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SPACE TELEOPERATION RESEARCH

AMERICAN NUCLEAR SOCIETY EXECUTIVE CONFERENCE
REMOTE OPERATIONS AND ROBOTICS IN THE NUCLEAR INDUSTRY
REMOTE MAINTENANCE IN OTHER HOSTILE ENVIRONMENTS

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Pine Mountain, Georgia
April 23-24, 1985

SPACE TELEOPERATION RESEARCH OUTLINE

This presentation consists of four sections. The first section is a brief introduction to the NASA Space Station Program. The second portion summarizes the results of a congressionally mandated study of automation and robotics for Space Station. The third portion presents a number of concepts for space teleoperator systems. The remainder of the presentation describes Langley Research Center's teleoperator/robotic research to support remote space operations.

SPACE TELEOPERATION RESEARCH

SPACE STATION

SPACE STATION AUTOMATION STUDY

SPACE TELEOPERATOR CONCEPTS

LANGLEY RESEARCH CENTER'S TELEOPERATOR/ROBOTICS RESEARCH

SPACE STATION

"President Reagan in his January 1984 State of the Union address directed NASA to develop a permanently manned space station and to do it within a decade."

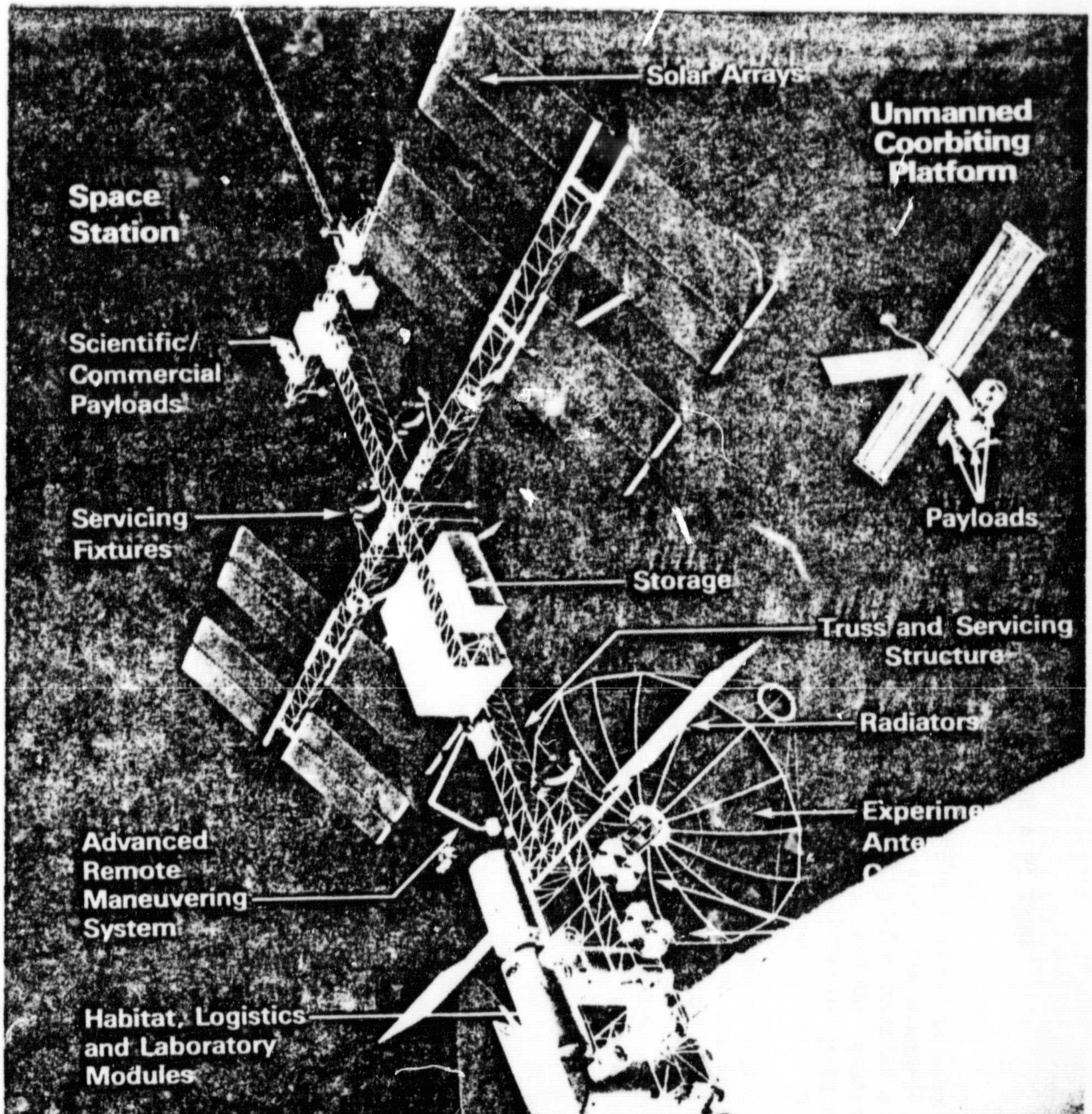
* * *

"At present, the space station is only a concept. NASA does not yet have a space station design."

* * *

"The concept, however, is clear and firm. A space station is a multipurpose permanent system in low Earth orbit consisting of both manned and unmanned elements--a manned base and associated unmanned platforms--that will significantly enhance the efficiency of space operations." (ref. 1)

Shown is one concept, the "power tower" a vertically oriented structure about 300 feet in length. The Shuttle orbiter is shown docked to the space station and a conceptual unmanned coorbiting platform is depicted.


Solar Arrays
Unmanned Coorbiting Platform
Space Station
Scientific/ Commercial Payloads
Payloads
Servicing Fixtures
Storage
Truss and Servicing Structure
Radiators
Advanced Remote Maneuvering System
Habitat, Logistics and Laboratory Modules
Space Shuttle Orbiter

WHAT IS A SPACE STATION?

"The space station base as currently conceived is a cluster of functionally oriented modules. Its principal elements will be a utility module for essential services such as power and thermal management; a habitat module able to house six to eight astronauts comfortably; one or two pressurized laboratory modules; a logistics module for supply and replenishment; and pallets or platforms carrying scientific instruments and repair equipment for both the base and the platforms. The space station base will be tended by the Space Shuttle."

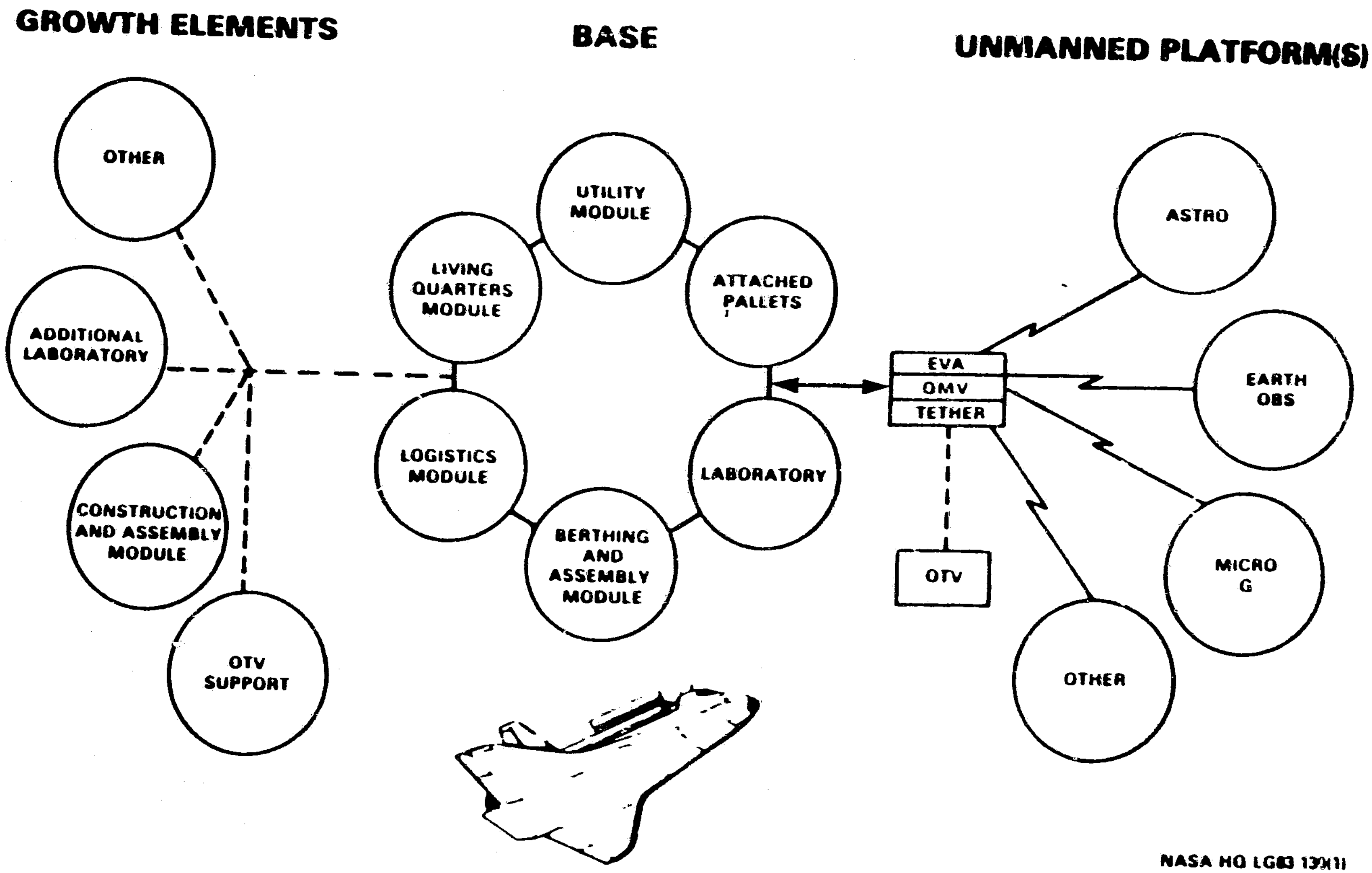
* * *

"From the start, the system is conceived as one that can evolve over time into a more capable facility. NASA and its industrial partners will design a space station that upon becoming operational early in the 1990's will be useful in its own right, but not particularly large. Later on, as requirements emerge and funds permit the station could, if the country wished, be expanded. This evolutionary characteristic of the space station represents a challenge to all who are involved in its design."

* * *

"The space station concept encompasses both manned operations and unmanned spacecraft. Astronauts will be employed in tasks and roles where our experience and intuition tell us that the presence of man is uniquely valuable. At the same time, NASA realizes that many activities, particularly those of a routine nature or those that can be programmed in advance, are better suited for automated systems. The challenge will be to design a space station that combines the best of both modes; we must find the proper mix of man and machine." (ref. 1)

SPACE STATION PROGRAM ARCHITECTURE: WHAT IS A SPACE STATION



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FUNCTIONS OF A SPACE STATION

The space station is a multi-purpose facility. The current mission model includes science and applications, observation, technology development and demonstration, commercial laboratories and production facilities (e.g. crystal growth, pharmaceuticals), and operational activities such as servicing, maintenance, and repair of satellites, support of unmanned platforms, assembly of large space systems, and as a transportation node for transfer to other orbits or planetary missions.

To efficiently accomplish these many and varied functions, the development and application of advanced automation, teleoperator and robotics technology is required.

FUNCTIONS OF A SPACE STATION

- On-orbit laboratory
  - —Science and applications
  - —Technology
- Permanent observatory(s)
- Transportation node
- Servicing repair facility
  - —Free flyers
  - —Platforms
- Manufacturing facility
- Assembly facility

A space station is a multi-purpose facility

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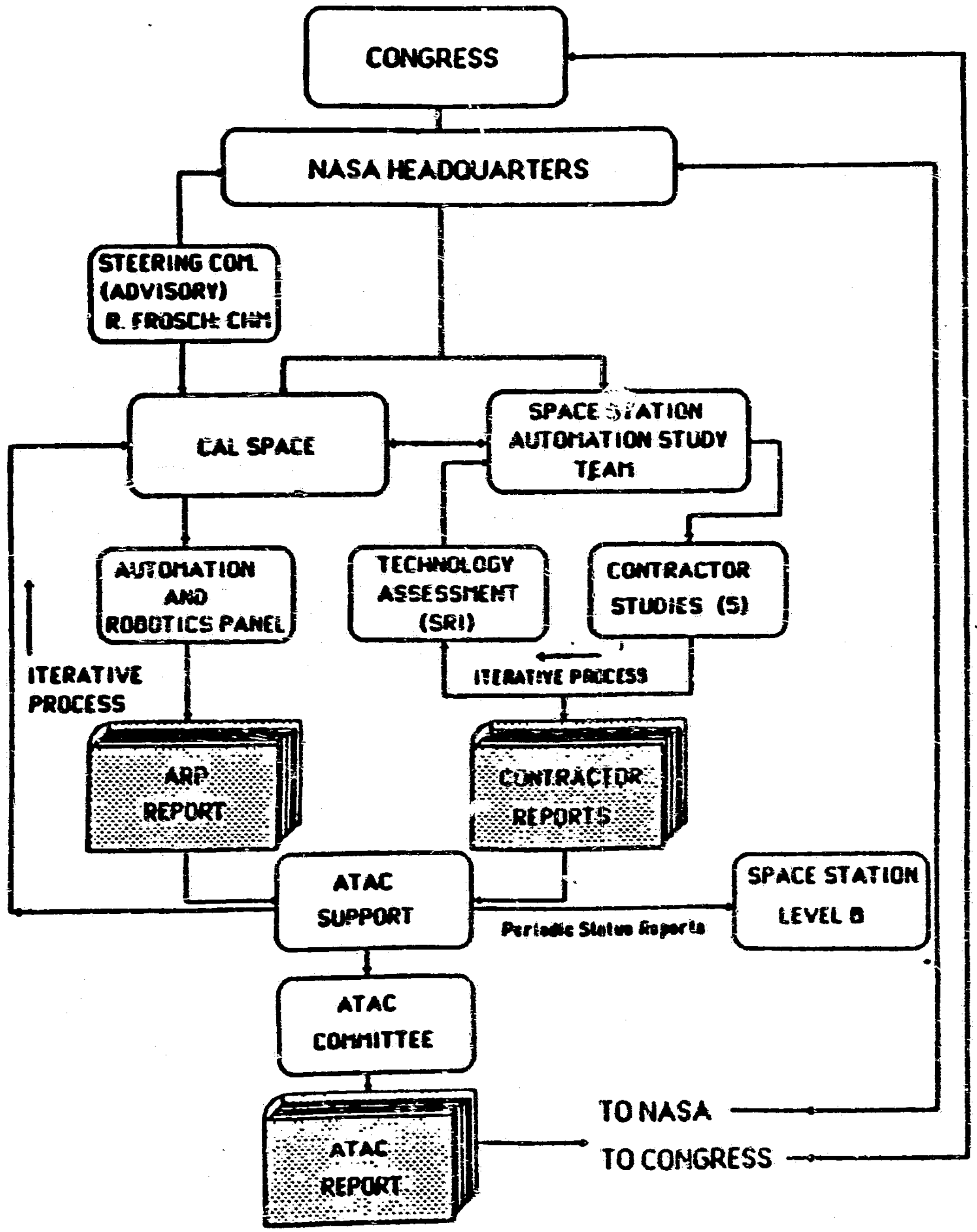
SPACE STATION AUTOMATION STUDY

During 1984, the Senate Appropriations Committee of the 98th Congress required that NASA establish an Advanced Technology Advisory Committee (ATAC) and that the committee prepare a report by April 1, 1985, identifying advanced automation and robotics (A&R) technologies for the Space Station program. Congress became convinced that the Space Station program should not only incorporate advanced A&R, but should also use this opportunity to stimulate national development of these technologies. In April 1984, the staff of the Senate Appropriations Committee and NASA agreed to establish the Space Station Automation Study. The study was organized and directed by the Level A Space Station Program Office at NASA Headquarters. Six contractors formed a design team and produced reports which contributed to the study. Five major aerospace corporations conducted studies of how advanced A&R could be used in Space Station subsystems, and the sixth contractor performed a technology assessment based on the A&R state-of-the-art and the other contractor design concepts.

The California Space Institute (Cal Space) organized and administered the Automation and Robotics Panel (ARP). A steering committee, headed by Dr. Robert A. Frosch, Vice President of Research for General Motors Corporation and a previous administrator of NASA, guided and participated in the ARP. ARP consisted of specialists in the field of automation, computer science, robotics, industrial development, and aerospace engineering from industry, universities, and government. The Panel charter was to provide guidance on the application of advanced A&R to the Space Station and how the Space Station might help advance A&R capabilities for the nation.

The results of these studies are contained in references 2 through 9.



AUTOMATION/ROBOTICS STUDY

SPACE STATION AUTOMATION STUDY

CONTRACTOR REPORTS

As I have mentioned, six contractors participated in the Space Station Automation Study supporting both the Automation and Robotics Panel and the Advanced Technology Advisory Group. Five aerospace contractors were members of a design team with each member studying a specific aspect of space station operations to develop system concepts and designs and identify advanced automation and robotics technologies. The sixth contractor, SRI International, was responsible for technology assessment.

Hughes Aircraft Company was assigned the task of developing an automation concept for the autonomous operation of space station subsystems. The objective of the Hughes study was to identify those functions associated with the operations of such subsystems as electric power, thermal control, and communications and tracking (ref. 5).

The TRW Space and Technology Group task was to define the technology requirements for automated satellite servicing operations onboard and in conjunction with the space station (ref. 6).

The General Electric Company was assigned to assess automation technology required for remote operations, including manufacturing applications. GE analysed a large number of space station missions and produced an in-depth development of automation requirements for two manufacturing design concepts: a gallium arsenide electroepitaxial crystal production and wafer manufacturing facility, and a gallium arsenide VLSI microelectronics chip processing facility (ref. 7).

The Martin Marietta Aerospace study responsibilities covered two areas. The first area was the application of automation technology for the total space station and selected subsystems (environmental control and life support, electrical power and information and data management). The second area was the system-level applications of automation technology for assembly, construction, repair and modification of a Space Station and its various elements (ref. 8).

The Boeing Aerospace Company and Boeing Computer Services Company study covered the Operator-System Interface (OSI). The study characterizes an OSI for an extravehicular robot system to perform maintenance functions on the Space Station, develops OSI senarios for that system, and assesses the associated technologies (ref. 9).

SRI International was responsible for technology assessment and as such formed a technology team to review and assess the design concepts. This team provided assessments of the advanced automation and technology needs as determined by the aerospace contractors and assisted the contractors with the integration of these technologies into the conceptual design. In addition, SRI provided an overall technology plan for the Space Station A&R (ref. 4).

SPACE STATION AUTOMATION STUDY

CONTRACTOR REPORTS

- 0 **HUGHES** - AUTOMATED SUBSYSTEMS OPERATIONS
  - COMMUNICATIONS
  - ELECTRICAL POWER & THERMAL
  - SYSTEM MONITORING & CONTROL
- 0 **TRW** - SATELLITE SERVICING
- 0 **GENERAL ELECTRIC** - SPACE MANUFACTURING - Valley Forge
  - GAAs CRYSTAL PRODUCTION
  - GAAs MICROELECTRONICS CHIP FABRICATION
- 0 **MARTIN MARIETTA** - AUTONOMOUS SYSTEMS AND ASSEMBLY
- 0 **BOEING** - OPERATOR/SYSTEMS INTERFACE — Comp Service (AI)
- 0 **SRI** - TECHNOLOGY ASSESSMENT

[Very good assessment] Oscar Firschein

How do you fix it when it breaks?

Not how to build it. How do you take care of it & fix it.

SPACE STATION AUTOMATION
SUMMARY

"The Automation and Robotics Panel (ARP) concludes that Congress was correct in its initial judgement: NASA can indeed significantly improve the effectiveness and reduce the cost of Space Station operations through the use of advanced automation and robotics. Capabilities in A&R will be accelerated, leading to broad national benefits." (ref. 3)

The Initial Operational Capability (IOC) Space Station should be designed to assist and accommodate advances in A&R. These designs should feature modularity, reserve capacity, flexibility, and standard protocols and should allow for ease of operation, recognition, and movement by teleoperator/robotic systems; these include standardized markings (e.g., bar codes), color codes, connectors and other fastenings, and computer/network interfaces.

Standardized CAD/CAM data bases are required which not only include the design information but also include the information on assembly, testing, and modeling such that expert systems can be developed for monitoring, fault isolation, reconfiguration and computer planning systems developed as an aide in teleoperation and use by future robots.

The use of A&R for the Space Station program can be viewed in two major areas: teleoperator/robotic systems for servicing, maintenance, repairs, and assembly; and computerized systems to reduce the manpower requirements of planning, monitoring, diagnosis, fault recovery of space systems and subsystems to increase the autonomy and operational capability and flexibility of space station.

Research topics include:

Mechanisms and Control which involves modular manipulator design, end effectors and tool design, and adaptive and intelligent control systems.

Sensing and Perception which includes remote and contact sensors, multisensor integration, data base verification and modification based on sensor data and development of methods of incorporating sensor information for closed loop control and input to expert systems and automatic planning systems.

Artificial Intelligence areas include expert and knowledge-based systems, natural languages, CAD data base definition and maintenance procedures, and automatic planning and scheduling systems.

Computer and Systems Science research involves architectures, communication, real-time distributed network operating systems, fault tolerance and security.

Operator/System Interface includes speech input/output, natural language understanding, advanced displays and controls for teleoperator/robotics systems but especially for effective

SPACE STATION AUTOMATION STUDY
SUMMARY

Cost Reduction, Avail. [illegible] [illegible]

- o NASA CAN INDEED SIGNIFICANTLY IMPROVE THE EFFECTIVENESS AND REDUCE THE COST OF SPACE STATION OPERATIONS THROUGH THE USE OF ADVANCED AUTOMATION AND ROBOTICS. CAPABILITIES IN A&R WILL BE ACCELERATED, LEADING TO BROAD NATIONAL BENEFITS

- o DESIGN THE IOC SPACE STATION (INITIAL OPERATIONAL CAPABILITY) TO ACCOMMODATE MAJOR EVOLUTION AND GROWTH IN ITS USE OF AUTOMATION AND ROBOTICS

50K [illegible] tool

- o RESEARCH TOPICS
  - MECHANISMS AND CONTROL
  - SENSING AND PERCEPTION
  - ARTIFICIAL INTELLIGENCE
  - COMPUTER AND SYSTEM SCIENCE
  - OPERATOR/SYSTEM INTERFACE

Robotics ≡ ~~[illegible]~~ Human Factors

AI ≡ Human Factors Enhancement

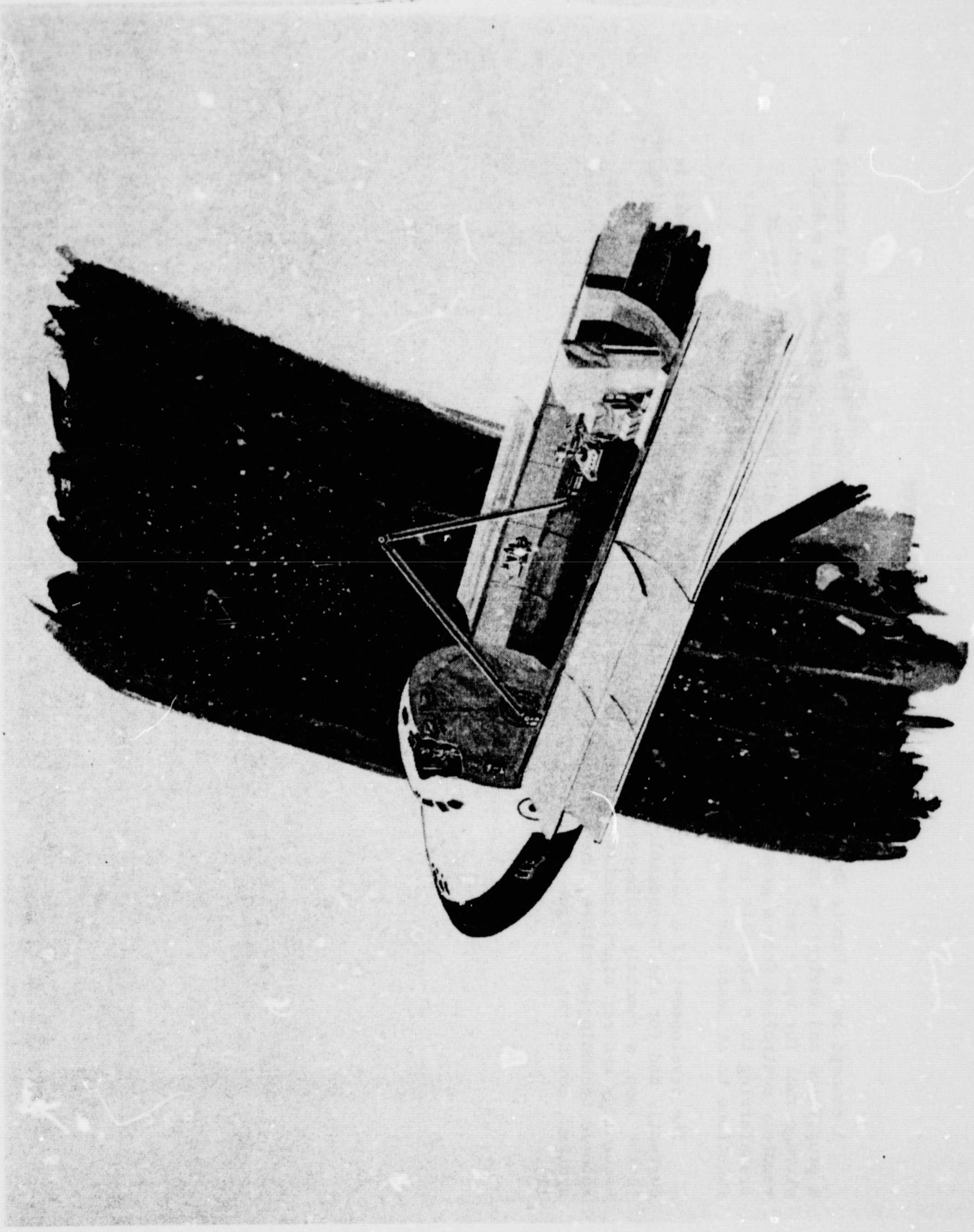
Sensors ≡ Detection and Perception

How end effectors and computer communicate!!!

DEXTEROUS MANIPULATOR - CONCEPT

The illustration shows two dexterous manipulators, mounted on the end of the Remote Manipulator System (RMS) arm, operated and controlled from a master unit on the Aft Flight Deck. The dexterous manipulators are designed to duplicate the motions of a human arm and shoulder, including sensing forces and feeding them back to the master. The concept enables remote operations to be performed within the payload bay (ref. 10).

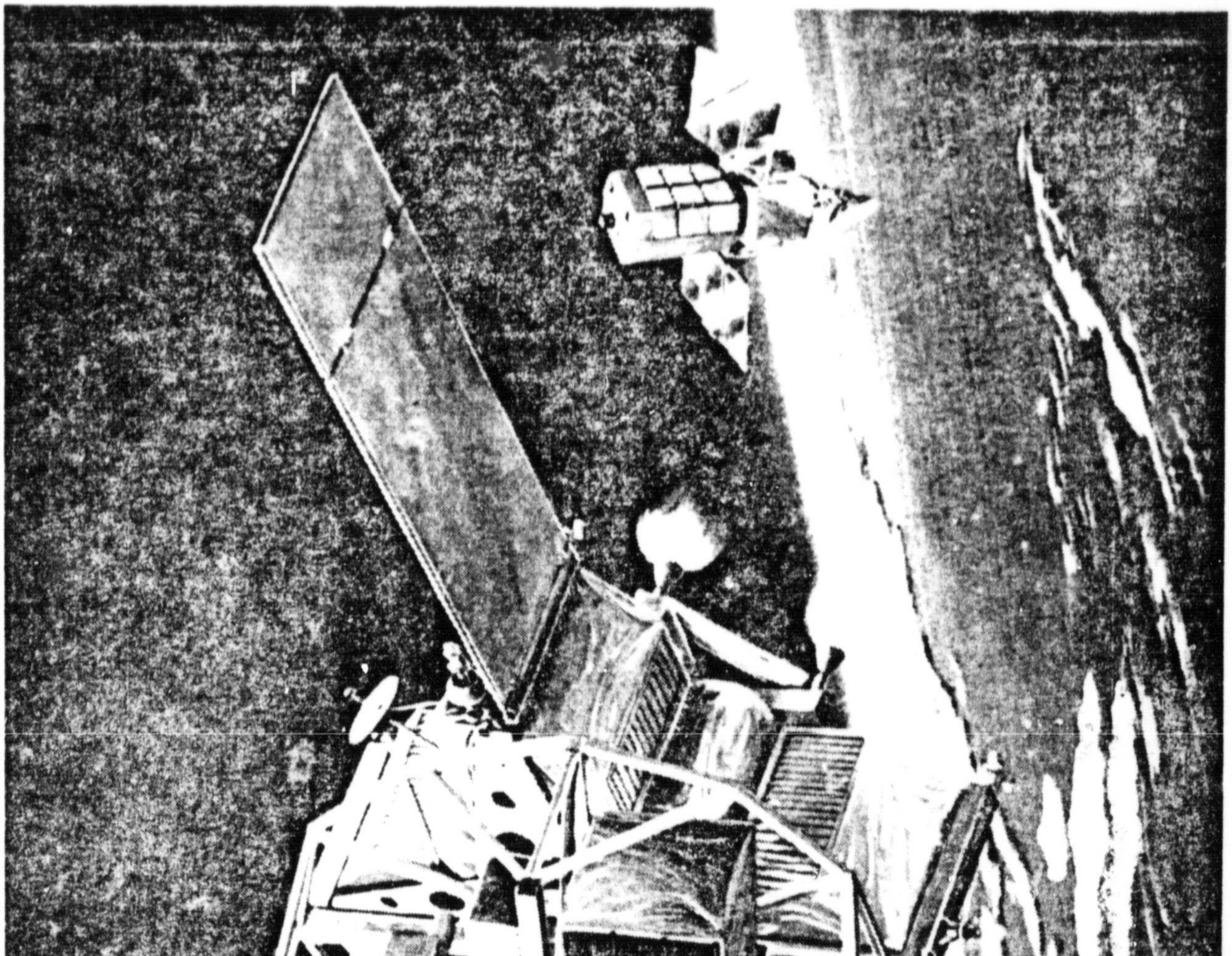
Bob Kenton control algorithms + sensors to use SLY



REMOTE ORBITAL SERVICING SYSTEM

A concept for a Remote Orbital Servicing System (ROSS) is shown. The ROSS would consist of a propulsion and navigation system, video and sensor systems, manipulator systems, a modular storage rack for spare parts, and communication to a remote control station. The vehicle, remotely controlled from a ground or space control station, would have the capability of transferring to a satellite in orbit, attaching to it, and performing servicing and repair functions to at least the same extent as an EVA astronaut.

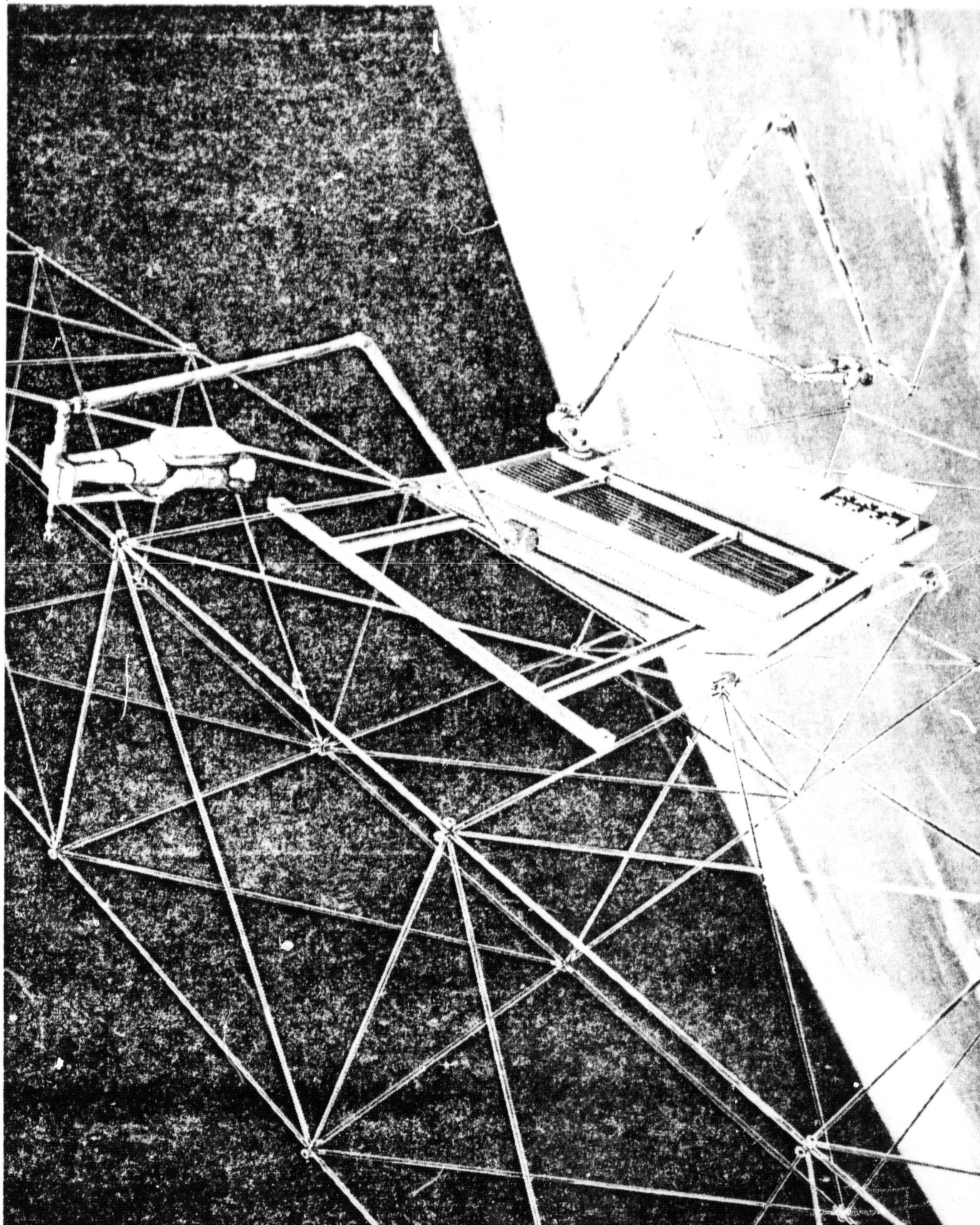
The development of a totally autonomous robotic system to accomplish the varied tasks is currently and for the foreseeable future beyond the state of the art. However, by retaining man in the loop, a remotely (teleoperator) controlled system can be developed with today's technology and can significantly increase our capabilities to perform space operations. As robotic technologies mature, these advances can be integrated to further automate the remote systems, moving man to higher levels of supervisory control and increased capabilities (ref. 11).



MOBILE REMOTE MANIPULATOR SYSTEM (MRMS)
MANNED SPACE ASSEMBLY

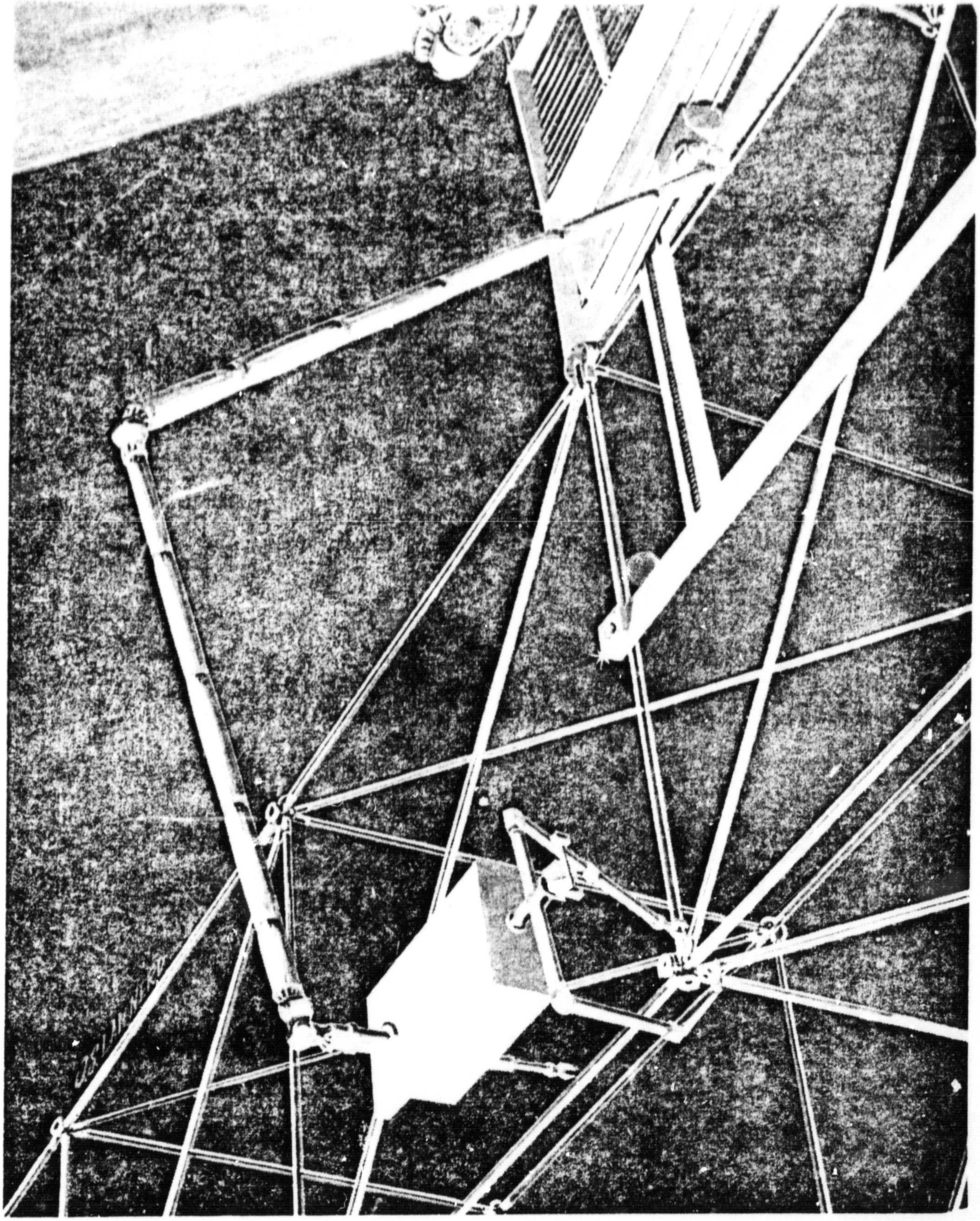
In the Space Station reference documentation, a mobile remote manipulator system (MRMS) is the major piece of assembly and construction support equipment used to move people and material over the Space Station structure. The basic unit consists of a crawling mechanism and a remotely controlled manipulator arm.

A concept for using the MRMS as a platform for assembly of space structures using Extravehicular (EVA) astronauts has been developed (ref. 12 & 13). An artist's illustration of this concept with the MRMS platform and push/pull drive mechanisms is shown. The construction parts are stored on the platform and the manipulator arm is used to deliver them to two EVA astronauts, who are placed in position by two additional manipulator arms. These two positioning arms will be used on opposite sides of the MRMS platform and provide the option to have the astronauts work as a pair in a dual arm mode to effect the assembly of large members such as illustrated in the truss structure (ref. 8).



DEXTROUS MANIPULATOR SYSTEM
REMOTE SPACE ASSEMBLY

A remotely controlled dual arm dexterous manipulator system could be used in conjunction with the Module Remote Manipulator System for assembly of space structures. Shown is an artist's concept of a system which could accomplish the same tasks as the EVA astronauts. Initially the MRMS would be a teleoperator. Then, as technology is developed, it would become more autonomous (ref. 8).



TELEOPERATOR AND ROBOTICS SYSTEM SIMULATION (TRSS)

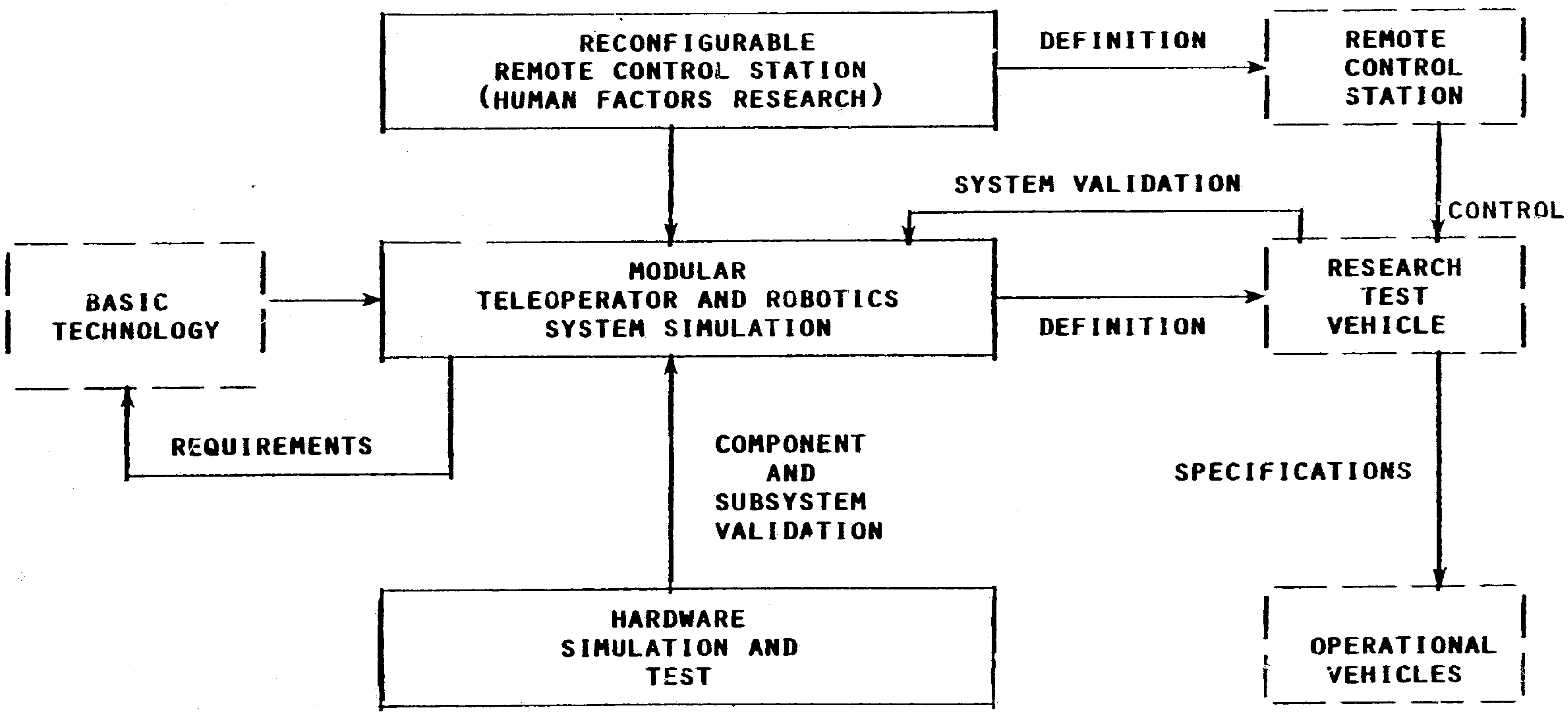
The attached flow chart shows the element of the TRSS in the solid boxes and the flow of technology from basic to test and operational capability in the dashed boxes. The program objective is to conduct systems integration and analysis as well as basic research in man-machine interface, control system design, and the application of artificial intelligence techniques for planning, monitoring and subsystem management. The central element of the program is a modular software systems simulation coupled to a remote control station for man-machine interface. Mature base technologies will be included as modules in the systems simulation to perform system analysis and interdiscipline interaction/sensitivity studies.

The success of simulation depends heavily on the validity of the models used. Therefore, a key element of this activity is to accurately define the models and validate them at the component, subsystem, and systems level through comparison with hardware tests, laboratory experiments, and ultimately the actual system. This will be accomplished by maintaining close coordination with all agency activities in remote systems from the base research level to systems test. Thus, simulation becomes a vehicle to bring together all aspects of the agency's activities in teleoperation and robotics.

The integrated modular software simulation of the remote system, coupled to a reconfigurable remote control station, is required to efficiently and cost-effectively analyze current capabilities, identify high pay-off technology areas, and integrate emerging concepts in robotics. The output of the simulation will be used to specify a teleoperator concept for design, development, and testing. The demonstrated capability will reduce the technical risks and qualify the technology concept, resulting in specifications to develop the required future systems for remote operations.

TELEOPERATOR AND ROBOTICS

SYSTEMS INTEGRATION AND ANALYSIS

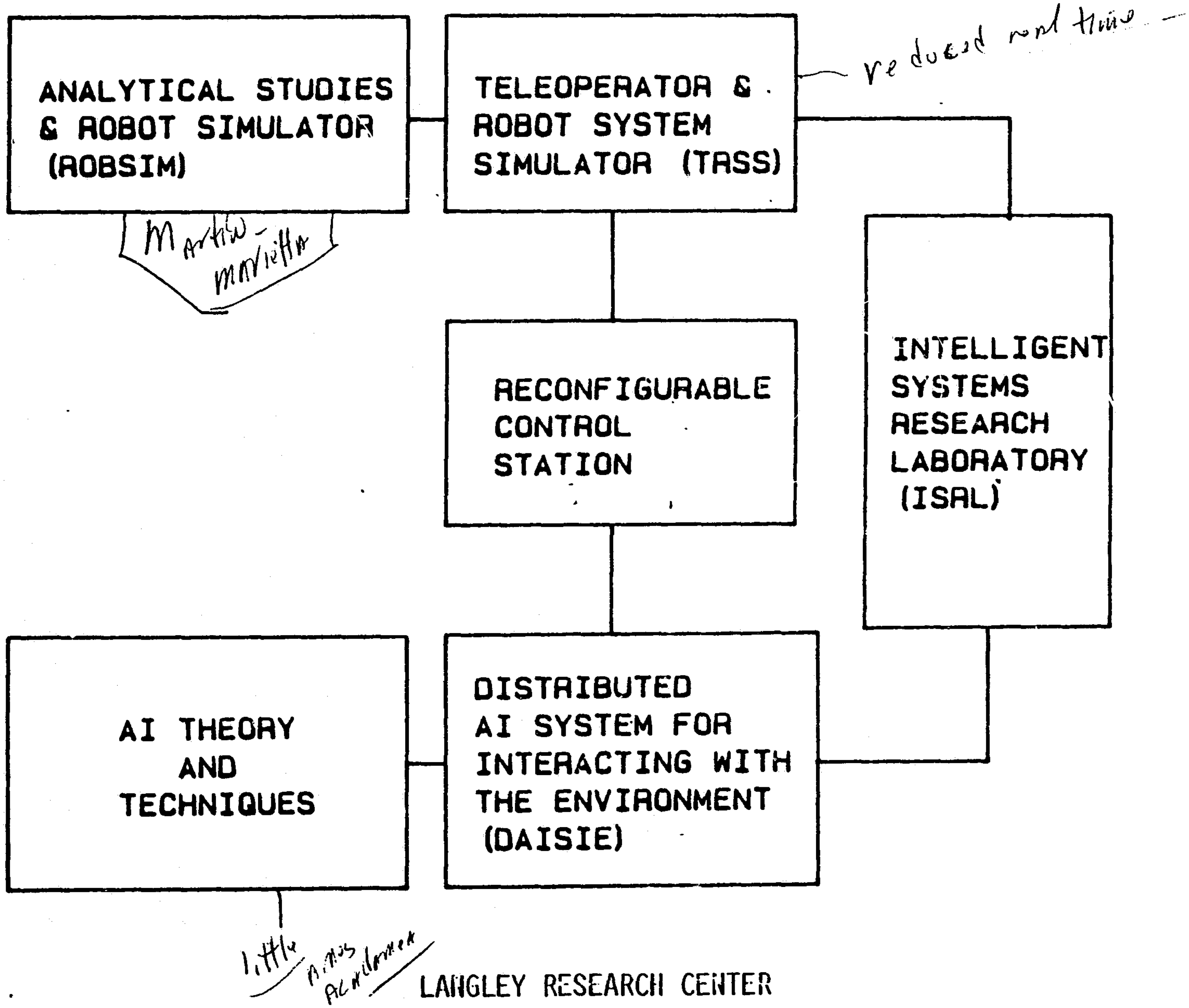


LARC TELEOPERATOR/ROBOTICS RESEARCH FACILITIES

The facing diagram depicts the components of the teleoperator/robotics research facilities now operational at Langley Research Center.

The major elements of the system level research facility are:

- ISRL (Intelligent Systems Research Laboratory) which includes actuators, sensors computers, and display devices linked by a real-time network.
- TRSS (Teleoperator/Robotic System Simulation) which is a real time, man-in-the-loop kinematc simulation of teleoperator and robotic devices. The software simulation resides in the Cyber 175 but is coupled to actual hardware components in ISRL.
- DAISIE (Distributed Artificially Intelligent System for Interacting with the Environment) which is a testbed for interfacing AI algorithms to teleoperator/robotic components. DAISIE is implemented in a hierarchical structure with the top level AI portion residing in a VAX 11/750 and communications to the lower level units in ISRL.
- ROBSIM (Robot Simulation) is an interactive, high-fidelity, off-line robotic simulation able to define and analyze robotic devices and environments in kinematic, dynamic, or inverse dynamic modes. This program operates in non real-time on a VAX 11/750.
- RECONFIGURABLE OPERATOR CONTROL STATION which supplies the display and controls for operator interface to TRSS, ISRL and DAISIE.

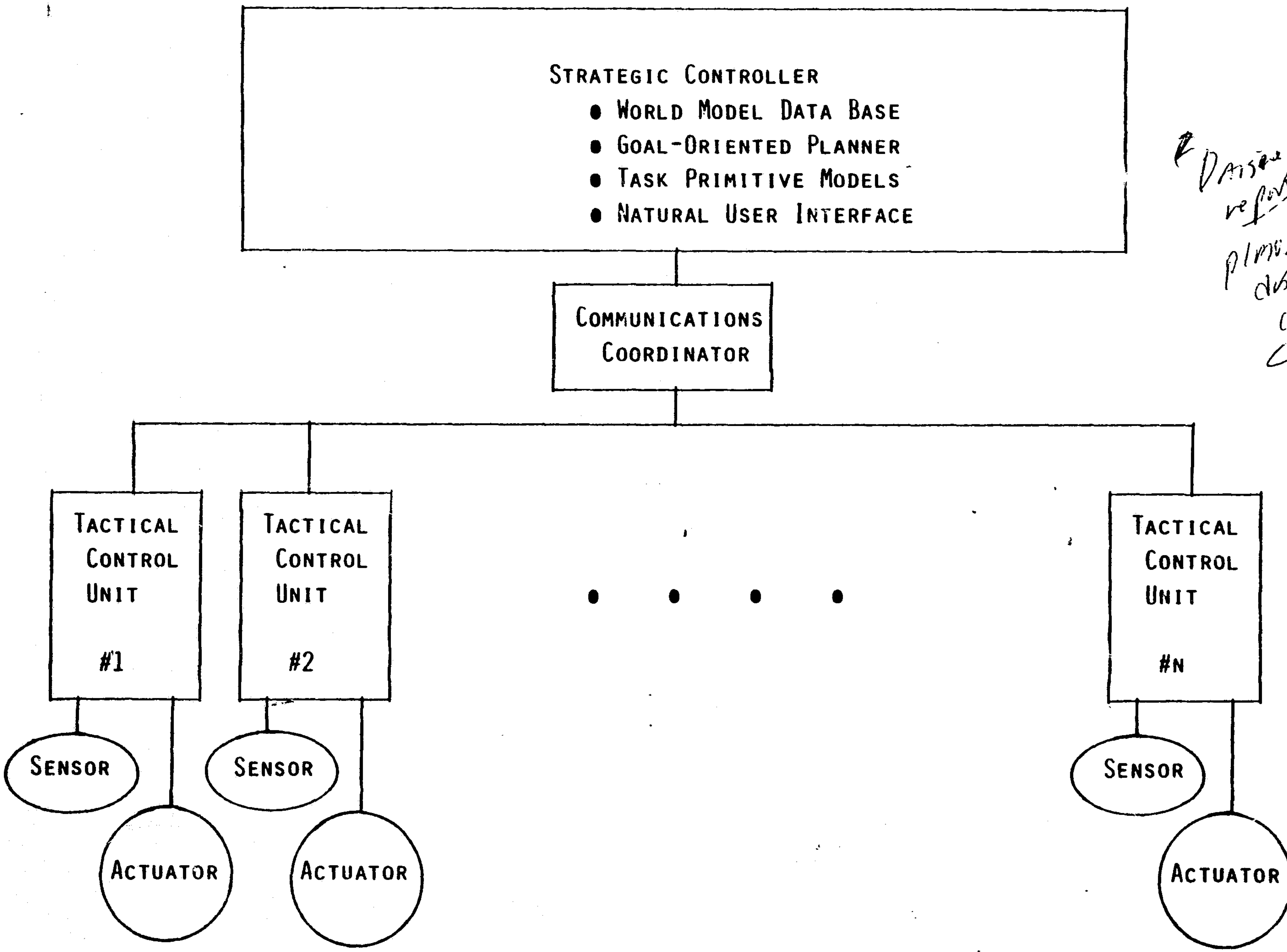


LANGLEY RESEARCH CENTER
TELEOPERATOR/ROBOTICS RESEARCH FACILITIES

DISTRIBUTED ARTIFICIALLY INTELLIGENT SYSTEM FOR INTERACTING WITH THE ENVIRONMENT (DAISIE)

DAISIE is an integrated system of hardware and software modules connected in a hierarchical structure. It is designed to serve as a testbed for research in the area of Artificial Intelligence (AI) techniques applicable to space teleoperator/robotic systems. The DAISIE structure shown on the facing page has been implemented in the Intelligent Systems Research Laboratory (ISRL) at Langley. It consists of a strategic control element, which is the AI section, coupled through a communications coordinator to the computer network of the lab. The lab network couples the various processors (tactical control units) which control the hardware elements including manipulators, sensors, end effector, and control station.

The initial implementation of DAISIE has been verified through two experiments. One experiment used a blocksworld database and planner to intelligently manipulate a simple physical environment. The second experiment was a demonstration of a joint-space collision avoidance algorithm. Currently the sensory hardware and software for database generation and verification are being implemented and interfaces between the strategic element and the teleoperator control station are being developed. Linking the operator control station with the AI planner will enable research in techniques that will be necessary as systems progress from direct operator control toward higher degrees of computer control (ref. 14).



Daisie reports planner distributed controller

DISTRIBUTED ARTIFICIALLY INTELLIGENT SYSTEM FOR INTERACTIVE WITH THE ENVIRONMENT (DAISIE)

Jim Albus

INTELLIGENT SYSTEMS RESEARCH LAB

This figure illustrates the organization of the Intelligent Systems Research Laboratory (ISRL), the integration point for Langley's Automation and Robotics research and development. The shaded items are FY85 upgrades. ISRL is built around a distributed network of powerful computers. A second parallel network is being added.

Two computers tie two PUMA six-degree-of-freedom industrial manipulators, and are the high level controllers for the microprocessors which drive each axis of the manipulator and the microprocessors for the end effector. The highly instrumented end effector can be commanded in position, rate or force; and has proximity sensors as well as force/torque sensors in each finger and in the wrist. Automatic peg insertion (active compliance) has been demonstated using this "smart" end effector. Work is being done to utilize the end effector drive to power interchangeable tools.

The operator can select automatic functions or can manually control the manipulator (teleoperator control) from the reconfigurable control station. The operator can select from several control modes; and he can select the visual presentation from multiple TV cameras and from a high speed graphics system. LaRC is buying one of a set of six-degree-of-freedom hand controllers being built for JSC. A touch sensitive display has been installed in the control station, and a new speech recognition and synthesis system is being purchased.

Equations of motion for the manned simulation are solved on the CYBER 175 computer. The VAX 11/750 computer serves as the interface for the laboratory networks, the new GTI graphics system, and the Hyperchannel high speed digital data bus. The VAX also hosts the ROBSIM Robot Simulation program. Developed by Martin Marietta Aerospace over a 3 year period, ROBSIM enables the engineer to define a multiarm manipulator system, graphically display its simulated motions, and develop advanced control laws (ref. 15).

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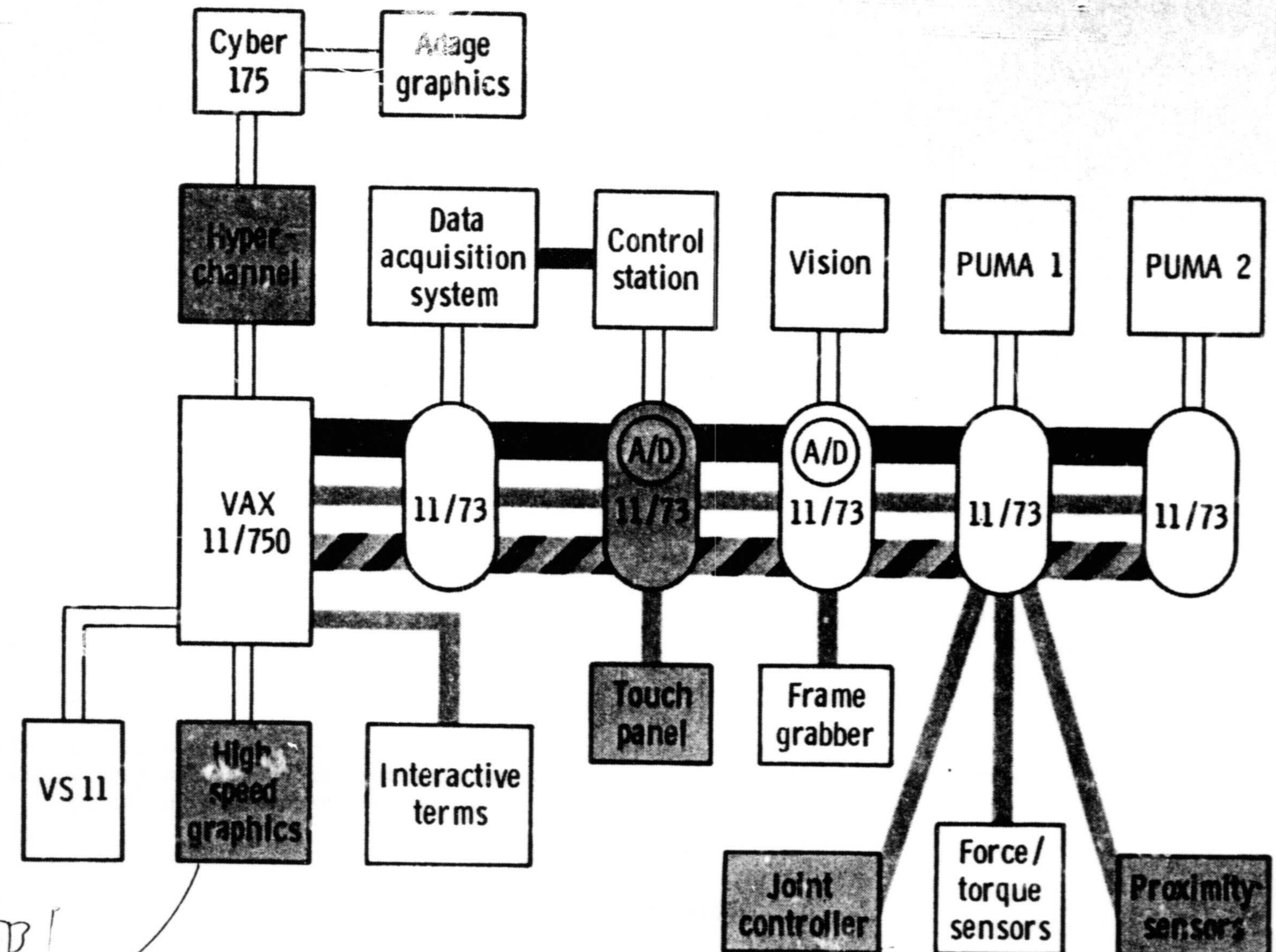
INTELLIGENT SYSTEMS RESEARCH LAB

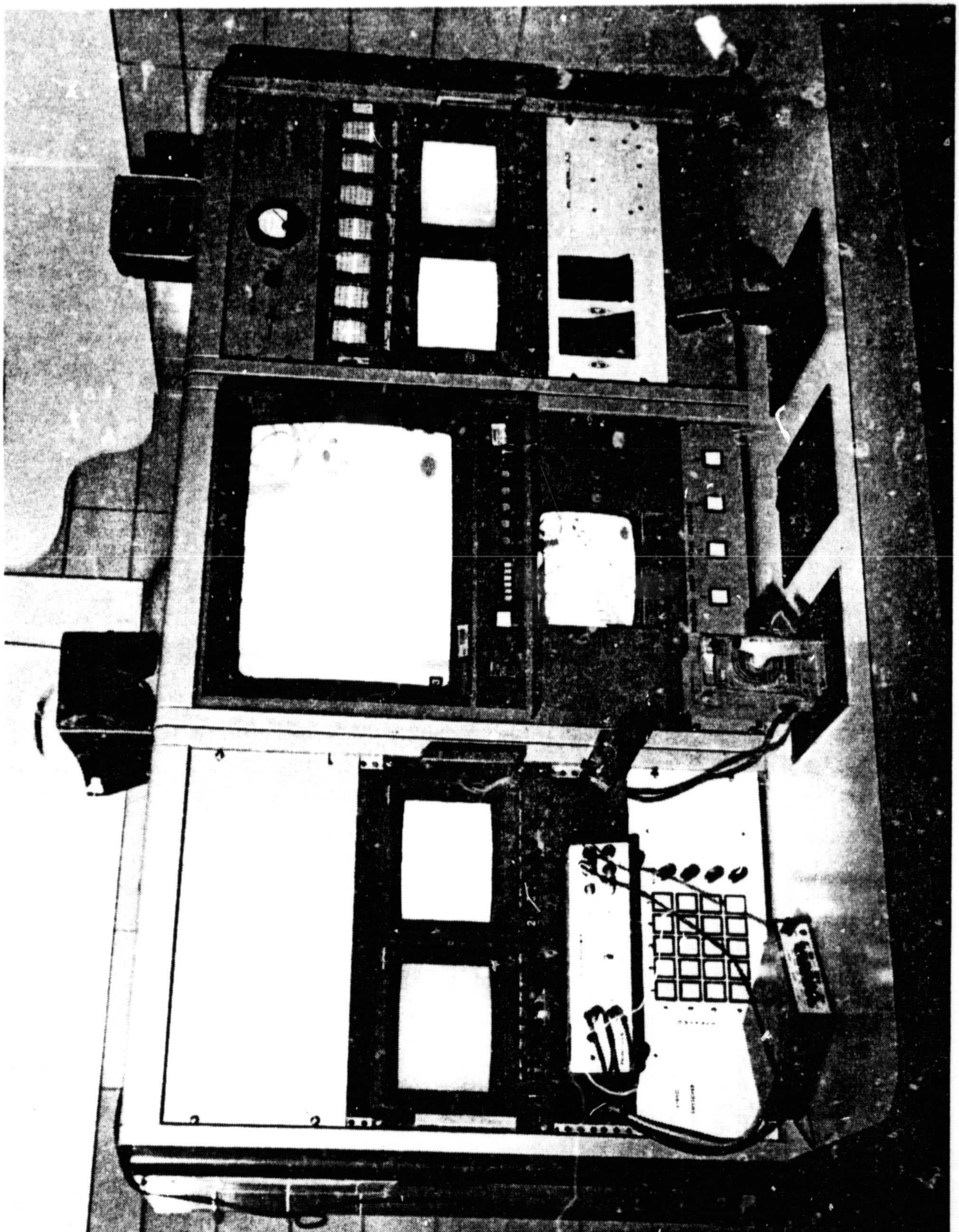


TELEOPERATOR/ROBOTIC RECONFIGURABLE CONTROL STATION

The facing page shows one configuration of the teleoperator/robotic control station. The control station is the operator interface to the Teleoperator Robotics System Simulation (TRSS) and components of the Intelligent Systems Research Laboratory (ISRL).

During FY84, baseline teleoperator studies were completed using joint-by-joint and resolved rate control modes with direct vision of the task and indirect vision with closed circuit television. These study results are being compared with previous studies by SRI International and Grumman Aerospace Corp. In addition, a joint study was conducted at Grumman using their scaled force reflecting master/slave manipulator system.

The teleoperator task involved the insertion of a peg into a close tolerance hole. The force/torque sensors of the end effector system were used as sensor feedback to demonstrate sensor-based close-loop control for automatic insertion (ref. 16).



BASELINE TELEOPERATOR TEST AT LANGLEY/DIRECT TASK VIEW

This is the setup in the Intelligent Systems Research Laboratory for the direct view teleoperator tests. Subjects stood on the stand shown on the left side of the picture where they operated the hand controllers to drive the manipulator to perform tasks on the taskboard to acquire baseline man/machine interface performance data. Tasks involve grasping a steel cylinder with the manipulator jaws and using it to activate switches and/or place the cylinder in receptacles. The precision requirements of the task are varied by using pegs with differing relative dimensions to the receptacle. The taskboard is a duplicate of the one used in earlier tests by Grumman and SRI International. The manipulator is a Unimate PUMA with an in-house modified control structure, equipped with a microprocessor-controlled parallel jaw end effector/sensor system.

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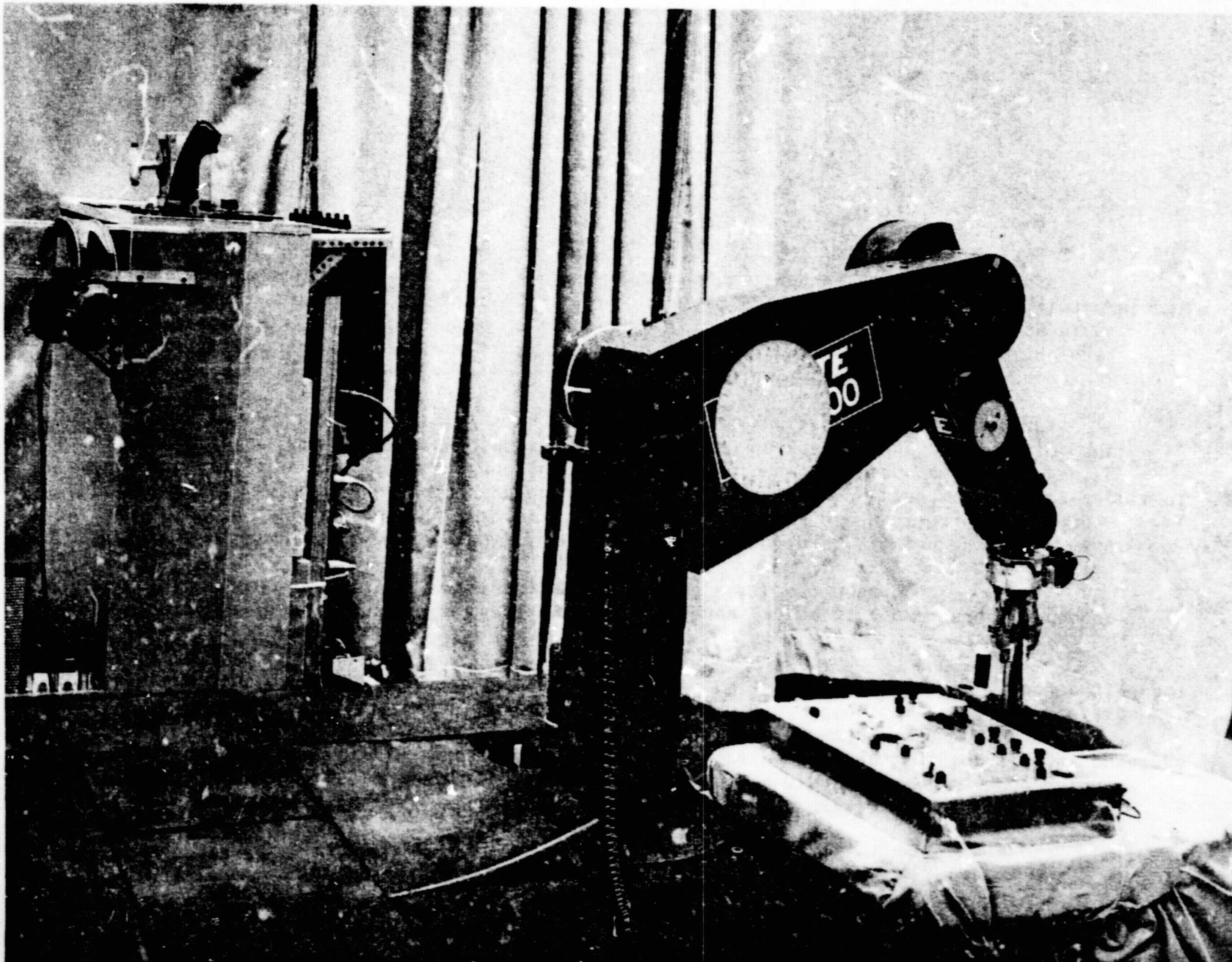


J by J
command

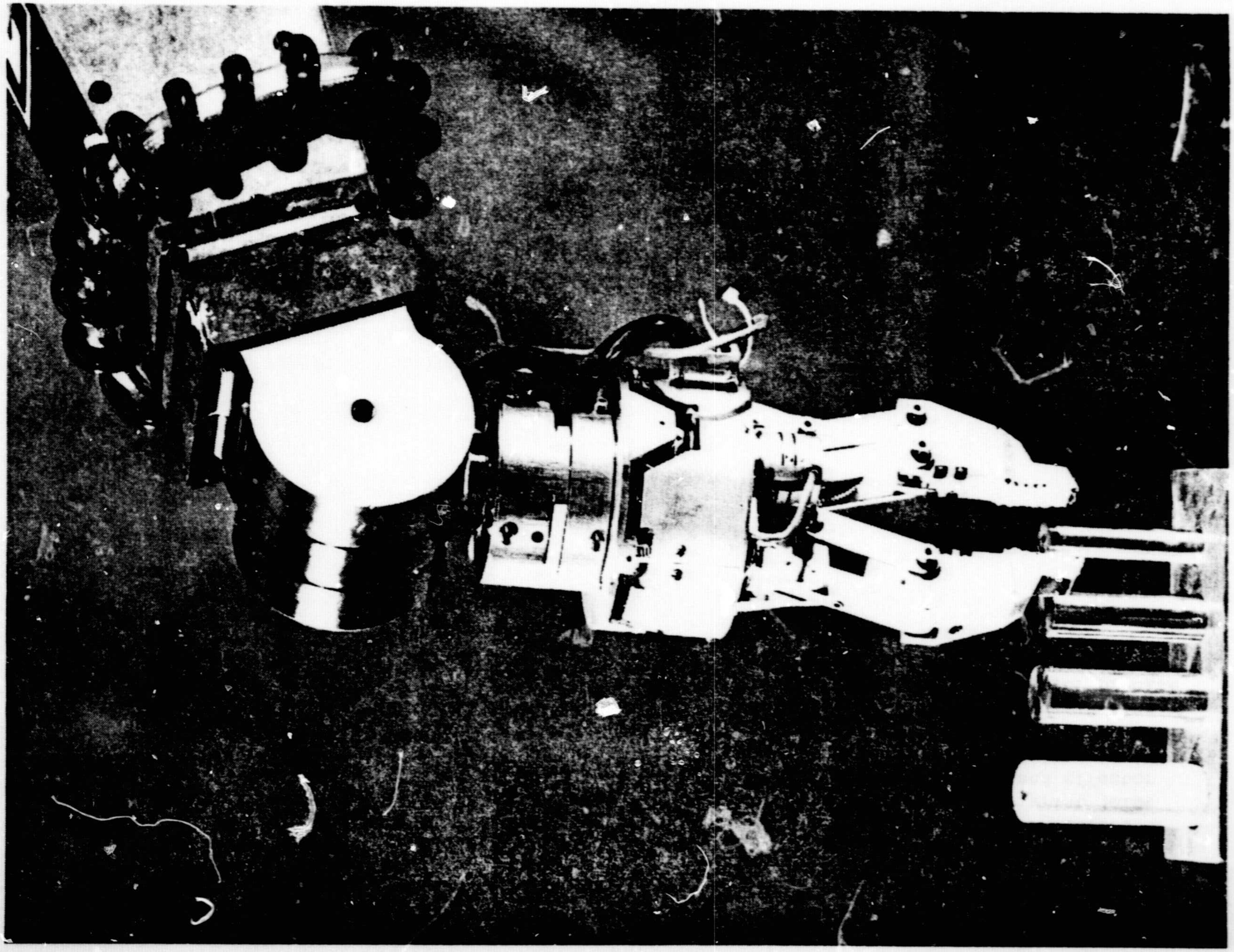
MICROPROCESSOR CONTROLLED END EFFECTOR

A microprocessor controlled robotic end effector has been developed for laboratory experiments in teleoperators and automated systems. Based on a University of Rhode Island mechanical design, the gripping surfaces of its two fingers remain parallel for all jaw openings because of its parallelogram actuator mechanism. The parallelogram is actuated by sector and worm gears driven by a D.C. torque motor in the base of the end effector. Rate and position feedback for control of jaw openings uses a tachometer and an incremental shaft encoder tied to a microprocessor.

Infrared proximity sensors in the fingers are scanned by the microprocessor to detect nearby objects and are used for collision avoidance and workpiece detection.

Force and torque sensing is accomplished by strain gages in the finger supports. Four channels of data (normal and side forces, pitch and yaw moments) are available from each finger. Additional force and torque information is available from a wrist mounted six-degree-of freedom sensor. The wrist force/torque sensor is also microprocessor controlled providing software control of calibration, coordinate transformation and data transfer. Both of the microprocessors communicate directly with a host computer over separate serial lines.

This end effector/sensor system is now undergoing evaluation and is being used in experiments in the use of force and proximity feedback in automation. In the coming year, systems software will be developed to control and interrogate the end effector using higher level commands from a host computer coordinating activities of manipulator arms, vision systems, and other sensors allowing research in both operator control and automatic operations.



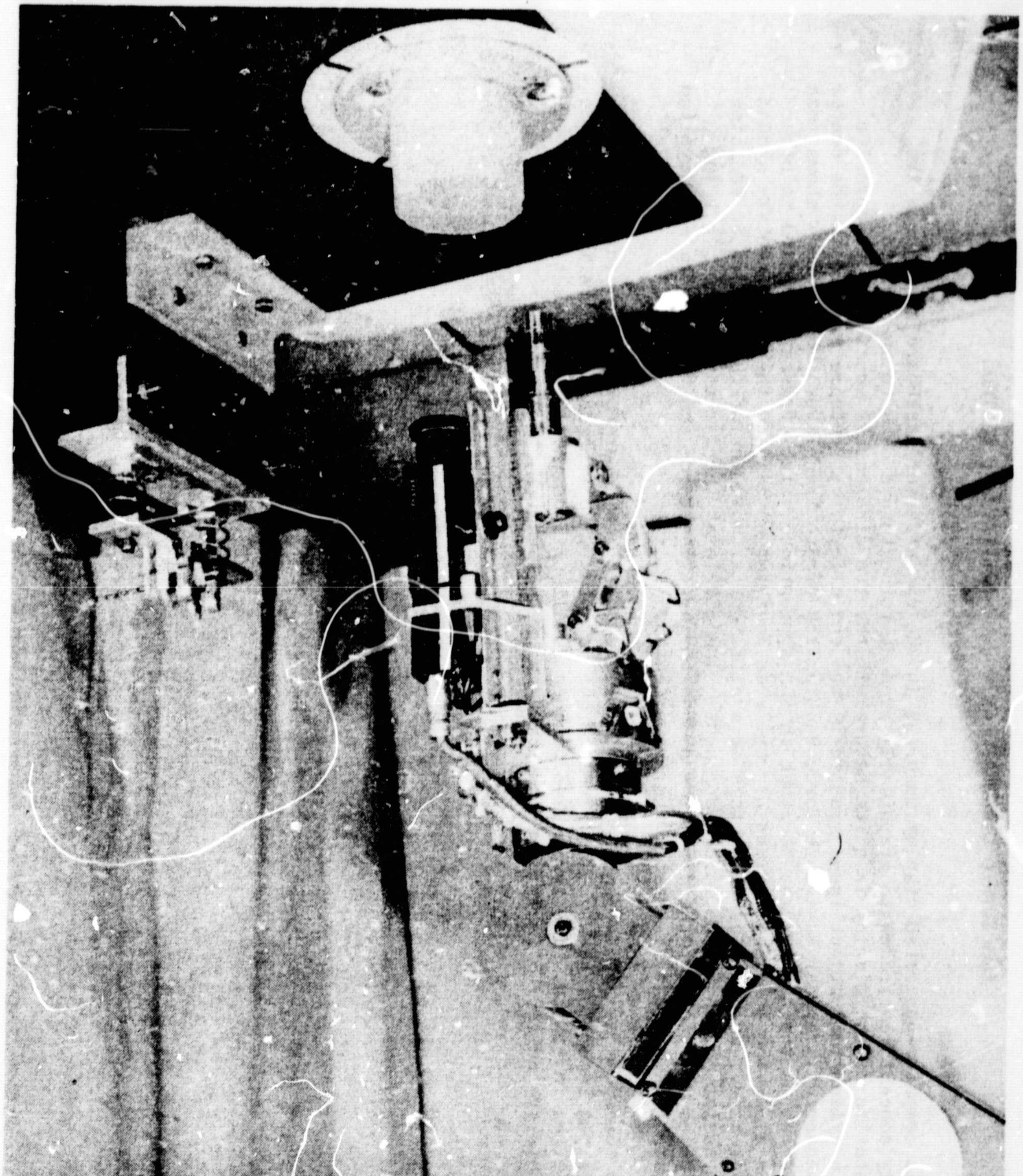
URI
design

6°

ARP
new. Soil sensor

QUICK CHANGE TOOL REPLACEMENT SYSTEM

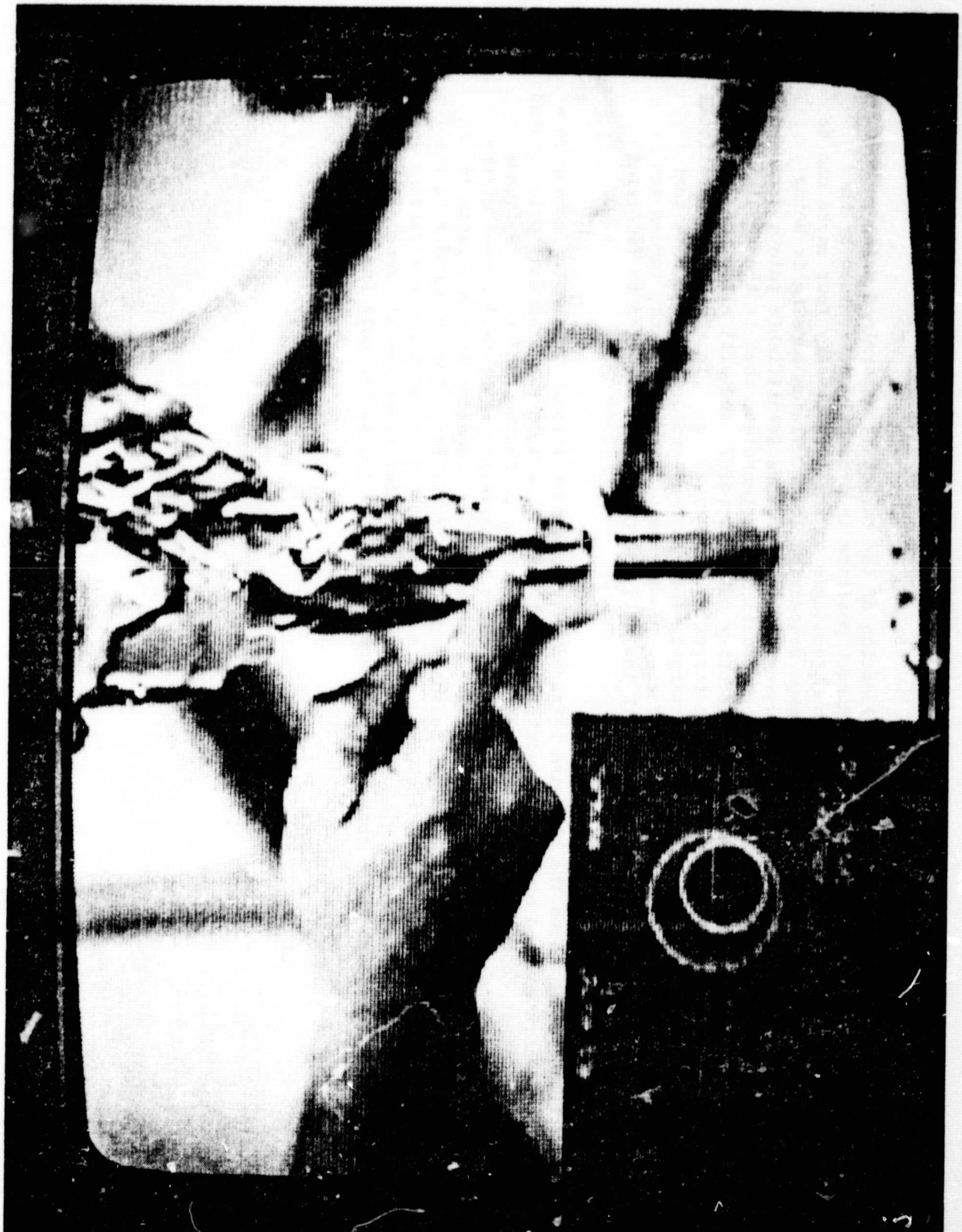
Capability of the parallel jaw smart end effector has been increased by the development of a tool storage rack and mechanisms for automated replacement of rotary tools such as socket wrenches and screwdriver bits. Rotary power for the tool is from the manipulator wrist joint through a ratchet held in the end effector jaws. Shown here is the parallel jaw end effector holding a socket wrench and poised to tighten retention bolts on a sensor model similar to those used on the Long Duration Exposure Facility. The socket wrench may be exchanged for the twist drill now stored in the rack by teleoperator control or a higher level of automation. Spring loading in the base of the tool rack provides compliance to reduce the requirements for precise positioning of the end effector.



CONCENTRIC CIRCLE FORCE/TORQUE DISPLAY AND CONTROL

This computer-generated display inserted in the end effector/taskboard scene uses two initially concentric circles to graphically present force/torque data to an operator. Interpretation of the display is quite natural if the two circles are considered as opposite ends of a cylindrical object (peg) grasped by the end effector. Pressure applied at the center of the sensor will appear as a pure force causing the peg to translate. The display shows this as a movement of the two circles together in the appropriate axis. Pressure applied to other locations along the longitude of the peg are seen as a torque causing the peg to rotate around the sensor axis. The display shows this as a differential movement of the circles in addition to the translation due to the force component. The circle at the far end of the peg being smaller helps to interpret the direction of the torque. The force and torque data are supplied from strain gages in the fingers of the end effector.

The force/torque display has been used for studies of teleoperator control for close tolerance peg insertion tasks. The force/torque data has also been used for active compliance automatic peg insertion. The forces and torques resulting from the peg's contact with the walls of the hole are nulled to facilitate insertion and withdrawal.

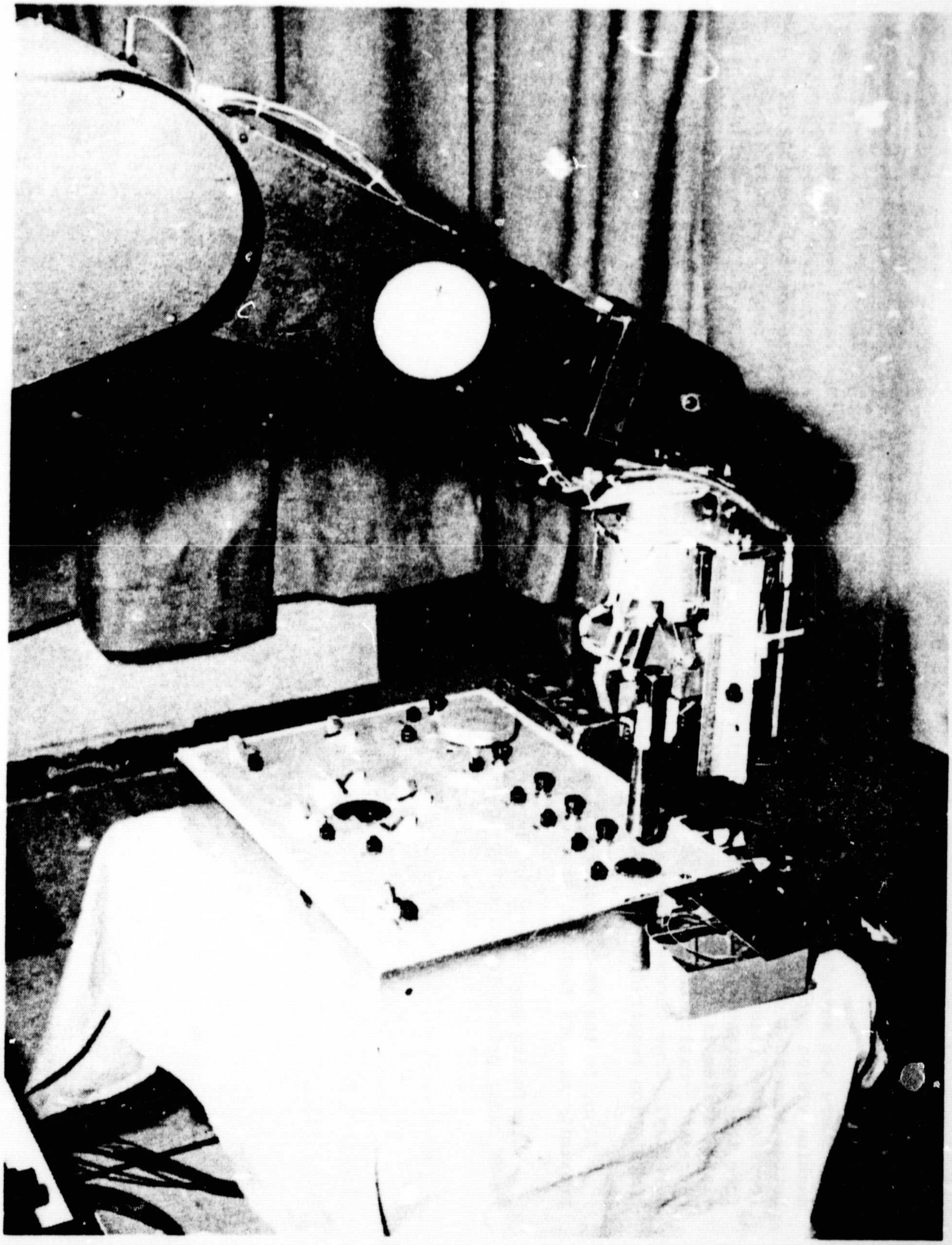


SENSOR BASED CONTROL OF A MANIPULATOR ARM

The three dimensional orientation and location of the target is determined using methods based on the perspective transformations. Target position is presently determined by the detection of four infrared LED's arranged in a rectangle on the target. Any four marks can be used but the use of the LED's lessens the image processing load. Vision sensing is being expanded so that the target can be located using any four or more identifiable points arranged in any reasonably convex shape on it. The introduction of a technique that is the result of a parallel effort will alleviate the need to identify physical points and will allow the derivation of the necessary points using the target's boundary shape. This will be operational in 1986. Upon contact of the tool with the target, force/torque sensors provide data that modify the amount and direction of applied force. In the peg-in-the-hole task, forces and torques resulting from the peg's contact with the walls of the hole are nulled to facilitate insertion and withdrawal.

The illustration shows the hardware involved in the demonstration. The vision sensor is a solid state camera mounted at the manipulator's wrist. The target is a cylindrical hole located on a taskboard that contains other plausible targets such as pushbutton and toggle switches. The sensor detects four LED's mounted on a pad located at the upper right hand corner of the taskboard and transmits their image to an image procesor. The processor in turn transmits the target location, derived from the image, to the arm controller. Force/torque sensors in the fingers and at the wrist of the manipulator inform the arm controller of the force vectors resulting from the peg's contact with the target. The controller processes all sensor data and derives manipulator joint angle commands necessary to move the peg to the hole and insert it.

NBS



LASER BASED SENSOR SYSTEMS

There are advantages to using laser based sensors rather than video based sensors in machine vision systems. First, the spatial and range precision of a coherent light system is better than that of an incoherent light system. This is due to the precise control possible in focusing the illumination energy on a targeted area and to the fine range resolution resulting from the minuteness of optical wavelengths. Second, the computational efficiency of a machine vision system is increased when a laser front end is incorporated. Because its pixel data is range information and not light intensity, object location and shape can be resolved more directly. True three-dimensional information can be derived without the complex intermediate computation required in an intensity based system.

Also, in the FM-CW configuration, lasers can be the basis for excellent proportional proximity sensors that are size compatible with precision work pieces.

The facing page lists the primary specifications of a prototype laser sensor based on the FM-CW radar principle currently under development.

HIGH ACCURACY SENSOR

BASIC PRINCIPLE→FM-CW LASER RADAR

<u>SPECIFICATIONS</u>

POINT RANGE MODE

- o RANGE - 0 TO 10 METERS, UPGRADABLE TO 100 METERS
- o PRECISION - .025 MM AT ALL OPERATING RANGES
- o CAPABLE OF HANDLING DIFFUSED SURFACES INCLINED AS MUCH AS 80 DEGREES
- o SENSOR SIZE INCLUDING ILLUMINATION SOURCE- CAN BE INSERTED IN 1MM HOLES

Dec. Delivery
Digital Signal
Beltway

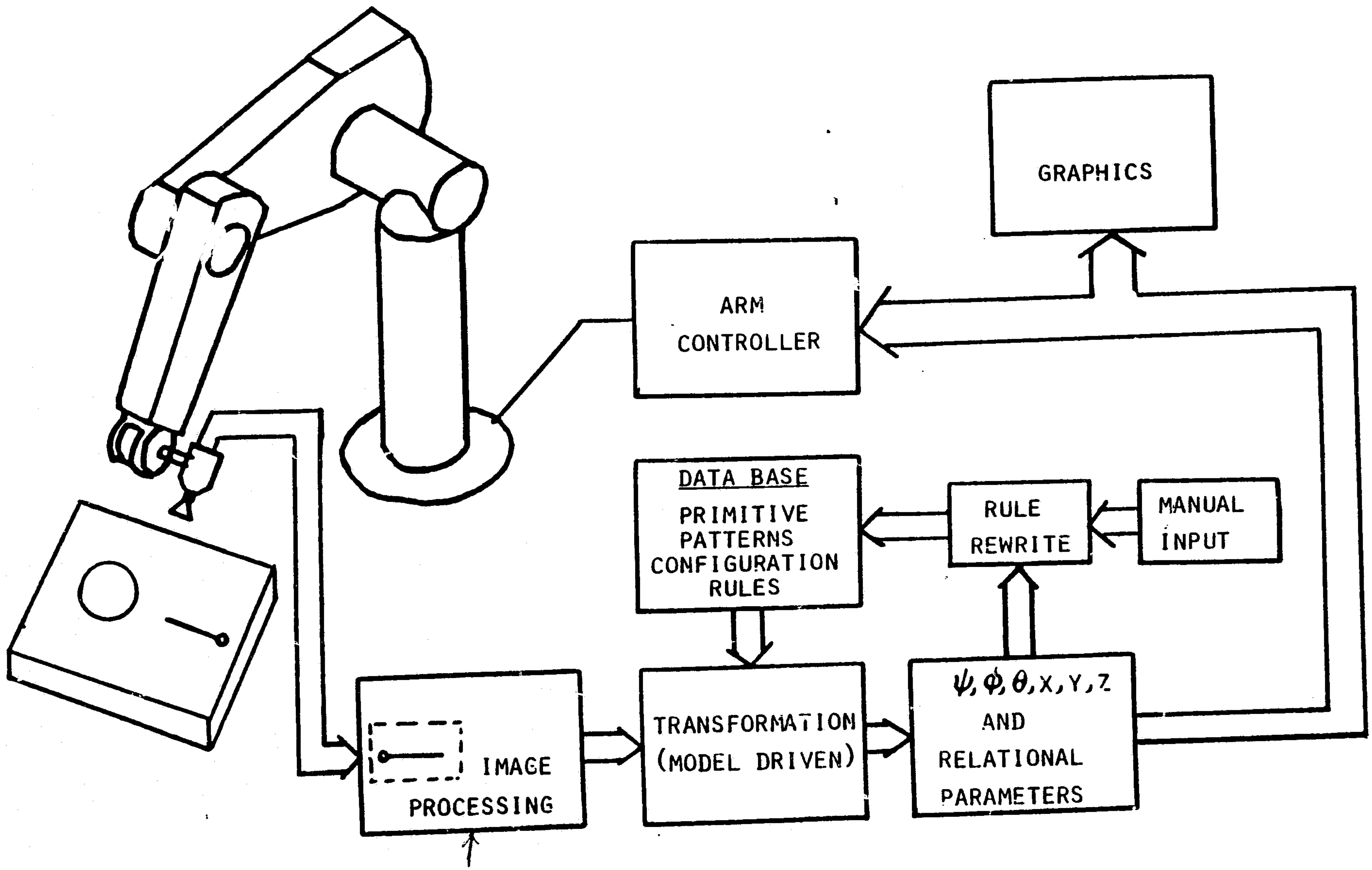
SPATIAL MODE

- o 8 BIT PRECISION
- o 500,000 PIXELS/SEC UPGRADABLE TO 10,000,000 PIXELS/SEC
- o PRECISION AT THE ABOVE RATES - 4MM X 4MM X 4MM

DIRECTED CONTROL TELEOPERATOR VISION

The primary function of robotic vision is to provide information about the position of the system's effector relative to objects of interest in its environment. This function is accomplished by the following subfunctions; isolation, description, identification, data transmission, and location. In a directed control teleoperator system, some of the subfunctions may be allocated to a human. Responsibility for accomplishing the subfunctions is divided between human and machine according to the compatibility of the subfunction with the human or machine.

The diagram shows the functional parts of a directed control teleoperator vision system. In this example, an object (a door handle) is isolated by the human and a description of it is selected from the data base. If the object is known, the human obtains the description and the machine generates a model appropriate for deriving location parameters from the image. If the object is not known, the machine selects a generic description from the data base and generates a model appropriate for deriving pattern parameters from the image. These parameters are used by the rule rewrite function to establish pattern configuration rules for the unknown object thereby updating the data base. The information contained in the derived parameters is also used for image restoration and for effector position command generation.



DIRECTED CONTROL TELEOPERATOR VISION

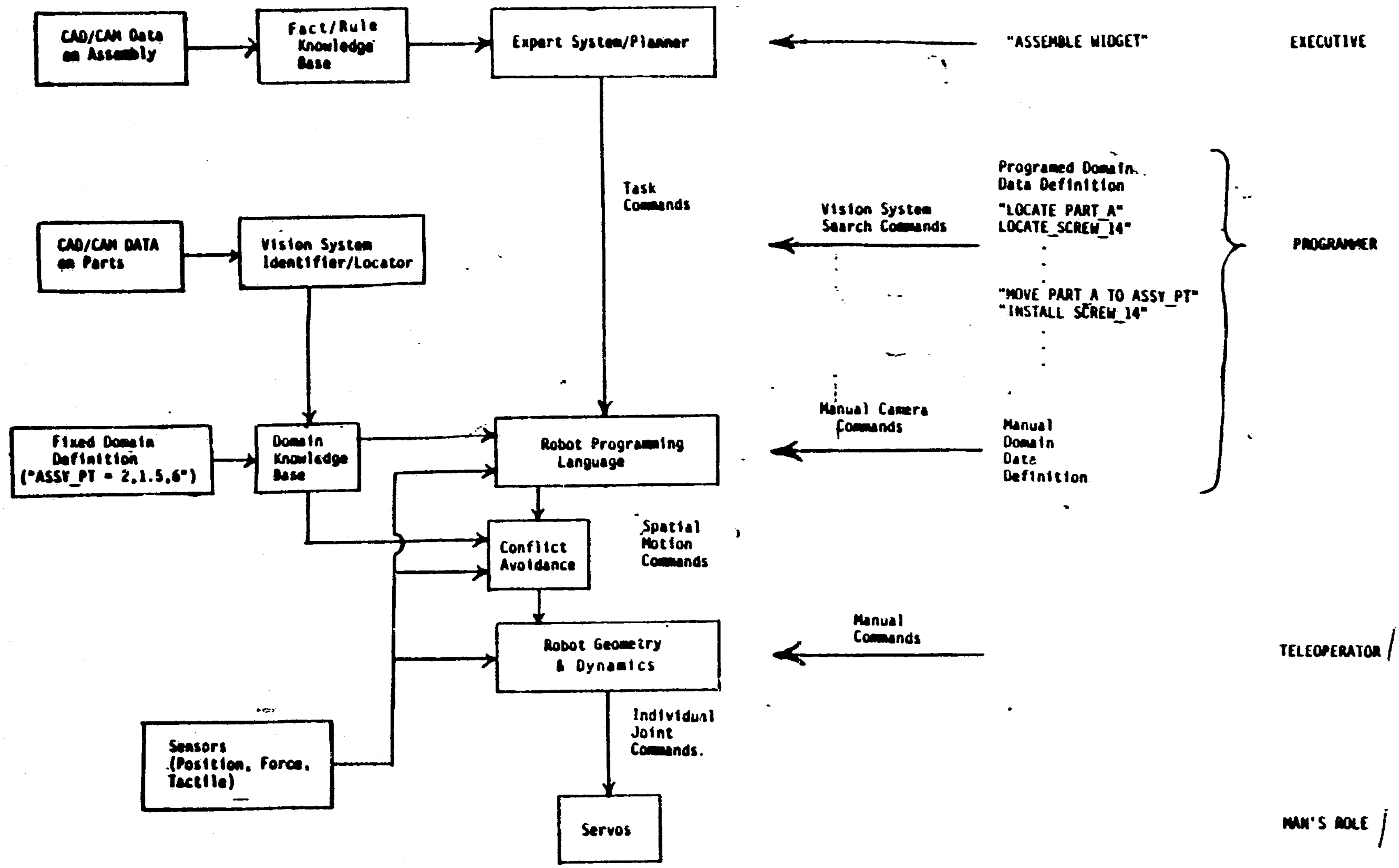
1st version

1 – 2 sec

GOAL-DIRECTED TELEOP… ROBOTIC SYSTEM

This figure shows a simplified block diagram for a goal-directed teleoperator/robotic system. This system is composed of several hierarchical levels, each of which, for reliability and operational flexibility, has been provided with an operator interface. The lowest level is a teleoperator in which continuous manual motion commands from switches, hand controllers, or master slave are transformed into individual joint commands to produce the desired manipulator operation. On the second level, the operator becomes a programmer, communicating with the robot programming language via a keyboard, touch panel, or speech system. Here, a primary concern is loading the environment or domain knowledge base. Two sublevels are provided: (1) a sophisticated 3-D vision system identifier which searches for, identifies, and locates parts and objects based on tabular CAD/CAM type information and directives in the program; and (2) a manual object identification and definition mode if no vision system is available or if no CAD/CAM data exist for particular items.

The third and highest level of the goal-directed robot involves an expert system/planner which uses goals supplied by an executive operator to perform complex tasks. These tasks are accomplished with the aid of a fact and rule knowledge base which might also be supplied by CAD/CAM information on assembly and manufacturing techniques, sequences, and tolerances. Complex tasks are decomposed into robot programming language commands and procedure calls using the known rules and sequences. Reading from the bottom up, the figure might be considered to represent an evolution of a goal-directed robotic system.



GOAL-DIRECTED TELEOPERATOR/ROBOTIC SYSTEM

① store info from testing in expert System to store Tech.

Human Engineering

SRI good dissertation on role of Expert systems

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END

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04/23/86