STANFORD RESEARCH INSTITUTE
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Proposal for Research

SRI No. ISU 73-84

EQUIPMENT FOR ARTIFICIAL INTELLIGENCE RESEARCH

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Proposal for Research No. ISU 73-84

EQUIPMENT FOR ARTIFICIAL INTELLIGENCE RESEARCH

I INTRODUCTION

Under the terms of National Science Foundation Grant, GK 36487, the Stanford Research Institute has been studying equipment needs for artificial intelligence research. We have identified in broad outline an equipment configuration that we feel will be highly flexible and useful for research. This configuration and its rationale are described in detail in an interim report prepared under the terms of the present grant.* The report is attached to this proposal.

As a step toward making equipment of this type available to the artificial intelligence research community, Stanford Research Institute (SRI) proposes a two-year program to design, fabricate, and test a prototype system consisting of the vehicle, arm, and vision system described in the interim report.

We shall be summarizing the conclusions of the interim report in Section II. In brief, the report recommends a list of equipment consisting of a robot-like research vehicle, a television-based vision system, and a manipulator arm. The recommended equipment is modular in the sense that the three major components--vehicle, arm, and vision system--can be used in any combination.

During the testing phases of the proposed project, we shall also perform a number of research tasks with the equipment that will be typical of the kinds of research for which this equipment is designed. Section II summarizes the equipment that we are proposing and mentions the kinds of research that can be performed with the equipment.

Section III contains a full description of the project team's plan of work for the proposed two-year program. In brief, we plan to put together the vehicle and arm systems during the first year and the vision system during the second year.

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*N. J. Nilsson et al., "Study of Equipment Needs for Artificial Intelligence Research," Interim Report, Grant GK 36487, SRI Project 2308, Stanford Research Institute, Menlo Park, California (June 1973).

In Section IV, we outline our plans for demonstrating the equipment and for reporting our progress. A description of the documentation to be produced is also contained in this section.

Subsequent sections describe the personnel to be involved in the project and the qualifications of SRI.

II DESCRIPTION OF EQUIPMENT AND RESEARCH TASKS

A. Equipment

1. General Description

The list of equipment recommended in the interim report was influenced heavily by the results of a survey to determine user needs for robotic equipment. (An analysis and description of the survey is contained in the interim report.) We determined that there were needs for a mobile vehicle, a vision system, and a manipulator arm system, all used in various combinations. One particular combination consists of all three of these subsystems integrated into a self-contained, radio-controlled robot device. In describing the proposed equipment, we will often, for convenience, make the assumption that it will in fact be integrated into such a complete robot system. It will be apparent, however, that various subsets of this equipment can be used alone.

The specifications for the recommended equipment are a compromise among user desires (as determined by the survey), available components, and cost considerations. We are proposing a list of subsystems that we think will meet most user needs at reasonable cost. We will first present a short overall summary of the equipment, then we will briefly describe each major subsystem. (For a complete description, the reader is referred to the interim report.)

The SRI team proposes a four-wheeled mobile cart with a square base of about 25 inches, a base that allows it to easily pass through a standard-sized doorway. The cart will be able to maneuver easily inside a small room such as an office. The entire system will be protected by a system of proximity sensors (such as bump detectors) so that it will not damage itself or harm others by high-speed collisions. The vehicle will be self-powered by batteries, thus unfettered by cables of any kind under normal operation. It will be able to travel at about three feet per second indoors over reasonably smooth floors, such as one might find in an ordinary laboratory or office, or outside on smooth surfaces. A complete robot system might weigh about 600 pounds fully loaded. In fact, a sturdy system is desirable to provide stability and precision for the camera and arm systems. The robot will have extra capacity (in terms of space, power, and control interface) to accommodate users' special equipment such as other types of sensors and effectors.

The visual system will be able to provide pictures of at least about 240 by 320 spatial resolution with 64 levels of gray scale. Color vision capabilities will also be provided. Field of view for the visual system will be variable roughly between 10 degrees and 40 degrees. The visual system will be capable of panning and tilting. The picture information will be made available as a stream of digital data ready for input into either fast computer core or some kind of user-supplied buffer. We have specified that an optically collinear range-finding device should be able to be added later with minimum difficulty.

For the manipulator arm we propose a design by V. Scheinman of Stanford University (see Figure 1). He designed it while on leave at MIT, and it is called the Scheinman-MIT Electric Arm. It is capable of grasping small objects of up to about 3 pounds. It is able to pick up, load, and transport objects such as books or small boxes, or it can be used in making assemblies of things. When mounted on the vehicle, it will be able to operate near the floor (e.g., to pick up items it might have dropped) and above a desk or table. It will be possible to add an optional second arm.

For input-output capabilities on the vehicle, we have specified a display and keyboard; a microphone and speaker can be easily added. The system will include all necessary interface equipment to allow easy connection to a user's time-shared computer, and it will be equipped with the software needed in controlling this interface equipment.

The system also includes a minicomputer to handle interface functions and to provide low-level control of arm, camera, and wheel motors. (For vehicle-based systems, we propose that the minicomputer be on board.) The vehicle will be radio-controlled from the user's main computer and will send television pictures back to this computer over a special video radio link. A simplified drawing showing the approximate appearance of a complete vehicle system is shown in Figure 2. Orthographic views of the system are shown in Figure 3.

2. Components

Vehicle System--We propose to obtain the vehicle itself from the Electro Limb Corporation of Downey, California. It will provide

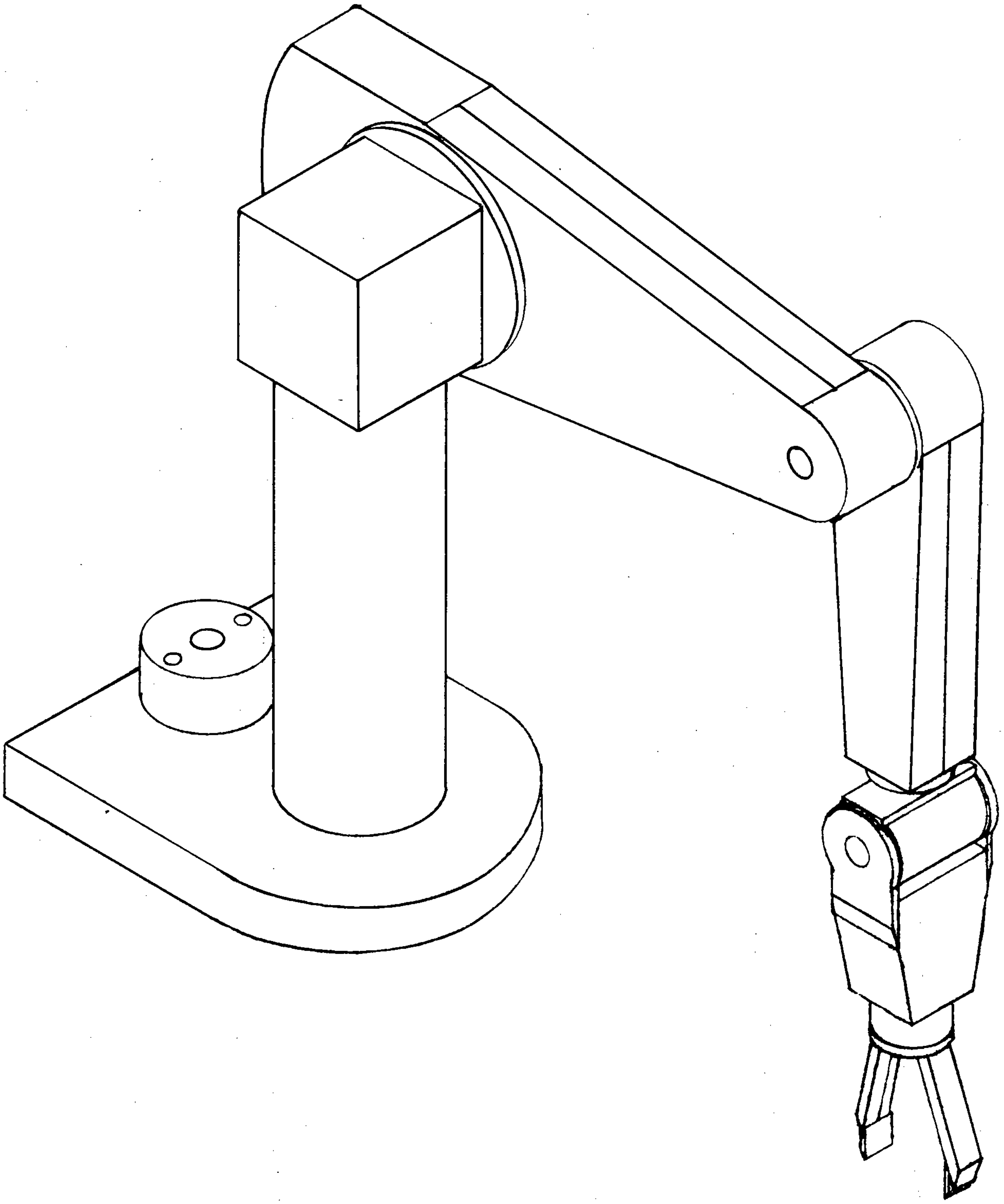


FIGURE 1 SCHEINMAN—MIT ELECTRIC ARM

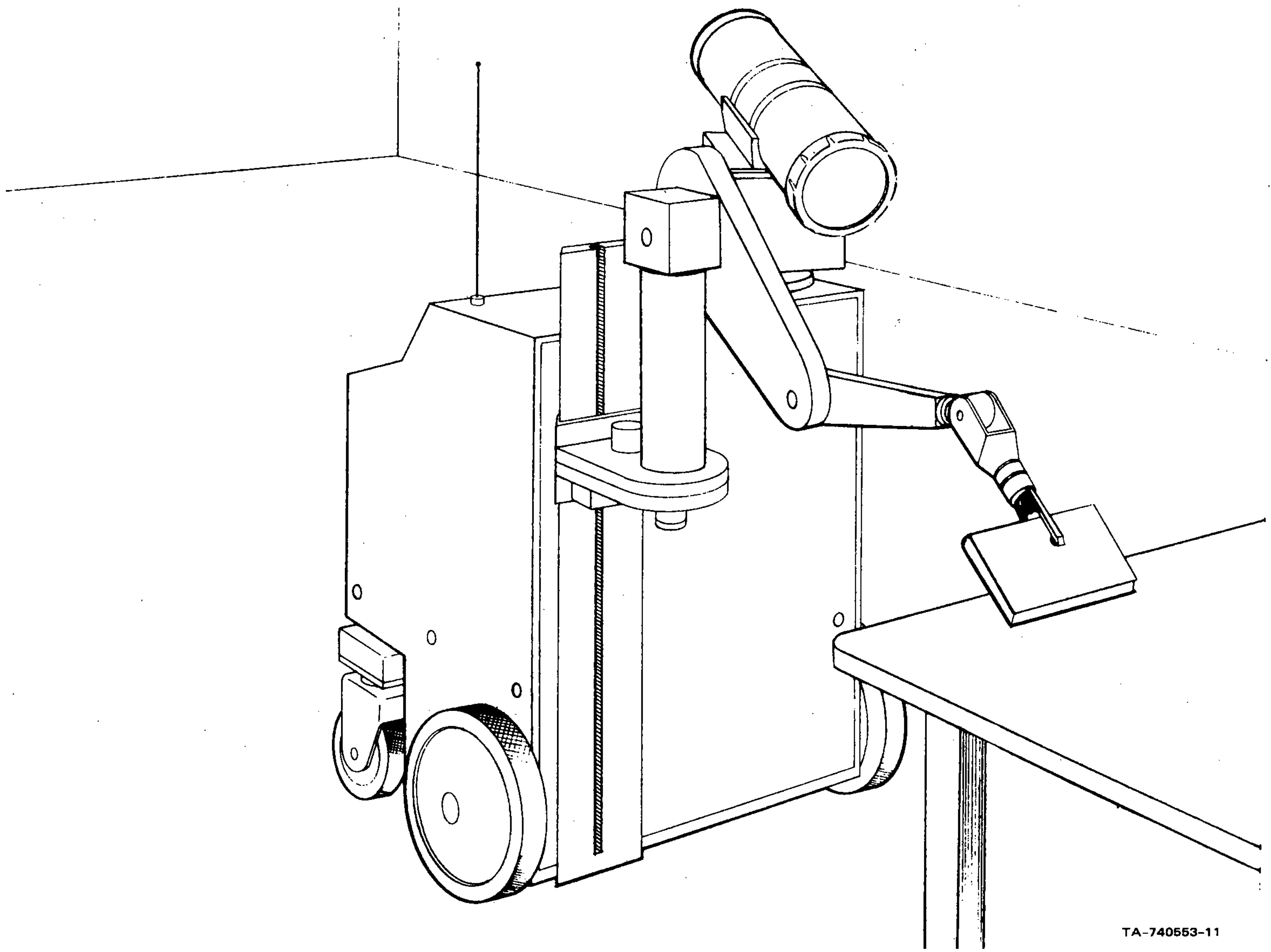


FIGURE 2 PROPOSED ROBOT VEHICLE

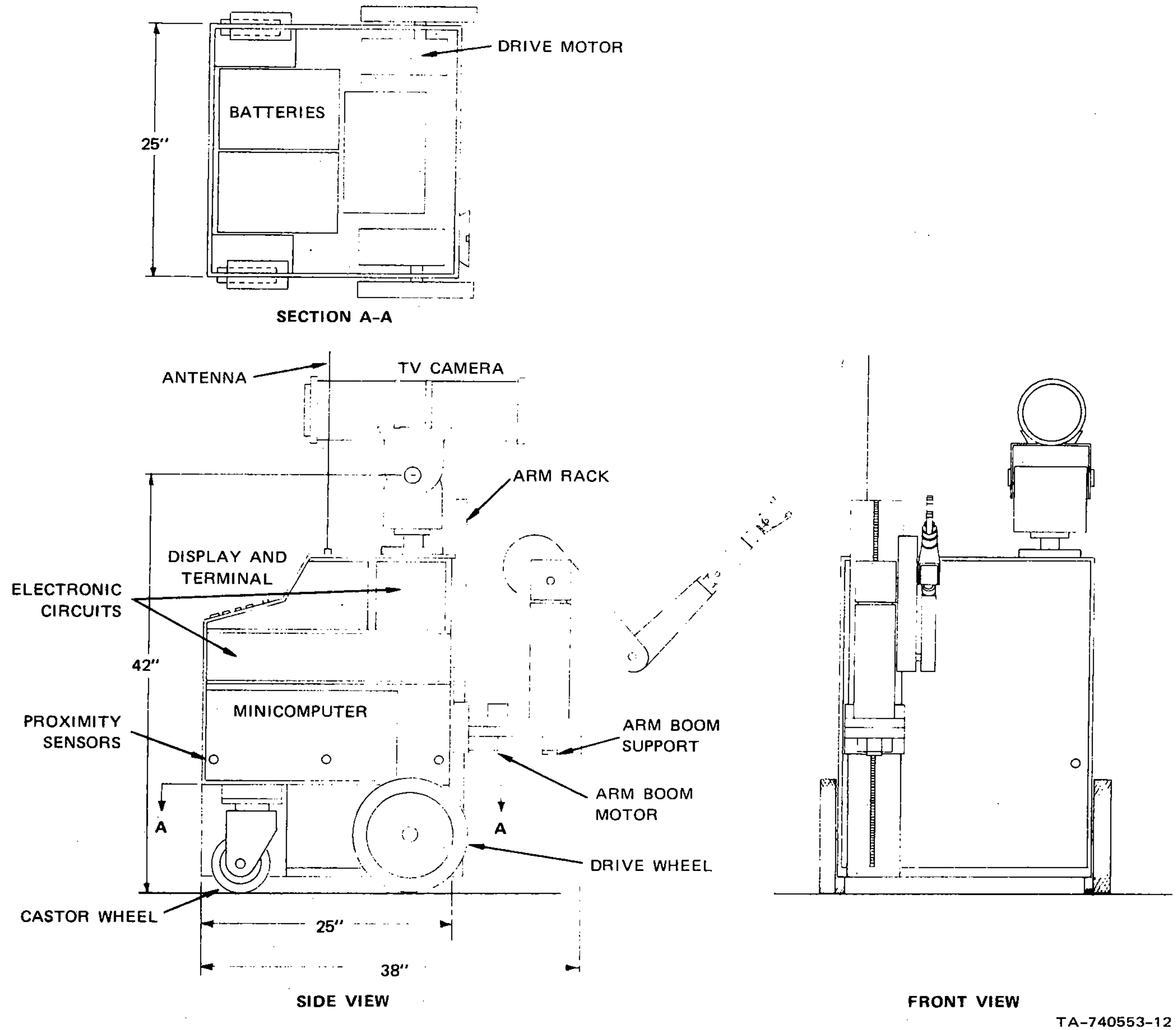


FIGURE 3 PROPOSED ROBOT VEHICLE—THREE VIEWS

the chassis, drive motors, control electronics, power supply, batteries, and battery-charging system, servo amplifiers, and other equipment associated with the vehicle. This equipment will be built to our specifications and will be delivered complete with a set of engineering drawings that we will include in our documentation. A copy of the quotation from Electro Limb is included in Appendix A.

The vehicle system will be derived from the SCAT Electric Wheel Chair manufactured by Wheelchairs, Inc. (a sister company of Electro Limb) also in Downey, California.

As shown in Figures 2 and 3, the Scheinman-MIT Electric Arm manipulator subsystem will be mounted on a 1-foot cantilever boom capable of sliding up and down under computer control along a channel-mast rack attached rigidly to the front of the vehicle chassis. This design was chosen for maximizing the reach of the arm over the surface of a table top while minimizing vibration or instability. A special feature of the design is a simple elbow support below the cantilever boom so that the arm can rest its elbow on the table while carrying out manipulation tasks on top of the table. This minimizes positional error because of distributed torques extending into the vehicle itself. The vertical translation of the boom along the channel mast could range from 12 inches to 42 inches above the floor, thereby satisfying the requirement for manipulation operations at table-top and floor-level heights as necessary.

Arm--The proposed arm is the one designed for desk-top use by Victor Scheinman for the MIT Artificial Intelligence Laboratory in the Fall of 1972. Currently, ten arms are being constructed. We include a quotation from V. Scheinman in Appendix A.

The arm has a human shape and is approximately two-thirds of human size. It has six electrically powered rotary joints plus a parallel jaw hand. The first five joints have electromagnetic brakes to hold the arm in a given position without requiring continuous motor power. The arm has a 40-cm radius hemispherical workspace (centered on the shoulder joint). It has a lifting capacity of approximately 1.5 kg (3.3 pounds) at full extension, and it takes approximately 1 second to complete simple (nontrajectory) motions. The resolution of arm motions is approximately 1 mm, and the accuracy can be 2 mm using calibration look-up tables with interpolation. The arm will have proportional touch sensors in its fingers in addition to a wrist-mounted strain gauge force balance. Space is available to allow the modular addition of a second arm on the same movable boom if two-handed tasks are desired. Of course, the arm can be used mounted on a table rather than on a vehicle.

Vision System--The description of the complete vision system is rather detailed, and the reader is referred to the interim report for full particulars.

Briefly, we recommend a COHU Model 2850 black and white television camera modified to include a four-position, remotely controlled color wheel. The camera will also have a remotely controlled 4 to 1 zoom lens (12.5- to 50-mm focal length). The camera will be mounted on a Pelco Model PT-550-M pan and tilt mount, which in turn can be mounted on the vehicle. The characteristics of the camera system are summarized in the following listing:

Electrical Characteristics

(1) Resolution: 320 × 240 (using one field) or 640 × 480 (using four fields).

(2) Bandwidth: 3.0 MHz.

(3) Sensitivity: High and flat spectral response of a Silicon-Diode-Array Vidicon.

(4) Signal-to-noise: 300:1, i.e., 50 dB.

(5) Dynamic range: $I_{max}/I_{min} = 75$ for $(I_{min}/I_{noise})_{min} = 4$.

(6) Gray scale levels: 64 levels (logarithmic scale preferred).

Optical Characteristics

(1) Focal length: Variable, 12.5 mm to 50.0 mm, using a 4:1 zoom lens (the corresponding view angle varies from 53° × 39° to 14° × 10.5°).

(2) Focus range: 4 feet (with open iris) to infinity.

Color Characteristics

Four-position color-filter wheel (red, green, blue, and neutral), internally mounted.

Mechanical Characteristics

(1) Size and weight: 22-inch long (constrained by 4:1 zoom), 6-inch diameter (constrained by internal color wheel), about 25 pounds (including electronics and casing).

(2) Remote control: Drive motors and readout potentiometers for controlling focus, zoom, iris, and color wheel.

When mounted on the vehicle, the camera transmits the television image back to the host computer system over a video radio link. There it will be processed by an analog-to-digital converter for storage in the host computer. The video analog-to-digital converter system is discussed next.

We propose to encode a TV picture into 240 by 320 picture samples, each of six bits of intensity on a logarithmic scale. Moreover, for activities such as real-time visual control of robot actions, it is desirable to perform the digitization as rapidly as possible, preferably in the time of one field scan (1/60 second). One such picture represents about 460,000 bits of information.

The robot minicomputer does not have enough memory nor input channel capacity to deal with such TV data. It is proposed, therefore, to transmit the picture from the TV camera (via a video transmitter/receiver link for mobile systems) back to the main computer. The digitizer will be connected directly to the main computer and will be capable of digitizing a picture and storing it automatically in core memory in the time of one TV field. Remote control of the camera (pan, tilt, iris, and so forth) will be exercised between the main computer and the robot through the on-board minicomputer. Control of any digitizer parameters will, however, be direct from the main computer just as is control of any other peripheral of the main computer.

In accordance with other elements of the proposed robot system, the digitizer components will be constructed with standardized interface conventions for the connections between them. It will therefore be possible to modify or redesign modules to meet particular user requirements and to avoid redesign of the whole TV data acquisition system.

<u>On-Board Logic and Control</u>--To provide maximum flexibility and expandability, all control systems and sensors will be interfaced as input-output devices on an on-board minicomputer. This policy allows additional future devices and sensors to be easily added. The minicomputer will also serve to decide the high-level commands from the main computer via the radio link. In addition, since some real-time response is required, calculations for control of the arm trajectory and for vehicle navigation will be accomplished by the minicomputer. The minicomputer will then set the command signals for all of the on-board analog and digital controls.

The minicomputer should have at least 8K of core memory to support the command interpreter, the arm trajectory control model, the navigation control program, and the other servo- and sensor-control programs. (Extra core memory modules can be added if desired.)

The communication between the on-board minicomputer and the main computer will be in standard ASCII teletype format since this standard is the most widely used. This allows the robot vehicle system to "look" like a teletype; hence the interface to the main computer will be as straightforward as possible.

The two most suitable minicomputers for the robot system are the DEC PDP-11/20 and the Data General NOVA 1220. Both of these companies have developed extensive software for their minicomputers, and both have excellent service organizations. The final choice will be based on the relative ease of developing software and a competitive bid on the entire minicomputer system. The pricing used in this proposal uses Data General quotes as representative prices.

Other Input-Output Devices--A microswitch keyboard with an 8 by 32 character Burroughs display will be mounted on the rear of the vehicle to allow an experimenter to communicate with the main computer or to modify the program in the minicomputer. Consideration has also been given to adding a microphone and loudspeaker so that audio communication can be provided to a speech analyzer and synthesizer on the main computer via a simple radio communication link. Because of the extendability of the minicomputer's input-output bus, special user devices can easily be added to the basic system.

Radio System--Two communication links are required for the robot system. One is a unidirectional television link from the robot vehicle to the main computer; a second is a bidirectional control link of about 50,000 baud capacity. Since both transmission and reception are required at the robot vehicle and we want to avoid the complexity of time-sharing the same channel, two separate radio frequency channels will be necessary. The separation between these channels and the video channel must be sufficient to prevent the continuous video transmitter aboard from interfering with the digital control link through the on-board control-link receiver. This will most easily be prevented by the selectivity of the control channel receiver. The radio system is more fully described in the interim report.

B. Research Tasks

The equipment we are describing in this proposal is capable of being used for a wide variety of artificial intelligence research tasks. There is increasing interest, even at some smaller universities, in research on robots, "hand-eye" devices, and machine vision. The equipment we are proposing to build should serve a majority of those interested (determined by our survey).

There are several different robotic research programs that could be described. In a research program at SRI, for example, we would use the proposed equipment for the control of an integrated robot consisting of arm, mobile vehicle, and television camera. A brief description of this program is contained in Appendix B.

Quite obviously, certain subsets of the equipment, for example the visual system, could be used alone. The visual system we have described is quite versatile and would permit research that involves the use of color and range information in addition to simple black and white intensity images. We foresee that automatic perception will continue to be one of the most important areas in artificial intelligence research over the next decade. It will be important that the research equipment have the required flexibility to serve the several different approaches that will be used.

III PLAN OF WORK

We have considered various plans for putting together the equipment we are describing. Although many of the items can be purchased commercially, there will be a great amount of work involved in specifying precisely the design, particularly of the vehicle and the video analog-to-digital equipment. It will take much effort to integrate the equipment into a working system and to document this system so that others may use these designs. In the interim report, the SRI project team estimated that the total cost of developing a complete system would be about $50,000 for equipment purchases plus about 30 man-months of labor.

In this proposal we recommend that this work be accomplished over a period of two years. A two-year project has certain advantages over a one-year one. In the first place, the work to be performed is probably too extensive for one year. In the second place, hardware technology is moving rapidly, and a two-year project will allow us more flexibility in making certain final design decisions.

We propose to assemble the vehicle, arm, and control system during the first year. A certain amount of research will be possible with this subsystem as soon as the major components are completed. During the second year, we would complete the entire system by adding the radio link, the vision system and some on-board input-output equipment. In addition to the design, assembly, and testing of equipment, we plan to do various representative research tasks during each of the two years. Descriptions of the work to be performed follow.

A. First Year's Work

During the first year we plan to design, assemble, and test the vehicle, arm, and computer subsystems. The components are listed in Table 1. We see from this table that the total cost of purchased equipment during the first year will be about $30,000 and the SRI labor needed for design, assembly, and testing is about 16 man-months. Detailed cost information is attached at the end of this proposal.

In our first-year program we are proposing an additional two man-months (near the end of the year) of labor to carry out various research tasks with the equipment. Such research will center on manipulation algorithms for the arm and navigation algorithms for the cart. We will thus have an opportunity to develop more high-level computer programs that can exercise the basic routines we will be programming in the minicomputer. The development of these routines in turn will give us feedback about design decisions in time to allow us to make needed modifications during the second year.

B. Second Year's Work

During the second year, we propose to design, assemble, and test the vision system, the radio (including video) link, and the vehicle input-output equipment consisting of keyboard and display. These additions will be integrated with the first-year equipment so that the entire robot system functions together. The components to be developed during the second year are listed in Table 2. The total cost of purchased equipment during the second year is about $18,000, and the SRI labor needed for design, assembly, and testing is about 14 man-months. Again, detailed cost information is attached at the end of this proposal.

During the second-year program, SRI proposes an additional two man-months of labor be allocated to research tasks with the developed equipment. This research will be primarily devoted to using the vision

Table 1

FIRST YEAR ROBOT SYSTEM COMPONENTS AND THEIR TIME AND DOLLAR COSTS

Item	Cost (dollars)	Probable Supplier	SRI Labor (man-months)
(a) Vehicle Subsystems			
Chassis, drive motors and controllers, frame, wheels, speed and brake controls, suspension system, shaft encoders, drawer for batteries, arm slide, rack, boom, motor and controller, position sensor, engineering drawings	$ 2,900	Electro-Limb Inc.	
Specification of above vehicle subsystems			1
Pan/tilt mount and motors	645	Pelco PT-550-M	
Angle sensors on mount	100		
Batteries (set of 6)	300	Sears Roebuck	
Inverters and regulators	150	1 Kw Tripp-Lite	
Proximity sensors 12 transmitters 8 receivers	700	Scientific Technology, Inc. Model 7064	
Assembly and testing			0.5
Miscellaneous design, assembly, and test of entire vehicle subsystem			1
Subtotal	$ 4,795		2.5
(b) Arm Subsystem			
Scheinman-MIT Electric Arm and gripper Wrist force sensor Angle and velocity sensor Controllers and sensors	$ 5,000	V. Scheinman	
Electronics for wrist force sensor	250		1
Design, mounting on vehicle, and testing			1
Subtotal	$ 5,250		2
(c) Minicomputer and Interface Subsystem			
Type 8154 NOVA 1220 W/8K Core	$ 6,300	Data General	
Type 4008 Real-Time Clock	400		
Type 4015/CPU Communications Controller (50 kb Synchron modem)	2,250		
Type 4020 Interval Clock (for above)	175		
Type 4014 I/O Interface for A/D	200		
Type 4032/1200 Basic A/D Interface	700		

Table 1 (Concluded)

Item	Cost (dollars)	Probable Supplier	SRI Labor (man-months)
(c) Minicomputer and Interface Subsystem (Concluded)			
Type 4036 I/O Interface for D/A	$ 200		
Type 4037/1200 D/A Converter Control	300		
Type 4007 I/O Interface	200		
Type 4010/1220 TTY I/O Interface	150		
Type 4040 16-Bit Digital Interface	450		
Type 4041 I/O Register (for above)	100		
Type 4044 WW Pins and Sockets	260		
Type 4009/1200 TTY Modification Kit	100		
Type 4055B/1220A/D Chassis	1,200		
Four each Type 4055N 16-Channel Multiplexor @ $300	1,200		
Type 4055I Buffer Amplifier	200		
Type 4055E A/D Converter	750		
Type 4055K Timing and Control	230		
Type 4056H D/A Decoder and Chassis	2,600		
Five each Type 4056B 8-Bit D/A Converter @ $250	1,250		
Three each Type 4056C 10-Bit D/A Converter @ $275	825		
Six each Type 4056D 12-Bit D/A Converters @ $300	1,800		
Computer programs			2
Miscellaneous design, assembly, and testing			2
Subtotal	$21,840		4
(d) Miscellaneous Equipment			
Manual Controller Specification	$ 500		1
Battery Charger	100		
Subtotal	$ 600		1
(e) Other			
Documentation			3
General design, assembly, and testing of entire system			1.5
Subtotal			4.5
Total	$32,485		14

Table 2

SECOND YEAR ROBOT SYSTEM COMPONENTS AND THEIR TIME AND DOLLAR COSTS

Item	Cost (dollars)	Probable Supplier	SRI Labor (man-months)
(a) Vision Subsystem			
TV camera with 4:1 zoom lens; internal color wheel; special dot on lens center; controls for color wheel, zoom, focus, and iris; controls for camera electronics	$ 7,300	COHU #2850	
Video A/D equipment			
Signal conditioning circuits	200		
A/D converter	3,000	Datel System ADC-UH8B (8-bit 10 MHz)	
Sync separator	75		
Control logic	400		
Packer	100		
Format specifier	100		
Power supplies	300		
Design, assembly, and testing			2
Vision subsystem testing			1
Subtotal	$11,475		3
(b) Radio Subsystem			
Transmitters, receivers, antennas, filters, etc.	$ 3,700		
Interface circuits	500		
Design, fabricate, and test			3
Subtotal	$ 4,200		3
(c) Vehicle Input-Output Devices			
256-character display	$ 995	Burrough's BDS-40832-200 Self-Scan Panel Display	
Power supply	100		
Keyboard	250	Microswitch 78 SWT	
Power supply	50		
Assembly and testing			0.75
Subtotal	$ 1,395		0.75
(d) Other			
Computer programs			2
Documentation			2
Maintenance	$ 1,000		0.75
General design, assembly, and testing			2
Subtotal	$ 1,000		6.75
Total	$18,070		13.5

capabilities of the system as an aid in manipulation and navigation. Again, the major purpose of the research is to provide guidance for the final design of subsequent robotic systems.

IV REPORTING AND DOCUMENTATION

In this section we shall briefly outline our plans for demonstrating the performance of the developed equipment and for issuing written reports and documentation.

Documentation will be given very close attention. We have budgeted sufficient resources to ensure that each item of equipment, the computer programs, and the operation of the subsystems and the entire system will be clearly and completely explained. The documentation will be in the form of reports and engineering drawings. These will be detailed enough to be used by, say, a competent contractor to produce copies of the equipment or by a research group that has decided to construct its own system. We shall be documenting the systems while we design, assemble, test, and modify them so that we shall have up-to-date descriptions at all times.

A report will be issued at the end of each year of the proposed two-year program. These reports will contain, in addition to descriptions of the equipment, a complete discussion of the design rationale, experimental test results, and research results.

In addition to reporting and documentation, we will set ourselves milestone points at which we will demonstrate the performance of the various subsystems as they are completed. We shall invite NSF personnel and any interested observers to witness demonstrations at SRI at the end of the first and end of the second year's work. The milestone demonstrations are briefly outlined in Table 3.

V CURRENT SUPPORT

Current and planned future support for Mr. Burtis Meyer, the proposed principal investigator, is as follows:

NSF Grant No. GI-38100X Exploratory Research in Advanced Automation	40 percent
ARPA Contract DAHC04-72-C-0008 Artificial Intelligence--Research and Applications	20 percent

Table 3

ROBOT EQUIPMENT MILESTONE DEMONSTRATIONS

Time	Demonstration
9 months	Scheinman-MIT Electric Arm performing simple tasks (picking up and setting down objects) under control of the minicomputer and the PDP-10 host computer.
9 months	Vehicle performing simple navigation tasks (e.g., going through a doorway) under control of minicomputer and host PDP-10 computer.
12 months*	Vehicle and arm system performing simple navigation and object manipulation tasks.
15 months	Vehicle input-output system functioning (display and keyboard).
18 months	TV picture input through the digitizer to the host PDP-10 computer via cable.
21 months	Finished radio system functioning. Arm and vehicle controlled via radio from host PDP-10 computer.
21 months	TV picture input to host PDP-10 computer over the video radio link.
24 months*	Vehicle, arm, and vision system controlled over radio link from PDP-10 computer. System will perform simple navigation and object manipulation tasks.

*We will invite interested observers to these demonstrations.

Should this proposal from SRI to NSF be accepted, the principal investigator will allocate 40 percent of his time to the work.

VI CONTRACTUAL MATTERS

A. Estimated Time and Charges

The estimated time required to complete this project and report its results is 104 weeks. The Institute could begin work on receipt of a fully executed contract. A cost estimate for the proposed study is attached.

B. Reporting Schedule

A report containing system documentation will be submitted at the end of each year of the work.

C. Acceptance Period

This proposal will remain in effect until 1 June 1974. If consideration of the proposal requires a longer period, the Institute will be pleased to consider a request for an extension of time.

D. Artificial Intelligence Center Computer Facilities

Computation for the proposed project will be done on a PDP-10/PDP-15 computer installation located in the Artificial Intelligence Center at SRI. This computer is government-furnished equipment, provided to SRI for use in a major research program in the field of artificial intelligence. We believe that permission can be obtained for its use on other U.S. government projects, such as the one proposed here, as long as such use does not interfere with the work of the primary sponsor. We foresee no likelihood of such interference for the duration of the proposed project. Although there are no direct charges for use of this computer, the proposed project will provide an appropriate share of the expenses for computer support personnel.

VII PERSONNEL

The principal investigator will be Mr. Burtis Meyer. Other SRI engineers and scientists who may participate include: Gerald Agin, Stanley Fralick, Gerald Gleason, Nils Nilsson, David Nitzan, William Rupert, and B. Michael Wilber. Biographies of these key individuals follow.

BURTIS W. MEYER, SENIOR RESEARCH ENGINEER
ARTIFICIAL INTELLIGENCE CENTER
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Digital equipment design; system conception; logic design; digital signal analysis

Professional experience

- Time Data Corporation; designed digital signal analyzer, Fourier transform computer, and multichannel underwater-sound signal analyzer
- Signetics Corporation; Applications Engineer, designed three Automatic Integrated Circuit Testers
- General Electric Computer Laboratory; designed Magnetic Tape Control System, research projects in Cryotrons, tunnel diodes and associative memories

Academic background

- B.S.E.E. (1952), Montana State University; M.S.E.E. (1954), USAF Institute of Technology; E.E. (1960), Stanford University

Publications

- 5 articles in trade publications such as *Electronics* and *EDN*
- 4 internal reports at General Electric Computer Laboratory
- 3 patents on digital systems

GERALD J. AGIN, RESEARCH ENGINEER
ARTIFICIAL INTELLIGENCE CENTER
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Artificial intelligence, computer vision, robotics, high-acceleration servomotors, stepper motors, motor control logic

Professional experience

- Staff engineer, IBM Corporation:
  - Designing, specifying and simulating printed circuit motors, stepper motors, and their controls for high speed printers and other I/O devices
  - On resident study assignment at Stanford University
  - Planning and liaison for a large programming system for logic design automation
- Student engineer, Radio Corporation of America

Academic background

- B.S. in electrical engineering (with honors, 1963), Lehigh University; M.S. in electrical engineering (1968), Syracuse University; Ph.D. in electrical engineering and computer science (1972), Stanford University

Publications and patents

- Coauthor of "Computer Descriptions of Curved Objects," *Proceedings, Third International Joint Conference on Artificial Intelligence,* Stanford University (1973)
- Four patents on D.C. servomotor controls

Professional associations and honors

- Institute of Electrical and Electronic Engineers
- Eta Kappa Nu, Phi Beta Kappa, Tau Beta Pi

STANLEY C. FRALICK, STAFF SCIENTIST
TELECOMMUNICATIONS DEPARTMENT
ENGINEERING SYSTEMS DIVISION

Specialized professional competence

- Signal detection and parameter estimation techniques; communication system design and analysis; pattern recognition; adaptive systems; optical data processing

Representative research assignments at SRI (since 1969)

- Analysis and modeling of multipath, dispersive, and nongaussian noise effects on communication systems
- Design and development of hospital telemetry systems
- Design and development of spectrum monitoring systems
- Research on radiation of Walsh Waves
- Development of signal classifier for seismic sensors

Other professional experience

- Department manager, Sylvania Electronics Defense Laboratories; investigated and applied detection/estimation theory, pattern recognition, adaptive systems, and optical data processing to electronic warfare problems; designed and developed digital reconnaissance equipment
- TRW; analysis of advanced radio guidance, telemetry, and satellite communications systems
- Project engineer, Atlas Weapons System, Vandenberg AFB, U.S. Air Force; technical direction of installation/checkout/test launching
- Communications officer, U.S. Air Force; responsible for communications maintenance section at AC&W site

Academic background

- B.S. (1956), M.S. (1957), and Ph.D. (1965) in electrical engineering, Stanford University

Publications and patents

- Author of "Nonparametric Estimation of Bayes Risk," *IEEE Trans. Info. Theory* (1971); "An Adaptive Receiver for Signals of Unknown Frequency," *IEEE Trans. Comm. Tech.* (1968); "Learning to Recognize Patterns Without a Teacher," *IEEE Trans. Info. Theory* (1967); numerous papers presented at IEEE technical meetings
- Author of numerous Sylvania/TRW reports
- Patent on a digital adaptive pattern-recognition machine (coholder)

Professional associations and honors

- Institute of Electrical and Electronics Engineers--Groups on Communication Technology and Information Theory
- Pattern Recognition Society
- Armed Forces Communications Electronics Association
- Tau Beta Pi

GERALD J. GLEASON, RESEARCH ENGINEER
ARTIFICIAL INTELLIGENCE CENTER
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Digital and analog control system design and evaluation; real-time computer control and display systems development; nuclear physics control and instrumentation design and nanosecond pulse technology

Representative research assignments at SRI (since 1972)

- Design of multi-port computer interface for real-time applications
- Development of storage tube display interface
- Evaluation and recommendation of hardware for artificial intelligence research and industrial automation in the U.S. and Japan

Other professional experience

- Computer systems engineer and engineering manager, Stanford University Artificial Intelligence Laboratory (1967-72); digital control systems development in a timesharing environment
- Project engineer and engineering co-ordinator, Stanford University High Energy Physics Laboratory (1959-67); development of instrumentation for electron-electron colliding beams experiment

Academic background

- A.A.E.E. (1959) in electrical engineering, Heald Engineering College; electrical engineering and digital system design studies (1966-71), Stanford University

Professional associations

- Institute of Electrical and Electronic Engineers; Computer Society; Cybernetics group and Instrumentation and Control group

NILS J. NILSSON, STAFF SCIENTIST
ARTIFICIAL INTELLIGENCE CENTER
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Artificial intelligence; pattern recognition

Representative research assignments at SRI (since 1961)

- Studies in the theory of pattern recognition
- Studies in heuristic search and automatic problem-solving procedures
- Automatic theorem-proving studies
- Robot systems research
- Head, Artificial Intelligence Group (1963-67)

Other professional experience

- Acting associate professor, Computer Science Department, Stanford University (half-time, 1968-69)
- Taught courses in pattern recognition at Stanford University and at University of California (Berkeley)

Academic background

- M.S. (1956) and Ph.D. (1958) in electrical engineering (communication theory), Stanford University

Publications

- 16 articles on pattern recognition and artificial intelligence
- *Learning Machines*, McGraw-Hill (1965); *Problem Solving Methods in Artificial Intelligence*, McGraw-Hill (1971)

Professional associations

- Member of editorial boards, *Artificial Intelligence: An International Journal* and *Pattern Recognition*
- Tau Beta Pi
- Sigma Xi

DAVID NITZAN, SENIOR RESEARCH ENGINEER
ARTIFICIAL INTELLIGENCE CENTER
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Machine perception in the field of artificial intelligence; modeling of static and dynamic properties of square-loop magnetic cores; computer-aided analysis of nonlinear circuits including magnetic cores; all-magnetic computer logic circuits including multipath cores

Representative research assignments at SRI (since 1959)

- Application of artificial intelligence to industrial automation
- Scene analysis using stereopsis and range data for artificial intelligence
- Research on image-charge transfer in electrophotography
- Research on modeling of magnetic cores for computer circuit analysis
- Development of an automated circuit-analysis computer program (MTRAC)
- Measurement of magnetic core parameters
- Flux switching in magnetic circuits
- Computer analysis of a current sensor
- Flux switching in multipath cores
- All magnetic logic circuits including multipath ferrite cores

Other professional experience

- Visiting associate professor, Technion, Israel Institute of Technology (academic year 1970-71)
- Taught courses in electrical machinery and feedback control systems, University of California (Berkeley) (1954-59)
- Design of electrical installations and control for Kaiser Engineers
- Field engineer, Bechtel Corporation (1953-54); construction of the Pittsburg, California power plant
- Field engineer, Sollel Boneh Company, Israel (1951-53); design of electrical installations in factories

Academic background

- B.S. in electrical engineering (1951), Technion, Israel Institute of Technology; M.S. (1956) and Ph.D. (1959) in electrical engineering, University of California (Berkeley)

Publications and patents

- Author of "Introduction to Electrical Engineering," Michol Book Company, Haifa, Israel (1971); Coauthor of "Digital Magnetic Logic," McGraw-Hill Book Company, New York (1969); 16 papers--3 on magnetic amplifiers, 2 on flux-switching in multipath cores, 3 on all magnetic shift registers, 7 on flux-switching models and their application to computer-aided analyses of magnetic circuits, and 1 on eddy currents
- 8 patents on magnetic logic circuits

Professional associations

- Institute of Electrical and Electronics Engineers
- Scientific Research Society of America

WILLIAM P. RUPERT, RESEARCH ENGINEER
ARTIFICIAL INTELLIGENCE CENTER
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Pattern classification system design and evaluation; multivariate data nonparametric analysis; modeling of human cognitive processes; computer interface design

Representative research assignments at SRI (since 1966)

- Application of pattern-recognition techniques to radio signal processing
- Development of a representation for natural human speech suitable for voice message input to electronic computers
- Time-series data conditioning and selective averaging
- Supervision of upgrading and maintainance of computer controlled mobile automata and manipulator

Other professional activities

- Research engineer, Electronics Research Laboratory, Montana State University (1964-66); project leader for study of pattern-recognition techniques for classifying radio signals
- Member of the technical staff, Radar Division, Hughes Aircraft Company (1963-64); systems analysis with three-dimensional phase-frequency scanning and tracking radars

Academic background

- B.S.E.E. (1963) and Ph.D. in electrical engineering (1969), Montana State University; graduate studies (1963-64), University of Southern California

Publications

- Author of SRI reports, "Voice Data Processing: Segmentation of Speech to Characterize the Information-Carrying Units" (1967) and "A Representation for the Information-Carrying Elements of Natural Speech" (1968)
- Coauthor of SRI report, "Special Signal Analysis Technique Evaluation (U)" (1968)

B. MICHAEL WILBER, RESEARCH MATHEMATICIAN
ARTIFICIAL INTELLIGENCE CENTER
INFORMATION SCIENCE AND ENGINEERING DIVISION

Specialized professional competence

- Software systems

Representative research assignments at SRI (since 1964)

- Design and implementation of a complete utility software package for a small computer
- Design and implementation of a time-sharing operating system and hardware for a small computer
- Development of a small management information system
- Design and implementation of hardware and real-time computer programs for psychophysical experiments
- Planning and management of a small computer installation for time sharing

Other professional experience

- Stanford University (1964-66): design of a large medium-scale computer; implementation of a (computer) ring associative language; implementation of a model of memory; redesign and reimplementation of a symbolic computer-assisted instructional subsystem
- Lawrence Radiation Laboratory; large scientific data processing programs

Academic background

- B.S. in mathematics (1964), Massachusetts Institute of Technology; M.S. in computer science (1966), Stanford University

Publications

- "LINC-8 Text-Handling Software for On-Line Psychophysical Experiments," Digital Equipment Corporation Equipment Users' Society, 1967 Fall Symposium

Professional association

- Association for Computing Machinery

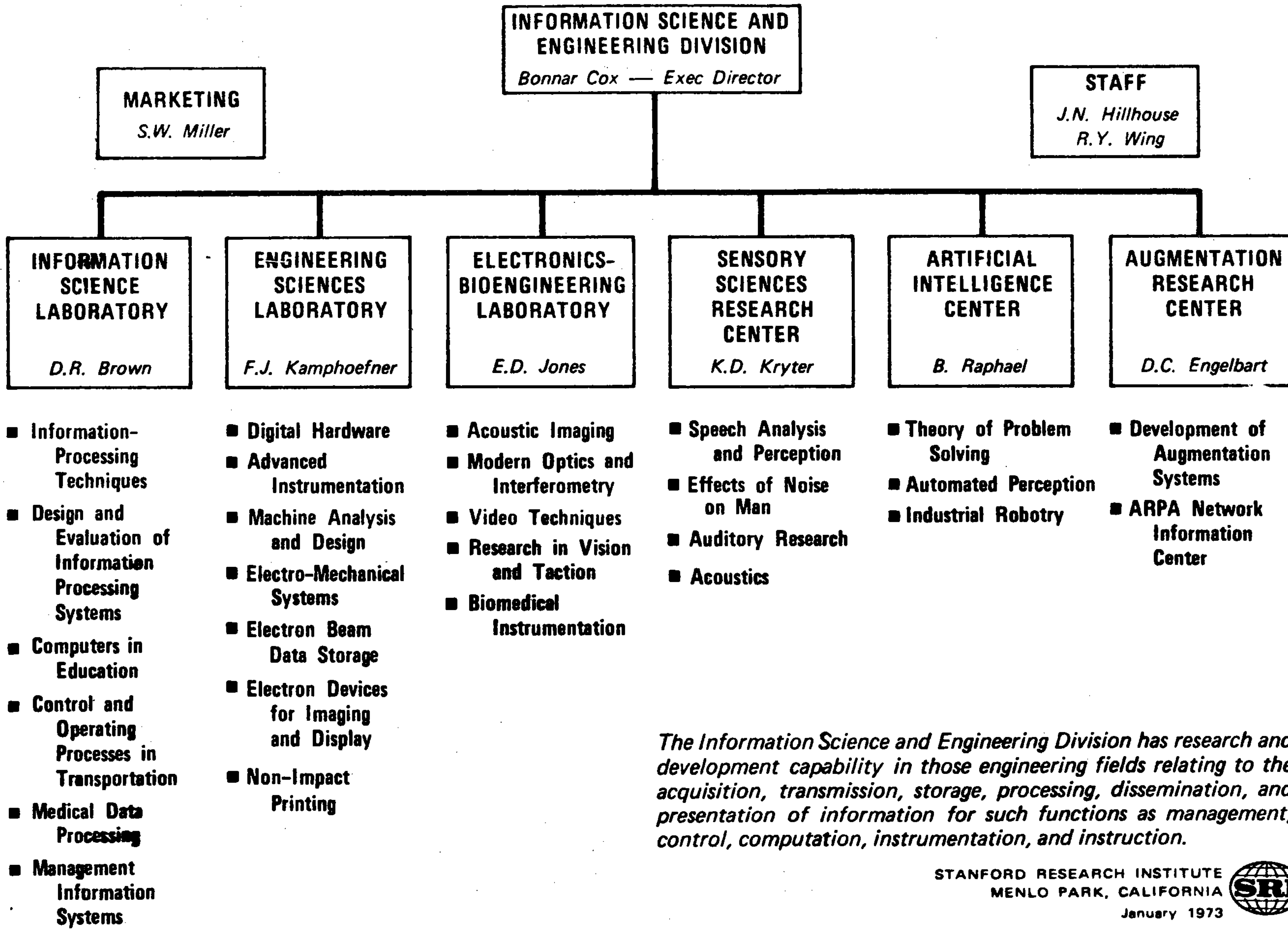
VIII QUALIFICATIONS

The work being proposed will be carried on within the Information Science and Engineering Division of SRI. In this section, we give a brief summary of the capabilities of this division.

A. Information Science and Engineering Division

The Information Science and Engineering (ISE) Division has research and development capability in those engineering fields relating to the acquisition, transmission, processing, dissemination, and presentation of information for such functions as management, control, computation, instrumentation, and inspection. Research ranges from basic to applied; it is often multidisciplinary in nature and includes the conception and development of advanced techniques and devices, theoretical analyses, and overall system design, implementation, and testing. When appropriate, research results may culminate in prototype or finished hardware, which may include fabrication of subassemblies or complete operating mechanical and electronic systems. In general, these are one-of-a-kind developments, since SRI does not provide production-line capability. (See Figure 4.)

The major programs of ISE are carried out in three laboratories and three research centers briefly described herein. Each of the laboratories is composed of a number of groups with complementary interests and skills. The emphasis on research in computer applications and techniques, particularly interactive man-and-computer developments, brings a requirement for specialized computer facilities. The Information Science and Engineering Division has several computer systems in its own quarters, each of which is continuously used in direct support of on-going Division research projects. Present systems include two DEC PDP-10's, one with multiple input-output graphic work stations and very large secondary storage in a time-sharing environment and the other with special connections for the study of robots. ISE also has a DEC PDP-11 with a large-disc pack and a high performance CRT terminal for system experiments in text-handling and language studies, and four other minicomputer systems. A considerable library of support software is also maintained. As appropriate, use is made of the main SRI computation facility, which includes a CDC 6400 and an IBM 360/40, as well as commercially available time-sharing computer services outside of SRI.



The Information Science and Engineering Division has research and development capability in those engineering fields relating to the acquisition, transmission, storage, processing, dissemination, and presentation of information for such functions as management, control, computation, instrumentation, and instruction.

STANFORD RESEARCH INSTITUTE
MENLO PARK, CALIFORNIA
January 1973

FIGURE 4 ORGANIZATION OF THE INFORMATION AND ENGINEERING DIVISION

B. Artificial Intelligence Center

The Artificial Intelligence Center (AIC) conducts a variety of research programs aimed at increasing the ability of automatic systems to solve problems and to perceive and interact with the physical world.

The AIC was founded more than ten years ago as the Learning Machine Group, which pioneered in the development of adaptive pattern classification systems. Current work on automatic pattern perception concentrates on scene analysis--the interpretation and representation of data from real three-dimensional scenes. This analysis is usually based upon optical data such as that obtainable by a TV camera; however, the Center is also developing devices and algorithms for processing other kinds of sensory data such as depth.

The study, development, and implementation of automatic problem-solving methods is a major activity of the Center. This work has led to new principles for heuristic search, new formal logical theorem-proving techniques, and new approaches to designing problem-solving systems.

Automatic methods for interpreting the syntax and semantics of natural English are a continuing interest of the AIC. The major current goal in this area is a speech-understanding system, that will react appropriately to a broad range of English sentences spoken into a microphone.

Problem solving, scene analysis, and natural language capabilities have been brought together in the programs that operate Shakey, a mobile computer-controlled robot. Shakey can solve problems requiring objects to be pushed about the laboratory, can recover from certain errors, and can carry out several forms of learning.

A new interest of the AIC is the development of perceptual and decision-making capabilities to promote industrial automation. Systems are being assembled to assess and demonstrate the technical and economic feasibility of new automatic approaches to visual inspection, materials handling, and assembly tasks.

C. Information Science Laboratory

Research in the Information Science Laboratory (ISL) includes the development of techniques and applications and the evaluation of information systems including computers, transportation control systems, and other information-handling systems.

The Computer Science Group specializes in programming, computer architecture, and man-computer communication. Programming techniques include methods for the proof of program correctness, the design of languages and aids for the generation of fault-free and rugged programs, and the organization of adaptive files for management support systems. Computer architecture includes techniques for the design of ultra-reliable computers and highly parallel computers, for the diagnosis of digital systems, and for the organization and assessment of complex computer systems. Man-computer communication includes interactive and graphic data analysis and analytic and generative techniques for computer-aided instruction.

The Information Systems Group is engaged in the analysis, design, and evaluation of large-scale information systems. Projects are addressed to the specific needs of government and commercial clients. In responding to such requests, project teams tend to be multidisciplinary and include specialists from other parts of the Institute.

The Systems Programming Group designs and develops software systems. Emphasis is on the production of user-oriented systems together with all supporting documentation. Research on the nature of the support software needed to facilitate the development of large systems and the proper methods of software project management is also performed.

The Transportation Engineering and Control Group carries out research in air traffic control, automobile traffic control, and rail traffic systems. Activities range from the application of advanced engineering techniques for policy development through technical analysis and evaluation to actual implementation. Control and operating policies stress practicality with effective performance. Implementations include development of software programs for on-line surveillance and control.

In addition, the Laboratory conducts research on the use of computers in education and training.

D. Augmentation Research Center

The Augmentation Research Center (ARC) is an externally supported, multiple-sponsored group of 35 persons working in close cooperation on the problem of "augmenting the human intellect." They concentrate on the use of highly interactive computer systems designed to aid individuals and groups in such manipulations of information as

- Externalizing and storing "ideas" in symbolic forms, e.g., English text, drawings, and other special structures.
- Studying the stored material using high-speed computer display coupled with specialized information-retrieval techniques.
- Modifying and updating the stored material by responses to a highly sophisticated system of commands which range from detailed editing to wholesale rearrangement of information structures.
- Assessing other computation and storage facilities through the ARPA Computer Network.

One system, NLS, can be viewed as an intellectual tool kit for communication, planning, information storage and retrieval, access to outside facilities through the ARPA Network, and other explicit applications areas such as programming.

Another system, the Network Information Center (NIC), is both an on-line and off-line reference and communication system offering a subset of ARC capabilities to the ARPA Network community as well as other special features required of a network facility.

Besides designing computer systems, ARC is studying and creating methodology for using these systems for intellectual tasks such as system design, management, and implementation.

E. Electronics and Bioengineering Laboratory

The Electronics and Bioengineering Laboratory comprises two groups: the Bioengineering Group and the Electronics and Optics Group.

The Bioengineering Group is concerned with research in human sensory information processing and biomedical engineering. A variety of research programs are being conducted on spatial and temporal interactions in vision, touch, and hearing. Objectives include learning more about the nature of these systems; conceiving new hardware systems that might be developed for communication, display, and medical purposes; and researching instruments in the biomedical field. Among the group's accomplishments are the development of an optometer for automatic objective refraction of eye glasses, a portable reading aid for the blind (called the Optacon), and special computer-based facilities for psychophysical testing in visual accommodation with related instrumentation including a high-accuracy eye tracker and a high-resolution fundus camera.

The Electronics and Optics Group does research on imaging techniques and video information processing. A variety of research projects have been undertaken in the field of electrostatic printing, bandwidth reduction, modern optics and holography, and acoustic-optical systems. Among the group's accomplishments have been the Videograph electrostatic printer, electrostatic color facsimile, electrostatic stencil-screen printing, and reduced bandwidth facsimile systems. Recently, a new concept in color encoding was developed whereby color information can be recorded on conventional black-and-white film. In addition, a single vidicon television camera can be used to produce high-quality color television imagery. This color-encoding technique is now being developed for remote sensing in earth resources applications.

Under sponsorship by the National Institutes of Health, a new program has recently been launched to develop an ultrasonic camera for medical diagnostic use. This camera illuminates internal organs of the body with high frequency sound energy and converts the transmitted energy to an optical field for real-time viewing by a physician. Experiments to date show that high quality useful images can be produced with such a camera.

F. Sensory Sciences Research Center

The goals of the Sensory Sciences Research Center are to provide knowledge about man's processing of stimuli presented to his sensory receptors and to apply and utilize physical acoustics to measurement, transmission, and control of sound and noise. The interdisciplinary staff includes physicists, electrical engineers, physiological and experimental psychologists, audiologists, and statisticians.

An important part of the Center's activity has been study of the effects of noise on man. Effort is directed toward creating and applying valid measures of the physical characteristics of noise, as they affect people, for application to the engineering design of noise sources and the physical control and management of noise in the environment. Some of the laboratory studies deal with physiological and psychological reactions in man when asleep and awake immediately after exposure to noise.

The Sonics Group studies noise control for ground transportation systems; underwater acoustics; and use of sound in nondestructive testing, audio engineering, and architecture.

A long-term effort is aimed at defining and describing the function of normal and pathological ears stimulated by speech and other complex signals. Specially designed laboratory facilities and instruments are available for this work.

Work in the area of speech includes studies of speech perceived as an information-bearing signal for word recognition or talker recognition by man or machine, studies to identify the speech-signal properties that are correlated with abnormal physiological states, and studies on mechanical generation of a signal similar to human speech that carries some of the same information.

G. Engineering Sciences Laboratory

Research in the Engineering Sciences Laboratory is directed toward the physical realization of information systems including new sensors, advanced instrumentation, storage and display, special data input-output systems, and advanced device technologies.

The Digital Development Group develops advanced digital hardware to fill the needs of a client for a new product, to demonstrate the feasibility of new techniques, to contribute to the solution of a system problem, or to provide special instrumentation required for other research and development programs. Current projects include the development of automobile traffic control equipment and systems, and studies of the present and future state of the art in electronic components and equipment construction techniques.

Research and development in novel pickup, storage, logic, and display electron devices based on the formation and use of submicron-sized film structures and advanced electron optics is emphasized in the Physical Electronics Group. Included are investigation and development of new concepts and phenomena for electron devices, high-speed electron-beam-addressable memory and logic systems, very high-resolution thin-film technology, scanning-electron-probe instrumentation, low-voltage multipoint field emitters, and field-ionization mass spectrometry.

The Mechanical Group works in mechanical design, fluid mechanics, and solid dynamics, which include the development of electromechanical and fluid/electrostatic systems. Research projects have included high-speed document handling, several nonimpact printing methods, and transducer development. Projects often stress the interaction between mechanical engineering and other disciplines (e.g., electrostatic atomization of fuel oil and compatible burner design, development of an external blood-pressure transducer, and development of a continuous high-speed laundry process).

Appendix A

COPIES OF LETTERS AND DATA FROM SUPPLIERS

ELECTRO-LIMB, INC.
P.O. BOX 3584, LOS AMIGOS STATION
DOWNEY, CALIFORNIA 90242

September 14, 1973

Nils J. Nilsson, Ph.D, Staff Scientist
Stanford Research Institute
Artificial Intelligence Center
333 Ravenswood Avenue
Menlo Park, California 94025

Dear Dr. Nilsson:

Subject: Quotation on Robot Systems Components

As per SRI literature of June 1, 1973, (Robot Design), components tabulation sheets and verbal conversation with you and your staff, quotations are referenced to tabulation sheets and are valid for six months from date of this letter.

A. Vehicle Subsystems

1.	Chassis, drive motors and controllers, frame wheels, casters, axles, speed and brake controls, suspension systems, shaft encoders, battery drawer	2,300.00
2.	Arm slide, rack, platform, motor and controller, position sensor. All detailed drawings of the above are included.	600.00

D. Minicomputer and Interface Systems

3.	Motor Controllers and Servos -	
	6 Fixed Speed Design and Test	500.00
	7 Variable Speed Design and Test	1,750.00

G. Miscellaneous

1.	Manual Controller, Design, Assy, Test	500.00
2.	Battery Charger	100.00

If you have any questions, please do not hesitate to contact us.

Sincerely,

J R Allen

James R. Allen

mrc

VICARM
3689 South Court
Palo Alto, CA 94306

June 13, 1973

Mr. Gerald J. Gleason
Artificial Intelligence Center
Stanford Research Institute
333 Ravenswood Avenue
Menlo Park, CA 94025

Dear Mr. Gleason:

Per your recent request we are pleased to submit the following quotation on the manufacture and delivery of an "M.I.T. Arm."

M.I.T. Arm with tachometers and potentiometers on all six joints. This includes a parallelogram motion type hand, wrist mounted strain guage type force balance, a power supply, motor electronics, and a simple manual controller. Strain gauge electronics is not included.

Typical performance specifications:

Max. load carrying capacity - 1.4 kg.
Workspace - a 40 cm. hemispherical radius centered on the shoulder joint.
Speed - 1 second to complete most simple motions.
Resolution - 1mm.
Accuracy - 2mm using calibration tables.
Weight - Approx. 5 kg.

Price is $5,000 and delivery is 16 weeks ARO or November 15, 1973, whichever date is later.

Sincerely yours,

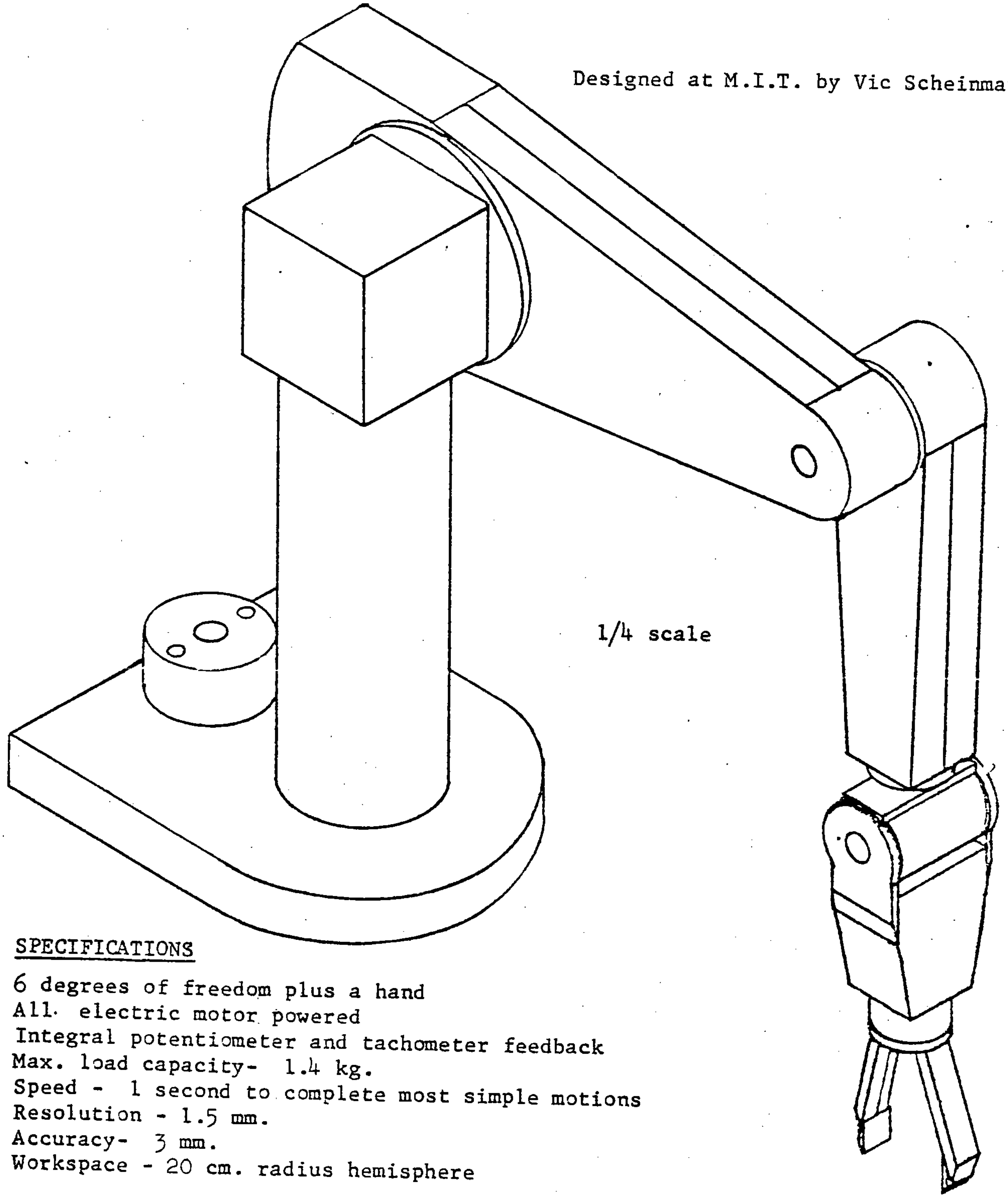
Victor Scheinman

Victor Scheinman
President

VS/cpc

THE M.I.T. ELECTRIC ARM

Designed at M.I.T. by Vic Scheinman



1/4 scale

SPECIFICATIONS

6 degrees of freedom plus a hand
All electric motor powered
Integral potentiometer and tachometer feedback
Max. load capacity- 1.4 kg.
Speed - 1 second to complete most simple motions
Resolution - 1.5 mm.
Accuracy- 3 mm.
Workspace - 20 cm. radius hemisphere

PRICE - about $4000 including hand and some electronics

VICARM
154 EAST DANA STREET
MOUNTAIN VIEW, CA. 94041

VICTOR SCHEINMAN
PRESIDENT
PHONE (415) 965-0557
(415) 321-1440

Appendix B

RESEARCH ON ROBOTS

RESEARCH ON ROBOTS

A Short Description of a Proposed Research Program

by

Nils J. Nilsson
Artificial Intelligence Center

July 1973

I Introduction

For several years the Artificial Intelligence Center at the Stanford Research Institute (SRI) has been engaged in research on robots. Much of this research has been performed with our mobile robot, Shakey, and is documented in various papers,[1,2]* reports[3,4] and a film.[5]

Considerable progress has been made in incorporating into the computer-controlled system that controls Shakey the perceptual, problem-solving, learning, and decision-making routines which permit it to carry out, autonomously, simple assigned tasks in a highly constrained laboratory environment. It now appears appropriate to extend these techniques from simple domains to more real-life environments, with the expectation of learning how intelligent, man-made systems can interact usefully with more complex and realistic worlds.

Another impetus for beginning now to deal with more complex environments

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*References are listed at the end of this note.

comes from a recently completed preliminary design[6] of some new robot hardware. This hardware, designed under NSF grant number GK 36487, will have considerably more versatility and research potential than that possessed by Shakey. It will consist of a mobile cart carrying a TV camera and a manipulator arm together with an on-board minicomputer.

We feel that future robot research promises to produce both major theoretical advances in artificial intelligence and significant practical applications. As examples of the practical application areas we might mention specifically (1) advanced automation techniques with a consequent improvement in industrial productivity, (2) security activities such as automated firefighting and patrolling, and (3) delivery activities such as automated messengers. Indeed, truly versatile robot systems will have wide-ranging applications in many civilian and defense tasks.

For these reasons we think that it is extremely important to begin this new phase of robot research. In this note, we give an outline of a proposal for a program of robot research.

II Outline of Program

There are two aspects to our proposed research program. One concerns the kind of tasks that we want the experimental robot system to perform. The sophistication and complexity of these tasks and of the task environment provides a reasonable measure of the state of the art of robot research and also allows predictions to be made about various practical applications. The tasks themselves, however, do not comprise the whole story, because one of the major purposes of the research is to develop the necessary basic science of robotics. The experimental tasks merely provide the context in which the second aspect of our program, basic robot research, is carried out. In this section we shall describe both aspects: tasks and basic research.

A. Tasks and Task Domain

Our proposed task domain for robot research is the office and laboratory environment of the SRI Artificial Intelligence Center. We envision a computer-controlled robot capable of traversing the rooms and corridors of this environment and able to perform a myriad of tasks for the humans within it. A typical class of tasks are of the form "Bring A to B," where A and B can both be instantiated in many different ways. One instance of this class would be "Bring this book to John" which itself has a great many interesting variations depending upon what the robot "knows" about the location of John and what person can help him if his initial efforts are fruitless. Other classes of tasks include problems like arranging meetings, notifying people at selected times about selected events, ascertaining the availability of various facilities, and so forth.

Our interest in this task domain rests on two facts: it will allow us to pursue in depth the core research issues to be described below, and it is convenient experimentally. Our interest does not rest on the belief that a factotum office aid is a needed commodity per se. In fact, at first glance some of these tasks might sound rather simple, but they involve complicated issues of visual perception, automatic planning and execution of actions, and large data bases of common sense knowledge. These research problems, to be discussed in more detail below, must be solved before any sophisticated applications of robots will be practical. The task domain we have described seems to be the most convenient one in which to face these problems.

B. Basic Research

There are two main areas in which we wish to pursue basic robot research. One concerns planning robot actions and executing these plans. The other concerns visual perception research for robots. We shall discuss each of these areas briefly below. Both areas are nicely integrated in the performance of the kinds of robot tasks discussed above.

1. Generating and Executing Robot Plans

Much work has been done on simple systems that generate robot plans[1,7] and some additional research has been performed on systems that coordinate the generation of plans with their execution.[2,8] Many problems remain, however. Some of these have been discussed in Ref. 9. We still do not have an entirely satisfactory methodology worked out for a system that generates plans in a hierarchical fashion, gathers whatever information is needed from the world, and then executes these plans in an efficient manner. We expect that the development of an experimental system for generating and executing plans in the task domain specified above will give us a much clearer picture of the problems involved and of the range of possible solutions. Quite probably such a system would be programmed in the new AI Language, Q-LISP,[10] currently being implemented at SRI.

2. Perception

In a recent report[4] we described in considerable detail our design for an entirely new visual perception system. This design is a very ambitious one, and we are now implementing a simplified form of the system. Here, we briefly describe some of the intended characteristics of the design, and point out the relation between issues of perception and other research issues that we have raised.

Our design is based on the premise that there exist easy ways of seeing things. The many contextual relations among real-world objects, together with an assumed availability of multi-sensory data (i.e., range and color data), suggest that under most circumstances some combination of perceptual cues can be found that would enable the system easily to locate and identify a given object. For example, to find a telephone in an office it may be easy first to find a desk (a horizontal surface of known color, height, and size) and then to find the telephone (a close-packed collection of small black regions) resting upon it. By contrast, it is much more difficult to find a telephone solely on the basis of its shape (the typical clue of past scene-analysis systems) using no contextual aids.

Very roughly speaking, our system can be partitioned into a low-level section consisting of a set of primitive perceptual operators and a high-level perceptual executive. The executive must know about many kinds of things: about perceptual properties of objects, about their contextual relations, about the operating characteristics of the available primitive operators, and about partial results generated by an ongoing analysis. The task of the executive is to combine these various kinds of information in order to define the next step of analysis; that is, to define which operator should be next applied to which portion of the scene under which of many different forms of top-level guidance.

III Method of Approach

To insure a highly focused research program we would set up various performance milestones for the robot system. The following graded list of tasks is a possible list of such milestones:

(1) pick up a book lying on a desk; pick up an object on the floor

(2) navigate from one named room to another

(3) bring an object from one room to another

(4) locate a particular human

(5) deliver the mail

While selecting the most appropriate set of performance milestones would require some additional study, it might be reasonable to expect that the tasks mentioned above could be performed by a robot device after about two years. The performance of such tasks would both demand and stimulate progress in planning and perception research.

We would probably work toward the achievement of these milestones by organizing our work into these major tasks:

(1) <u>Development of Intermediate Level Action Programs</u>
These programs will be the building blocks out of which the milestone tasks will be performed. They will include such basic abilities as picking up and setting down objects, navigating through doorways, communicating with humans, etc.

(2) Development of the Perception Programs

These programs will enable the robot system to orient itself visually, find objects, and check to see that various subtasks have been performed correctly.

(3) Development of the Planning and Execution System

This system will handle I/O between the robot and the experimenter and will decide how to perform a task, develop a plan for doing so and be responsible for carrying out the plan.

All three of these major tasks will be carried out in close collaboration with each other because of the high degree of interdependence between them. Each of the major tasks would require the development of a large knowledge base about the domain.

REFERENCES

1. R. E. Fikes and N. J. Nilsson, "STRIPS: A New Approach to the Application of Theorem Proving to Problem Solving," Artificial Intelligence, Vol. 2, No. 3/4, pp. 189-208 (Winter 1971).

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3. B. Raphael et al., "Research and Applications--Artificial Intelligence," Final Report, Contract NASW-2164, Stanford Research Institute, Menlo Park, California (December 1971).

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COST ESTIMATE FOR FIRST YEAR

Personnel Costs		
Project Supervision, 50 man-hours at [redacted]	$ [redacted]	
Senior Professional, 800 man-hours at [redacted]	[redacted]	
Professional, 750 man-hours at $[redacted]	[redacted]	
Technical, 750 man-hours at $[redacted]	[redacted]	
Clerical, 75 man-hours at $[redacted]	[redacted]	
Total Direct Labor	[redacted]	
Payroll Burden at 26%*	[redacted]	
Total Salaries and Wages	[redacted]	
Overhead at 105% of Salaries and Wages*	[redacted]	
Total Personnel Costs		[redacted]
Direct Costs		
Domestic Travel	$ [redacted]	
Materials and Supplies (see itemization in Table 1)	[redacted]	
Communications	[redacted]	
Report Production	[redacted]	
Total Direct Costs		[redacted]
Total Estimated Cost		[redacted]

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*Based on projected 1973 budget data, higher overhead and payroll burden rates were formerly negotiated. However, these have been adjusted downward (with the concurrence of the Resident Government Auditor) to reflect more favorable cost experience through the first six accounting periods.

Rather than setting forth these specific rates, it is requested that contracts provide for reimbursement at billing rates acceptable to the Contracting Officer, subject to retroactive adjustment to fixed rates negotiated on the basis of historical cost data. Included in payroll burden are such costs as vacation, holiday and sick leave pay, social security taxes, and contributions to employee benefit plans.

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COST ESTIMATE FOR SECOND YEAR

Personnel Costs		
Project Supervision, 50 man-hours at [redacted]	$ [redacted]	
Senior Professional, 800 man-hours at [redacted]	[redacted]	
Professional, 750 man-hours at [redacted]	[redacted]	
Technical, 750 man-hours at [redacted]	[redacted]	
Clerical, 75 man-hours at [redacted]	[redacted]	
Total Direct Labor	[redacted]	
Payroll Burden at 26%*	[redacted]	
Total Salaries and Wages	[redacted]	
Overhead at 105% of Salaries and Wages*	[redacted]	
Total Personnel Costs		[redacted]
Direct Costs		
Domestic Travel	[redacted]	
Materials and Supplies (see itemization in Table 2)	[redacted]	
Communications	[redacted]	
Report Production	[redacted]	
Total Direct Costs		[redacted]
Total Estimated Cost		[redacted]

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*Based on projected 1973 budget data, higher overhead and payroll burden rates were formerly negotiated. However, these have been adjusted downward (with the concurrence of the Resident Government Auditor) to reflect more favorable cost experience through the first six accounting periods.

Rather than setting forth these specific rates, it is requested that contracts provide for reimbursement at billing rates acceptable to the Contracting Officer, subject to retroactive adjustment to fixed rates negotiated on the basis of historical cost data. Included in payroll burden are such costs as vacation, holiday and sick leave pay, social security taxes, and contributions to employee benefit plans.