMENSIONS',/
        1 2X'(EG.
                        4,5
                                     )')
        READ(6,203)J1,J2
203
        FORMAT(2(13))
        WRITE(6,204)
204
        FORMAT(2X'ENTER X,Y,Z DELTAS (DECIMAL CM) BETWEEN ',/
        1 2X' ARRAY POSITIONS ALONG FIRST DIMENSION. ')
        READ(6, 205)(AD1(J), J=1, 3)
205
        FORMAT(3(F7.3))
        WRITE(6,214)
214
        FORMAT(2X'ENTER X,Y,Z DELTAS (DECIMAL CM) BETWEEN ',/
        1 2X' ARRAY POSITIONS ALONG SECOND DIMENSION. ')
        READ(6, 215)(AD2(J), J=1, 3)
215
        FORMAT(3(F7.3))
С
С
    DECODE THE NAME AND THE SPECIFIED
                                          INDICES INTO THE CORRECT LOCATION
С
        TABLE POINTERS.
С
        J = 0
        J = J + 1
10
        IF(J.EQ.31)GOTO 40
        IF(PA(J).EQ.8224)GOTO 10
        DO 20 K=1,3
20
        IF(PA(J).EQ.NAME(K))GOTO 7
        WRITE(6, 120)PA(J), NAME(1), NAME(2), NAME(3)
120
        FORMAT(4(A1))
        WRITE(6,100)
100
        FORMAT(2X'CANNOT FIND THIS NAME.'./
        1 2X'***TYPE +1*** TO RE-ENTER NAME',/
        1 2X'*** TYPE [CR]*** TO ABORT.')
        READ(6,206)BOR
206
        FORMAT(I3)
        IF(BOR.EQ.1)GOTO 500
        GOTO 40
С
С
    DETERMINE WHAT THE FIRST SPECIFIED INDEX VALUE IS.
С
7
        J = J + 1
        IF(J.EQ.31)GOTO 40
        IF(PA(J).NE.8232)GOTO 7
8
        J = J + 1
        IF(J.EQ.31)GOTO 40
        IF(PA(J).EQ.8224)GOTO 8
        ONE = PA(J)
        TWO = PA(J+1)
        F = (10*(ONE-8240)) + (TWO-8240)
        J = J + 1
        IF(J.EQ.31)GOTO 40
С
С
    DETERMINE WHAT THE LAST SPECIFIED INDEX VALUE IS.
С
```

17	J = J + 1
	IF(J.EQ.31)GOTO 40
	IF(PA(J).EQ.8224)GOTO 17
	IF(PA(J).EQ.8237)GOTO 17
	ONE = PA(J)
	TWO=PA(J+1)
	L = (10 # (ONE - 8240)) + (TWO - 8240)
С	
С	DECODE THE FIRST AND LAST INDEX NUMBERS INTO THEIR CORRESPONDING
С	LOCATION TABLE POINTERS AND STORE IN THE COMMON VARIABLES 'B1' AND
С	'E1'.
С	
	B1=NPT(K,F)
	E1=NPT(K,L)
	D A = 1
40	RETURN
	END



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с.		SUBROUTINE :	ARRLOC					
с - с -		ARGUMENTS :						
С С-		CALLED BY : L	OCTAB					
с с -		CALLS SUBROUT	INES : COOR					
		INPUT DATA :	J1,J2 AD1(3)		THE DIMENSIONS OF THE ARRAY. THE DELTA 'X,Y,Z' DISTANCES (IN CENTIMETERS) BETWEEN THE LOCATION POINTS ALONG THE FIRST DIMENSION ('J1')			
			AD2(3)	=	THE DELTA 'X,Y,Z' DISTANCES BETWEEN THE LOCATION POINTS ALONG THE SECOND DIMENSION OF THE APPAX			
			B 1	=	THE LOCATION TABLE POINTER FOR THE FIRST INDEXED LOCATION SPECIFIED IN THE ARRAY			
			E 1	=	THE LOCATION TABLE POINTER FOR THE LAST INDEXED LOCATION SPECIFIED IN THE ABBAY			
			DA	=	A FLAG SET EQUAL TO ONE TO INDICATE THAT AN ARRAY OF LOCATION POINTS HAS BEEN ENTERED.			
с - с -		OUTPUT DATA :	JPOS(1-6)		= THE JOINT POSITION VALUES FOR EACH OF THE LOCATIONS IN THE SPECIFIED ARRAY			
			AC(1-6)		= THE JOINT POSITION VALUES THAT CHARACTERIZE THE REFERENCE POINT USED BY THE COORDINATE TRANSFORMATION ROUTINE.			
с - с -		FUNCTION: TO JOI ARR	GENERATE AND NT POSITION V AY.	S' VA I	TORE IN THE LOCATION TABLE, ALL OF THE LUES FOR THE LOCATIONS OF THE SPECIFIED			
C		SUBROUTINE ARRLOC IMPLICIT INTEGER(B-Z) COMMON/ARMBUF/INBUF(64),OUTBUF(64) COMMON/LMOD/LTAB(90,4,7),PRES,DEST COMMON/OUT/JPOS(8) COMMON/CORT/AC(6),AXEP,AYEP,AZEP COMMON/ARR/B1,E1,J1,J2,AD1(3),AD2(3),DA EQUIVALENCE(EABORT,INBUF(28)) DIMENSION AY2(3),AXY(3)						
	SI	TORE THE LOCAT IN THE VARI.	ION TABLE POI ABLE 'PAA'.	ENT	TER FOR THE FIRST INDEXED LOCATION			
c		P P A = B 1						
	PL	ACE THE JOINT COMMON VARI BY THE COOR	POSITION VAL ABLE 'AC(1-6) DINATE TRANSE	LUE )' FOE	ES OF THIS FIRST INDEXED LOCATION IN THE WHICH WILL BE USED AS A REFERENCE POINT RMATION ROUTINE 'COOR'.			

15 C	DO 15 J=1,6 AC(J)=LTAB(B1,1,J)
	THESE LOOPS GENERATE THE CORRECT JOINT POSITION VALUES FOR ALL OF THE LOCATIONS IN THE ARRAY. THIS IS DONE BY SPECIFYING THE DELTA COORDINATE OFFSETS FOR EACH LOCATION IN THE ARRAY FROM THE FIRST SPECIFIED REFERENCE LOCATION ('AC(1-6)') AND OBTAINING FROM THE COORDINATE TRANSFORMATION ROUTINE THE CORRESPONDING JOINT POSITION VALUES, THEN STORING THESE VALUES IN THE CORRECT PLACE IN THE LOCATION TABLE.
	DO 110 J22=1,J2 JS=J22-1 DO 117 J4=1.3
117	AY2(J4)=JS*AD2(J4) DO 110 J11=1,J1 JR=J11-1 DO 120 JA=1,3
120 C	AXY(JA)=JR*AD1(JA)+AY2(JA) CALL COOR(AXY(1),AXY(2),AXY(3),0,0)
C C C C	HERE THE JOINT POSITION VALUES ARE STORED IN THE LOCATION TABLE UNDER THE CORRECT POINTER VALUE FOR THIS PARTICULAR NAME AND INDEX NUMBER.
115 110	DO 115 K=1,6 LTAB(PPA,1,K)=JPOS(K) PPA=PPA+1 RETURN END





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C	 SUBROUTINE : JOY	
C	 ARGUMENTS :	
C C	 CALLED BY : LOCTAB	
C	 CALLS SUBROUTINES : ARMIN	COOR SERVO POS
	 INPUT DATA : JPOS(1-6) =	THE VALUE OF ALL OF THE JOINT POSITION INDICATORS AT THE BEGINNING OF THIS
	INBUF(26) =	THE CHANNEL THAT CONTROLS THE VELOCITY
c c	INBUF(27) =	THE CHANNEL THAT CONTROLS THE 'GRASP' AND
	INBUF(31) =	THE CHANNEL THAT CALLS FOR A PRINT OUT ON THE TERMINAL OF THE PRESENT 'X,Y,Z'
C C	INBUF(32) =	THE CHANNEL USED TO RETURN CONTROL TO THE
	INBUF(37) =	THE CHANNEL THAT CONTROLS THE WRIST ROLL
c c	INBUF(38) =	THE CHANNEL THAT CONTROLS THE WRIST
c c	INBUF(39) =	THE CHANNEL THAT CONTROLS THE HAND ROLL.
C C	INBUF(40) =	THE CHANNEL THAT CONTROLS THE 'X' MOTION OF THE HAND.
C C	INBUF(41) =	THE CHANNEL THAT CONTROLS THE 'Y' MOTION OF THE HAND.
	INBUF(42) =	THE CHANNEL THAT CONTROLS THE 'Z' MOTION OF THE HAND.
	 OUTPUT DATA : AC(1-6)	= THE STARTING JOINT POSITION VALUES THAT ARE USED AS A REFERENCE POINT FOR THE COORDINATE TRANSFORMATION
	JPOS(1-8)	THE JOINT POSITION VALUES THAT ARE THE COMMANDED OUTPUT VALUES TO THE SERVOS THAT WILL CAUSE THE HAND TO MOVE IN THE DIRECTION INDICATED BY THE JOYSTICK.
	 FUNCTION: READS IN THE VAL CALCULATES THE P TO ACCOMPLISH TH JOINT POSITION V	UES OF THE JOYSTICK POTENTIOMETERS, ROPER JOINT POSITION VALUES E COMMANDED MOVES AND OUTPUTS THESE ALUES TO THE SERVOS.
	SUBROUTINE JOY IMPLICIT INTEGER (D-R) COMMON/ARMBUF/INBUF(64), COMMON/OUT/JPOS(8) COMMON/CORT/AC(6),AXEP,A EQUIVALENCE(EABORT,INBUF COMMON/XYZO/AO4,AO5,AO6 DIMENSION KIN(5),KBN(5),1	OUTBUF(64) YEP,AZEP (28)) KMD(3)

DATA KIN/37,38,39,27,42/ С С THE FLAG 'PTC' IS SET EQUAL TO ZERO. THIS FLAG IS USED IN THE GRASP С AND RELEASE FUNCTIONS TO CONTROL THE SETTING OF THE HAND BRAKE. С PTC = 0С С THE DELTA COORDINATE OFFSETS ('AX','AY','AZ') AND THE DELTA С ROTATIONAL OFFSETS ('A04', 'A05', 'A06') FOR THE WRIST AND HAND С ARE INITIALIZED TO ZERO. С AX = 0. AY = 0. AZ = 0. AO4=0. A05=0. A06=0. С С THE PRESENT JOINT POSITION VALUES ARE READ IN AND STORED IN THE С COMMON VARIABLE 'AC(1-6)' TO BE USED AS THE REFERENCE POINT FOR ALL OF THE COORDINATE TRANSFORMATION CALCULATIONS С С TO BE DONE BY 'COOR'. С CALL POS DO 525 JJ=1,6 525 AC(JJ) = JPOS(JJ)С С THE MESSAGE THAT TELLS WHICH SWITCHES CONTROL WHICH FUNCTIONS С IS SENT TO THE TERMINAL. С WRITE(6,526) 526 FORMAT(3X'TO RETURN TO THE TEACH TRAJECTORY MODE, ',/ 1 3X'FLIP SWITCH 32 TO THE DOWN POSITION.'/ 1 3X'FLIP SW 31 UP TO DISPLAY X Y Z VALUES.') С С THE VALUES OF ALL OF THE INPUTS FROM THE JOYSTICK BOX ARE С READ IN. С 20 CALL ARMIN С С THE VARIABLE 'RT' CONTAINS THE VALUE OF THE SWITCH USED TO С RETURN TO THE CALLING PROGRAM ('LOCTAB'). С RT = -INBUF(32)IF(RT-2000)40,527,527 С С THE INPUT VALUES FOR THE 'X' AND 'Y' MOTION ARE STORED IN THE С VARIABLES 'IX' AND 'IY'. С 527 IX = -INBUF(40)IY = -INBUF(41)С С THE THREE ROTATIONAL ANGLES OF THE HAND-WRIST, THE FINGER CLOSING, С AND THE 'Z' MOTION INDICATOR ARE DECODED INTO THE NUMBER '2' С FOR POSITIVE MOTION, OR THE NUMBER '-2' FOR NEGATIVE MOTION, С OR THE NUMBER 'O' FOR NO MOTION. THESE CODED NUMBERS FOR

```
EACH OF THESE FIVE MOTIONS ARE STORED IN THE VARIABLE 'KBN(1-5)'.
С
С
        DO 100 KL=1,5
        FLL=KIN(KL)
100
        KBN(KL) = ((INBUF(FLL) + 1850) / 1000) * (-2)
С
С
    THE VALUE OF THE POTENTIOMETER ON CHANNEL 26 IS READ IN AND USED AS
С
        A CONTROL FOR THE SIZE OF THE COMMANDED MOVE FOR EACH OUTPUT.
С
        THEREBY CONTROLING THE VELOCITY. THIS CONTROL VALUE
С
        IS STORED IN THE VARIABLE 'SPD'.
С
        SPD = ((-INBUF(26) - 2150)/10) + 1
С
С
   A VELOCITY FACTOR FOR EACH OF THE THREE ROTATIONAL ANGLES OF THE
С
        HAND-WRIST IS GENERATED BY MULTIPYING THE VELOCITY CONTROL
С
        VALUE ('SPD') BY THE PARTICULAR JOINT'S MOTION INDICATOR
С
        NUMBER ('KBN(1-3)').
С
        DO 200 J=1,3
200
        KMD(J) = KBN(J) * SPD
С
С
    EACH OF THE THREE ANGLES IS OFFSET BY ITS CORRESPONDING VELOCITY
С
        FACTOR ('KMD(1-3)').
С
        AO4 = AO4 + KMD(1)
        A05 = A05 + KMD(2)
        A06 = A06 + KMD(3)
С
С
    THE FINGER MOTION INDICATOR IS CHECKED TO DETERMINE IFTHE
С
        FINGERS ARE TO BE OPENED OR CLOSED. IF NEITHER,
        THEN BRANCH TO STATEMENT 300.
С
С
        IF(KBN(4).EQ.0)GOTO 300
С
С
    THE FLAG 'PTC' IS SET EQUAL TO ONE, AND WILL BE USED TO SET THE BRAKE
С
        ON THE FINGERS AFTER THIS FINGER MOTION IS FINISHED.
С
        IF(PTC.EQ.1)GOTO 75
        PTC = 1
С
С
    THE CORRECT VALUE IS SET IN 'JPOS(8)' TO RELEASE THE BRAKE ON THE
С
        FINGERS.
С
        JPOS(8) = 32767
        CALL SERVO(0)
75
        IF(KBN(4).EQ.2)GOTO 301
С
    HERE, THE COMMANDED JOINT POSITION VALUE TO THE FINGERS IS
С
С
        INCREMENTED FOR EACH OUTPUT TO CAUSE THE FINGERS TO OPEN.
С
        IF(JPOS(7)-30000)305,310,310
305
        JPOS(7) = JPOS(7) + 200
        GOTO 310
С
    HERE, THE COMMANDED JOINT POSITION VALUE TO THE FINGERS IS
С
        DECREMENTED FOR EACH OUTPUT TO CAUSE THE FINGERS TO CLOSE.
С
```

C 301 308 310		IF(JPOS(7)-3500)310,308,308 JPOS(7)=JPOS(7)-200 CALL SERVO(0) GOTO 20
C C C C C C C	THE	BRAKE FLAG IS CHECKED TO SEE IF IT IS SET ('PTC'=1). IF IT IS, THEN THE PROPER NUMBER IS PLACED IN 'JPOS(8) TO CAUSE THE BRAKE ON THE FINGERS TO BE SET. THE FLAG IS ALSO RESET TO ZERO.
300		IF(PTC.EQ.0)GOTO 720 PTC=0 JPOS(8)=32703 CALL SERVO(0)
	A FI	LOATING POINT VARIABLE 'ASP' IS DEFINED AS THE VELOCITY FACTOR 'SPD' MULTIPLIED BY 1/300 OF A CENTIMETER. THE NUMBER OF THESE DELTA INCREMENTS TO BE MOVED IN THE 'X', 'Y', AND 'Z' DIRECTIONS IS DETERMINED BY MULTIPLYING THIS DELTA STEP BY A DECODED VALUE FROM THE INPUT CHANNEL FOR EACH COORDINATE AXIS.
C 720 C C C C C C C		ASP=SPD/300. MX=(IX-1070)/75 BX=MX*ASP AX=AX+BX MY=(1070-IY)/75 BY=MY*ASP AY=AY+BY BZ=KBN(5)*ASP AZ=AZ+BZ
	ONCE	E THE DELTA MOTIONS IN EACH OF THE THREE COORDINATE AXES HAS BEEN CALCULATED, THEN THESE DELTA 'X', 'Y', 'Z' VALUES ARE GIVEN TO THE COORDINATE TRANSFORMATION ROUTINE SO THAT THE JOINT POSITIONS FOR THESE MOTIONS CAN BE CALCULATED.
c		CALL COOR(AX,AY,AZ,O,O)
	THES	SE CALCULATED JOINT POSITION VALUES ARE THEN OUTPUTED TO THE SERVOS.
		CALL SERVO(0)
C C C	IF S	WITCH 31 IS SET THEN THE ABSOLUTE 'X', 'Y', 'Z' COORDINATE POSITIONS ARE PRINTED OUT ON THE TERMINAL.
591 425 40		OHH=INBUF(31) IF(OHH.GT2000)GOTO 20 WRITE(6,591)AXEP,AYEP,AZEP FORMAT(2X'X=',F10.2,/,2X'Y=',F10.2,/,2X'Z=',F10.2) CALL ARMIN OHH=INBUF(31) IF(OHH.LT2000)GOTO 425 GOTO 20 RETURN
		END





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```
C --- SUBROUTINE : POS
С
С
 --- ARGUMENTS :
С
C
  --- CALLED BY : EMOVE LOCTAB
                                     JOY
С
С
 --- CALLS SUBROUTINES : ARMIN
С
С
  --- INPUT DATA : INBUF(5,8,11,13,15,17) = THE PRESENT VALUES OF THE
С
                                                  SIX JOINT POSITION INDICATORS.
С
C --- OUTPUT DATA : JPOS(1-6)
                                       = THE SCALED VALUES OF THE SIX JOINT
С
                                         POSITON INDICATORS AS CALCULATED IN
С
                                         THIS SUBROUTINE.
С
C --- FUNCTION: SCALES THE JOINT POSITION INDICATOR VALUES INTO
С
                  A RANGE OF 0 TO 32767.
С
         SUBROUTINE POS
         IMPLICIT INTEGER(A-Z)
         COMMON/ARMBUF/INBUF(64), OUTBUF(64)
         COMMON/OUT/JPOS(8)
С
    A CALL TO THE SUBROUTINE 'ARMIN' IS MADE TO READ IN THE VALUES OF THE JOINT POSITION INDICATORS.
С
С
С
         CALL ARMIN
С
С
С
    THE FOLLOWING TWO 'DO LOOPS' ARE USED TO
С
         GENERATE THE CORRECT INPUT CHANNEL NUMBERS
С
         (5,8,11,13,15,17,19) FOR THE SEVEN JOINT
С
         POTENTIOMETERS.
С
         JPOS(1) = INBUF(5) * 2 + 16383
         JPOS(2) = INBUF(8) + 2 + 16383
         K = 9
         DO 51 I=3,6
         K = K + 2
         JPOS(I) = INBUF(K) * 2 + 16383
51
         CONTINUE
         JPOS(1) = (JPOS(1) * 1.) - 22.
         JPOS(2) = (JPOS(2) * .9879) + 210.
         JPOS(3) = (JPOS(3)*1.001) - 30.
         JPOS(4) = (JPOS(4) * 1.0165) - 283.
         JPOS(5) = (JPOS(5) * .9904) + 45.
         JPOS(6) = (JPOS(6) * .997) + 15
         OUTBUF(7) = (OUTBUF(7) * 1.0227) - 400.
С
         RETURN
         END
```

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