FEDERAL PROGRAMS IN ARTIFICIAL INTELLIGENCE

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INTRODUCTION

Recent rapid advances in electronics and computer technology has greatly increased the potential for practially implementing applications of machine, or artificial, intelligence (A.I.) techniques. In this article we will briefly highlight some of the government research efforts in A.I. The purpose of this research is to provide the technology to reduce costs, fill gaps in current capabilities, provide new capabilities and increase productivity. Though several government organizations fund research in some common A.I. areas, the research is oriented toward organizational objectives, with the results tending to be mutually supportive and complementary rather than duplicative.

NASA'S RESEARCH PROGRAM IN AUTOMATED OPERATIONS

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The advent of the NASA Space Shuttle is opening a new era in space. A era where ready low-cost access to space makes possible large space-structures, and the beginning of space industrialization, increased global information services, and enhanced scientific exploration of the universe.

In the early 80's, it is estimated that roughly 85% of NASA's space program will be spent for other than transportation. Thus, NASA must look elsewhere besides propulsion if further substantial cost reductions are to be achieved.

Increasing the level of autonomy of space operations appears to be one approach to yielding large cost reductions. The Jet Propulsion Laboratory estimates that approximately one third of the cost of missions is associated with ground support operations. Thus, reductions in mission operation system development and operations costs can play a major role in reducing costs of space missions.

One way of characterizing the increasing autonomy desired is in terms of operations per command as shown in Figure 1. Some of the operations expected to be automated are indicated in Figure 2. Potential increased capability gains to be derived from increasing autonomy in the space program have been estimated in the

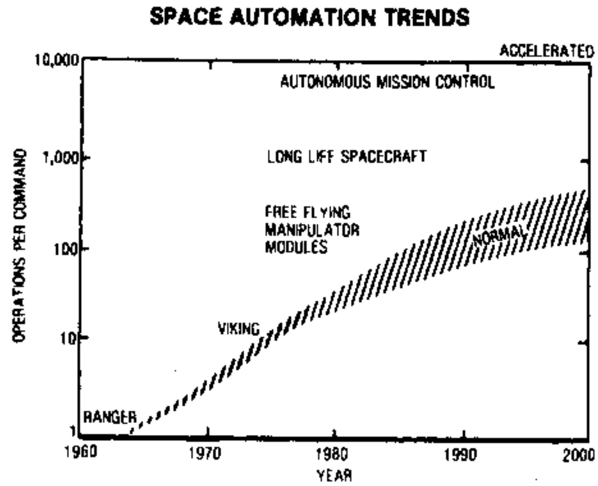

Figure 1

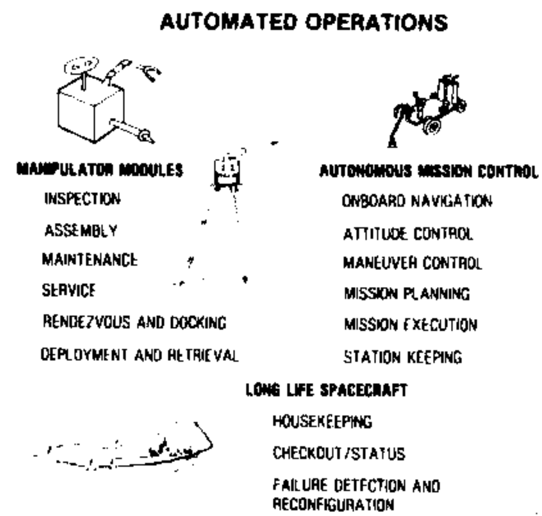

Figure 2

billions of dollars per year by 1990 as indicated in Figure 3. This figure does not include additional potential benefits such as can be achieved by on-board data processing.

Robotics and machine intelligence research at NASA draws upon automation, robotic and artificial intelligence techniques to reduce ground support requirements, provide real time control, new mission opportunities, and improved reliability and performance in support of space exploration, space assembly, automation of manufacturing facilities, launch and Earth

POTENTIAL BENEFITS ASSOCIATED WITH INCREASING AUTONOMOUS OPERATIONS

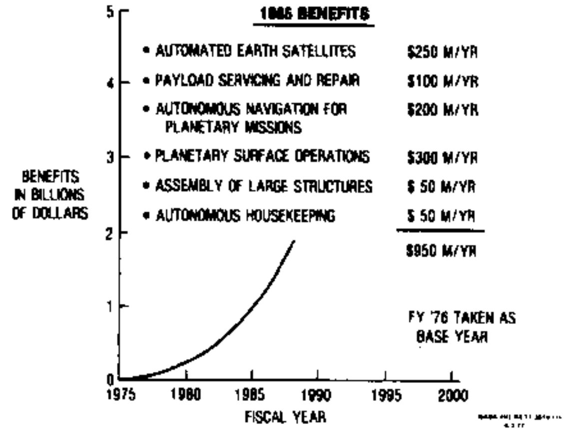

Figure 3

orbital operations, and remote operations of systems in hostile environments.

At the present time humans exercise direct control over nearly all decisions required by spacecraft or space experiments as well as those decisions associated with data handling and data processing. To do this requires extensive communications, ground support equipment, computer facilities, data processing equipment, and support personnel. All these items become expensive for extended missions or for extensive data collection and processing. In addition, due to communication time lags and the time needed to process information and verify decisions on the ground, the benefits which can be derived from real time operations at the spacecraft are often lost.

We are now entering the era, due to advances in computers, sensors and robotic algorithms where the increasing substitution of autonomous operations can yield large cost savings and increased mission return benefits.

The goal is to contribute toward a factor of ten reduction in ground-support costs, substantially reduce spacecraft system costs, and increase mission information return by a factor of 1000. Increasing spacecraft autonomy by automating onboard mission planning and modification will help contribute to this goal. Examples of applications are: self-checkout, test and repair; onboard data evaluation; semiautonomous spacecraft experiment control; supervisory teleoperator and semi-autonomous rover systems for planetary exploration and sample collection, evaluation and return.

Research in robotics/machine intelligence is performed principally at NASA's Jet Propulsion Laboratory with assistance from industry and universities supported by a HQ grant program. The program has two major facets. Theoretical studies are being conducted in university and industrial laboratories to complement those at JPL and to expand the machine approximation of human cognitive processes. At JPL, a robot demonstration program (Figure 4)

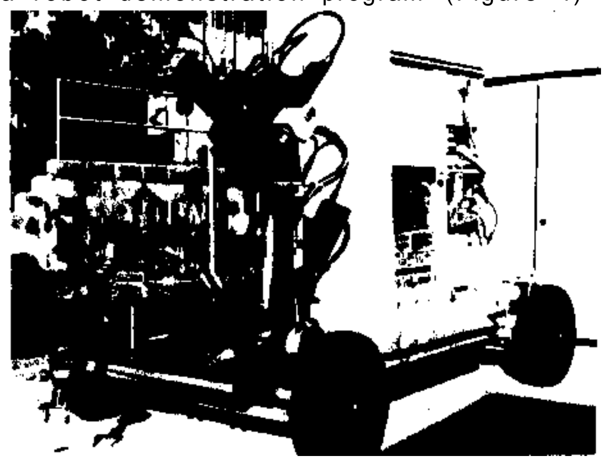

Figure 4, INTEGRAGED ROBOT TEST FACILITY

is being pursued to provide practical tests and evaluations of machine intelligence concepts, define research requirements and develop and demonstrate system applications. JPL is also currently focusing on (1) determining space program operations that can substantially benefit from the application of artificial intelligence technology (2) determining the appropriate application of this technology to these operations and (3) working with potential users to demonstrate the feasibility of these techniques to the level where they can be considered for future missions.

Under technical monitorship from JPL engineers, NASA Headquarters sponsors several research grants and contracts with major centers of artificial intelligence research. Currently, emphasis is centered on the development of programming theory for automated problem solving at the University of Maryland that makes more effective use of computer capacity; the use of scene analysis techniques at the Stanford Research Institute to automate a class of tasks involving the continuous monitoring or tracking of predefined targets; research in artificial intelligence at M.I.T. aimed at providing a better understanding of the computational aspects of cognitive process, and in designing machines that will automate such processes; research and hardware demonstration at R.P.I, on data acquisition and path selection decision making for an autonomous roving vehicle (Figure 5); and research

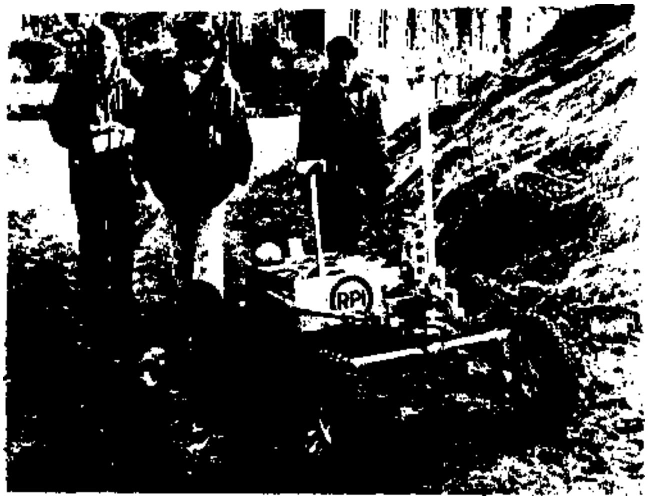

Figure 5, RPI ROVER

and demonstration at Stanford University of computer visual systems for exploratory vehicles.

Tentative targets for the Robotics/Machine intelligence research objective are:

- o Complete a study of potential applications of existing DOD and commercial automation technology to NASA operations by FY 1978.
- o Demonstrate autonomous roving vehicles capable of maintaining average speeds of 2 km/hr., or greater, on natural terrain, using onboard sensors and computing systems to perform the functions of navigation and guidance, including detecting and avoiding terrain hazards by FY 1979.
- o Complete conceptual designs for supervisory and semiautonomous control of teleoperators and experiments that will reduce performance time by a factor of five by FY 1979.
- o Demonstrate algorithms capable of extracting and characterizing, in one second, sets of high-level image features needed for selected robot or image - analysis functions by FY 1980.
- o Demonstrate, using the JPL integrated robotic test facility, supervisory teleoperator control providing a factor of 10 reduction in time, compared to direct manned operation, for structural assembly by FY 1980.

Current NASA funding in basic artificial intelligence and robotics research is approximately one million dollars per year, but is expected to increase in the coming years. In addition, there is funding for anticipated missions such as the 1984 Mars Rover mission.

During CY 1977 several workshops will be held between NASA and the A.I. community to increase their synergistic interaction in promoting NASA's goals in increasing autonomous operations.

NSF'S RESEARCH PROGRAMS RELATED TO ARTIFICIAL INTELLIGENCE

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Introduction

In the National Science Foundation, the three (3) programs which support the most Artificial Intelligence related research are the Intelligent Systems Program of the Division of Mathematical and Computer Sciences, the Automation, Bioengineering and Sensing Systems Program of the Division of Engineering and the Production Research and Technology Program of the Division of Advanced Productivity Research and Technology. As indicated by the titles of the programs, the interests of the Foundation range from basic research in computer and engineering sciences to fundamental problem oriented research addressed to the manufacturing process.

In evaluating proposals submitted to these programs, the Foundation makes extensive use of mail review by peers who help judge the scientific interest and technical integrity of the proposed research. Since intrinsic scientific merit is the primary criterion applied in selecting proposals for support, a clear definition of research objectives, as distinguishedfrom project or implementation objectives, is required. System building will be considered for support only to the extent necessary for the study of significant research questions. On the other hand, we are glad to consider research proposals to complement support from other agencies so as to provide more opportunity for studying basic research questions using systems which have been or are being developed primarily for other purposes. Typical grants in these programs range from $40,000/year to $100,000/year in amount. Most grants are for two years although longer or shorter commitments are made when appropriate.

Intelligent Systems Program

The Intelligent Systems Program is briefly described as follows:

"This program is directed toward research on computer-based systems which have some of the characteristics of intelligence. Relevant areas include pattern recognition, pattern generation, knowledge representation, problem solving, natural language understanding, theorem proving, and others which relate to the automatic analysis and handling of complex tasks."

It is one of six programs supporting basic research in computer science, the others being Theoretical Computer Science, Software Systems Science, Software Engineering, Computer Systems Design, and Special Projects. Some representative grants from this program are:

1. Molgen: A Computer Science Application to Molecular Genetics

   The general goal of this research is to develop a computer system (MOLGEN) to assist a molecular geneticist in planning laboratory experiments. The system is to be interactive, drawing on both the expertise of the human geneticist and the expert knowledge stored in the data base. In addition to the knowledge base, the major components of the computer system will be an experimental planning program, an enzyme simulation program, and DNA structure entry and editing system. Extensive use of heuristic and other "reasoning" strategies at decision points in the programs make this a research project in intelligent systems.

2. Curvature and Convexity in Scene Analysis Problems

   This study will investigate the interrelationships that exist among various parameters of surfaces in scenes and how they affect the information that is recorded in pictures of these surfaces. Special attention will be focused on the effects of surface curvature and convexity (or concavity) and the mutual interactions of these parameters and those that are associated with the direction of the illumination, the orientation of the surface and its texture and light reflecting characteristies.

3. Techniques for the Representation of Movement-Related Information Using a Digital Computer

   The long-range goal of this project is computer recognition and description of patterns of human movement. As a step toward that goal, research is being conducted on a computationally suitable notational system to serve as a low-level language for description of human movement. The notational system is event-oriented, rather than time-interval oriented, and the events themselves are primarily symbolic, rather than numeric; that is, significant events are indicated by changes in sematic relations rather than in numerical quantities. A related focus is the design and implementation of data and control structures appropriate to the description and manipulation of information related to human movement which may then provide a basis for an appropriate low-level programming language.

<u>Automation, Bioengineering and Sensing Systems Program</u>

The Automation, Bioengineering and Sensing Systems Program supports research in the engineering sciences related to the general area of machine decision and control. Although this subset of the program is referred to as advanced automation, the research overlaps into topics generally thought of as artificial intelligence. Technical areas include sensing systems, imaging systems to generate or enhance vision of pictures, pattern recognition and processing, feature extraction, learning systems, feedback decision and control, and robotics and manipulator research. The objective is to develop fundamental knowledge concerning the techniques inherent in automated machine decision making independent of the problem domain. Therefore, the Automation, Bioengineering and Sensing Systems Program is driven by the engineering science involved and not by any specific problem or goal and the individual projects span a wide range of investigations.

In sensing systems research, areas of investigation include physical or chemical sensors, laser ranging, electromagnetic or acoustical probing of physical or biological systems, and nuclear imaging. Holography, ultrasonic, optical, and other imaging techniques are studied both experimentally and theoretically in various problem domains. Pattern recognition and processing is a major portion of the advanced automation area, with emphasis on scene analysis by means of motion, color, texture or other parameters, and applications of syntactic pattern recognition methods. In the case of robotics or manipulator research, primary interest lies in the automatic coordination of joint motion under computer control, utilizing feedback techniques. Although these investigations have applicability to industrial manipulators, prosthetic devices, legged locomotion, muscle-skeleton problems and others, the research concentrates on the basic understanding of the mechanisms of joint motion and feedback control and utilizes computer simulation, kinematic models, and experimental techniques. Investigators supported by the Automation, Bioengineering and Sensing Systems Program perform theoretical and experimental research, computer modeling and simulation, and studies of the complete system.

Some representative grants from this program are:

1. Use of Range and Trispectral Reflectance Data in Scene Analysis

   This research focuses on the use of registered trispectral reflectance and range data of different indoor scenes, developing procedures for extracting geometrical and visual features to recognition of three-dimensional objectives by a high-level computer program with some knowledge of the environment. Specifically, the program will seek to establish geometrical and reflectance models for objectives with different shape, size, and surface spectral reflectance. Feature ex*-traction will be accomplished by applying the registered range and reflectance data to objects with planar and nonplanar surfaces.

2. Research on Space-Variant Optical Computers

   This program of research on space-variant optical computers involves two major phases. The primary effort during this first year will be aimed at optical techniques for performing coordinate transformations. This will include specifically: An investigation of the capabilities and limitations of the methods conceived of by Bryngdahl; a search for alternative methods using computer generated holograms but not subject to severe space-bandwidth product limitations of the curved-input-output-surface method; a search for new optical methods of any kind for performing space-variant linear filtering; and development of experimental experience with the known methods. The second phase of the program will be devoted to space-variant optical filtering of various kinds of data.

3. Theory of Pattern Processing Using New Charge-Coupled Device Architectures

   The central objective of this research is to establish pattern processing theory for charge coupled device processor architecture to be used in advanced automation. This can be divided into more specific objectives that include devising fundamental architectures for CCD and microprocessor-based advanced automation systems, establishing signal processing algorithms that are best suited for decision and control in such architectures, studies of unique signal processing possibilities such as registration, dilation, illumination variation and ranging, and verification of results (to the extent possible) using existing experimental systems. The approach will emphasize general solutions so as to have broad applicability.

Production Research and Technology Program

The Production Research and Technology Program's purview is the production system, i.e., the way goods are manufactured and produced. It is concerned with research on the technical problems which underlie both the physical transformations of objects and the informational transformations necessary to understand, model, control and carry out manufacturing operations. The program recognizes that major modifications in manufacturing leading to quantum jumps in productivity would be hastened if such a science base could be established and applied.

The first industrial revolution involved the transfer of skills from man to machine and much has been accomplished in this area. The second industrial revolution, which is in its infancy, involves the transfer of intelligence from man to machine. The Production Research and Technology Program is concerned with identifying and understanding those research problems whose solution is necessary to accomplish this transfer of intelligence from man to machine in the area of manufacturing.

The program's objectives include:

- o Promotion of problem-oriented research in bottleneck areas, where modest research investments can have high leverage in improving productivity.
- o Promotion of more fundamental, but still problem-oriented, research aimed at establishing a science base for manufacturing.
- o Revitalization of the industry/university collaboration that flourished prior to the late 1950's and 1960's.

Researchers include physicists, applied mathematicians, materials scientists, computer scientists (artificial intelligence researchers), and engineers (aerospace, mechanical, electrical and industrial).

Some representative grants from this program are:

1. Computer Integrated Assembly Systems

   The objective of this research is to make manipulation and vision systems for assembly and inspection more versatile and easier to use. There are four major areas of research. Manipulator Programming System: Previous research results will be used to complete a system which is a model for practical industrial systems. That system will be used as a research tool to develop language facilities for programming tasks involving several sensor equipped manipulators. The feasibility of a standard system for use by other labs will be evaluated. Analysis of Assembly: The programming of assembly examples solicited from industry will be studied. Common subtasks and subtask library will be identified. Assembly system and parts will be modeled functionally. Interactive Training System-for Assembly Programming: A simple interactive training system will be implemented which combines "teach mode" manipulator programming with simple symbolic commands and a library of models of parts. Relatively few positions will need to be specified because of position calculations from part models. A simple means of model building has been provided. Results of the analysis of assembly will be utilized in the form of a library of models. Inspection and Vision Programming Systems: An analysis of inspection tasks will be made to classify what information is necessary for programming inspection. In particular, an investigation will be made of dimensional inspection to determine what can be automated to aid programming. Unoriented parts in a box will be located and separated visually for grasping by a manipulator. The Vision Language will be used in picking parts, and will be extended to include parts models for that task and to represent the information found important in the analysis of inspection. A simple programming system for vision in assembly will be completed.

2. Machine Intelligence Research Applied to Industrial Automation

   The objectives of this proposed program are to devise and implement an advanced programmable/adaptable automation system with applicability to large important classes of material handling, inspection, and assembly processes for batch-production discrete part manufactured products. Two groups of tasks are planned: The major group includes goal-oriented research into advanced vision and maniputation techniques aimed at significantly extending the adaptive capabilities of industrial robots and providing simplified programming capabilities for automated visual inspection. The second group of tasks is to devise and implement software moduleB widely useful for computerized visual sensing, visual inspection and sensor controlled manipulation using standard hardware. These modules will reduce to practice past research results and make the research readily available to industry. Research to be pursued includes: development of minimally interactive methods to automatically generate computer programs for the visual inspection of parts and subassemblies by "training by showing;" use of solid state cameras to explore visual feedback of manipulators to positioning a robot and effector (hand) in real time; use of visual and tactile sensor feedback to accomplish precision manipulations; use of both range and intensity information requiring faster and more powerful image processing algorithms to apply to complex inspection problems to widen the utility of visual sensing.

3. General Methods to Enable Robots with "Vision" to Acquire, Orient and Transport Workpieces

   This research effort seeks to develop general methods by which computer-controlled robots using visual sensors can (1) acquire a workpiece (part) so that it may be brought to a fixture without a collision; (2) compute the orientation of a workpiece held in the robot hand; and (3) transport the workpiece to the fixture without collisions. The research is expected to result in new image processing techniques as well as kinematic equations for manipulators and robot system architecture which will enable a class of presently unsolvable industrial problems to be attacked.

   Planned activities include the following: Methods to acquire and orient workpieces with arbitrary resting states will be developed. Features which describe workpieces' orientation will be investigated. Some of these features will be based on a partial image of the workpiece and others on the complete image.

Features based on gray-scale pictures will be used when features based on binary pictures perform unsatisfactorily. Alternative methods to sample image data from different orientations during instruction will be examined. Graphs of image features versus orientation will be made. Procedures to make a decision about workpiece orientation will be developed which use multiple views of the workpiece. Obstacle avoidance techniques which employ a programmer's ability to specify a nominal workpiece trajectory using a switchbox will be tested. Experiments will be performed employing an accurate six-degree-of-freedom robot and a special fixture which houses dial gauges to measure orientation and position. A probabilistic model of the overall process will be formulated in an effort to decrease the average cycle time.

AUTOMATION AT THE NATIONAL BUREAU OF STANDARDS

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The objectives of the National Bureau of Standards program in Automation Technology are:

1. To provide standards for the interfaces between modular components of computer-aided manufacturing systems.

2. To provide standards for the languages used to program automation systems.

3. To provide performance measures for specification and procurement or robots and numerically controlled machine tools.

4. To carry out research in dynamic measurement and computer control techniques.

One of our most significant projects of the current year is our support to the Air Force in interface standards for their Integrated Computer Aided Manufacturing (ICAM) system. ICAM is envisioned as a set of application programs for design and manufacturing, integrated with simulation and other utility programs around a common data base. The Air Force plans to spend $75 million in 160 different contracts over the next 5 years to develop this software which must be both compatible and portable.

NBS has identified and evaluated 64 standards concerning the information transfer and data bases involved in the interfaces between the different applications programs, between the applications programs and the operating systems, the Data Base Management System, and the various terminals, peripheral devices, and satellite computers in a network system. Our recommendations on the use of these standards by the Air Force in this seminal project will influence the standards used by all manufacturing industry in the 1980's.

Our program plan for interface standards over the next 5 years is:

1. To develop guidelines for the specification of key interfaces for industrial robots, numerically controlled machine tools, and for robots and machine tool combinations.

2. To develop a formal Federal standard for these interfaces.

3. To continue to support the Air Force regarding Computer Aided Manufacturing standards related to the ICAM project.

In regard to our second program objectives, the development of language standards used in programming automation systems, we are currently engaged in finalizing a Federal standard on the APT programming language. This standard will allow all Federal installations to interchange their APT programs. The Navy estimates that this one standard will save the Government $3.8 million per year in reprogramming costs.

We will continue this work over the next five years with the publication of standard subsets and supersets of the APT language with validation procedures for testing APT compilers.

The third objective of our program is to develop performance measures for the specification, procurement, and evaluation of robots and NC tools.

We have developed a hierarchical classification system for different levels of robot control systems and will be providing consulting services to the Air Force on the development of advanced control systems for robots for building the F-16 aircraft. We plan to develop comprehensive performance test methods and evaluation techniques for robots by 1979 and techniques for evaluating dynamic performance of machine tools by 1980.

The fourth objective of our program is to carry out research in the technologies of computer control. Under this part of our program we have developed a control system modeled after the cerebellum, which is a part of the brain which computes the functions required for precise coordinated control of rapid movements of the limbs, hands, and eyes. This model called CMAC (Cerebellar Model Arithmetic Computer) was recognized by Industrial Research Magazine in its annual IR-100 competition as "one of the 100 most significant new technical products of year 1976." CMAC was considered important for a number of reasons:

First, it reduces a significant new neurophysiological theory to a mathematical formalism of sufficient precision to make possible scientific predictions of motor behavior.

Second, it is a new technique of computer memory management which makes practical the real time computation of a large class of important multivariant functions by table look-up. This class of functions includes those frequently encountered in the servo control of machine tools, robots, aerospace vehicles, and many industrial processes.

Third, it is a device which can be implemented with inexpensive microprocessor technology thereby making its use economical for a wide variety of control system applications.

Fourth, it is a device which can be interconnected in a hierarchical structure so as to generate sensory-interactive, adaptive, goal-directed behavior in autonomous systems. CMAC provides an entirely new approach to many significant problems in artificial intelligence, data base management, and large scale distributed computing systems.

The NBS Automation Technology Program is currently funded at $540K per year. This is expected to rise to $1.0 million in FY 78 and to about $3.0 by 1980. Of this funding approximately 20% is devoted to developing sensors and control technology.

OFFICE OF NAVAL RESEARCH PROGRAMS IN ARTIFICIAL INTELLIGENCE

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The Office of Naval Research supports two major research efforts in Artificial Intelligence: (1) large file systems and (2) maintenance automation.

I. Large File Systems

The non-numeric large file problem, most characteristic of civiliam and military logistics, management, financial, and personnel and data processing environments, is the problem area most poorly addressed by current computer technology. The requirement here, barely touched upon by research activity to the time of 1970, is the development of techniques to improve search and runtime efficiency; to design software which faces up to security issues in a highly interactive, network environment; to accomplish a major breakthrough by moving away from systems which produce calendar oriented, voluminous output; and to move vigorously toward the toal of real-time interaction between decision makers and stored data. In spite of almost twenty years of heralding the arrival of on-line computing, our current systems are largely batch oriented; output is voluminous and calendar directed; management by exception seldom occurs; there is very little direct, on-line manager interaction with computers. Large Data Base research activity, initiated by the Office of Naval Research in 1972, set out to develop a body of techniques for correcting these deficiencies.. Most important, the ONR program had the larger goal of moving computation from its current state of constituting a passive capability — all of that data sitting there in storage waiting to be asked questions which are seldom or never asked. The 1972 objective was to push strongly in the direction of activist systems which are capable of carrying on extensive English language dialogues, which have an automated capacity for comprehending relationships across data, for making inferences, for using that facility to take initiative, in real time, to alert managers to the impending occurrence of critical events. Knowledge systems used to anticipate and prevent crisis, not computers used to reconstruct the history of past disasters is the ultimate Large Data Base research objective. Large File System research has two major aspects; one being the design of software to facilitate the managerial data retrieval process; the other, being the creation of mechanisms to improve managerial — data base interaction. From the software design perspective, the program includes such elements as privacy and selective access control capabilities; procedures for automatic reconfiguration of files across storage media; the inclusion of smoothing algorithms to control the reconfiguration process; the routine creation of "utility files" containing summary data; data structuring to facilitate inferential search; the capability for providing statements on the accuracy or relevance of output; the incorporation of knowledge representation methodologies to create a context for interpreting the meanings of interrogations arriving from diverse sources. From the user perspective, the research includes real time interrogation; on-line modeling capabilities; a text reading, text summarization, and message prioritization capability; the development of a natural language front end to enable direct contact with computers by high level managers — this interaction ranging from "one liners" to sophisticated on-line browsing and simulation; building a capability for anticipating crisis situations through the setting and monitoring of automatic alarms or triggers.

II. Maintenance Automation

The increasing technological complexity of naval weapons systems, coupled with anticipated shortages of required manpower skills and rising repair costs, underscore the inevitability of an impending difficult situation in Fleet maintenance. Automation of Navy maintenance activities is proposed, not as a substitute for, but as a necessary adjunct to solving the problem by increasing the manpower supply, or improving the fundamental reliability of weapons.

Research objectives include:

a. Automating the processes of equipment failure diagnosis and repair, including: (1) Use of the computer as an "expert consultant" to the technician in performing general diagnosis and repair. (2) Developing fully automated diagnostics and repair capabilities for selected equipment areas. (3) Exploring possibilities of computer assisted jury rig advice for classes of malfunctions. (4) Where feasible, developing automated procedures for initiating/accomplishing jury rig solutions.

b. Automating the function of manufacturing required for unavailable spare parts, including: (1) Development of automated, onboard manufacturing capabilities. Possibilities range from use of numerically controlled machines to design of A.I. procedures for one-of-a-kind production. (2) Consideration of stocking rough finished (general utility) modules which, with A.I. manufacturing, can be tailored to a unique end item need.

c. The design of A.I. procedures for automating the function of testing for deterioration, damage, or miscalibration of on-the-shelf stocked items.

d. Mechanizing the function of equipment condition monitoring; the interest being that of automatic alarm ringing when pre-established threshold conditions are breached.

e. The exploitation of A.I. viewing and manipulation capabilities to reduce both damage and manpower requirements for onboard ship materials handling and movement.

f. Design of generalized, automated devices for accomplishing manpower intensive shipboard housekeeping functions.

g. The design of A.I. knowledge base, process modelling capabilities to schedule and monitor the totality of maintenance activities relevant to operating embarked carrier squadrons.

The field of Artificial Intelligence has produced fundamental results in the areas of machine conceptualizing, machine vision, and manipulation; these results are so promising as to indicate the advisability of a large investment to test the appropriateness/feasibility of these techniques for addressing the issues described above. Very recent results demonstrated the utility of A.I. algorithms for: (1) Understanding and responding to natural language questions on the wiring intricacies of a complex circuit design, and (2) automatic recognition and underscoring of circuit malfunctions, and (3) automated guidance to technicians on accomplishing the repair.

ARTIFICIAL INTELLIGENCE R&D AT THE NAVAL RESEARCH LABORATORY

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The need for A.I. technology is increasing rapidly in the Department of Defense in general and the Navy in particular. While the nature of the Navy's responsibilities becomes more difficult and the equipment becomes more sophisticated almost daily, the ability of the Navy to fulfill its missions has not fully kept pace. There are a number of reasons for this, the most significant of which are:

1. The people in the military are costly and yet mostly unskilled. The amount of the military budget spent on personnel has increased to 60%, and is likely to increase further with the continuation of the all volunteer military, yet due to some of the disadvantages of military service, it is difficult to draw and keep sufficient skilled labor to operate, maintain, and repair the widespread sophisticated equipment.

2. The training of people to handle and repair sophisticated military equipment is very expensive. Once trained, many military people can obtain substantially higher salaries in private enterprise and therefore often leave before the military has fully recovered the costs of their training.

3. Machines can operate in environments hostile to people, for example, under fire or in extreme climates or, for certain Navy applications, under water.

4. Successful operation of the modern military complex requires effective, efficient, and rapid command and control of a large complex of people and equipment. However, the systems for command and control have

not fully kept pace with the rapid advances in the equipment being commanded and controlled.

5. Skilled humans can still far outperform computers in many aspects of processing tasks, such as those associated with noisy signals from radar, radio, and acoustic equipment. Many other tasks such as the handling of day to day reports and mounds of paperwork can be more effectively handled by computers. It is therefore important that useful and trustworthy systems be made available to free military personnel for those tasks for which humans are best suited.

While it is true that the cost of computer software, expecially A.I. type software, is rising rapidly, the potential benefits from successful A.I. techniques far outweigh the initial costs.

The A.I. R&D at NRL is essentially concentrated in the Computer Science Laboratory in the Communications Sciences Division. The three full-time senior computer scientists have published more than fifty refereed journal articles and a book (Slagle, 1971). These publications have been in Computer Science in general with the main thrust in A.I. encompassing automatic clustering, pattern recognition, deduction, heuristic search, symbol manipulation, and intelligent knowledge base management. The current (Fiscal 1977) budget is $200,000. Next year, it is expected to exceed $300,000, a portion of which will go to outside contractors at universities, etc. Current project areas of interest, ordered by increasing funding level, are automatic speech compression, robotics, intelligent knowledge-based management systems, and clustering and pattern recognition. These projects will now be discussed.

The objective of the speech compression project is to develop a technique to enable low bit rate speech communication with minimum loss of quality. The main Navy application is to intersubmarine communication. The approach in this laboratory has been based on the use of alophones-small identifiable segments of speech similar to but more numerous than phonemes. If speech can be represented by a manageable number of alophones and be fully reconstructable, then the amount of data required to transmit the speech can be greatly reduced. Using digitized speech in the form of linear predictive coding (LPC) coefficients, we are applying cluster analysis techniques to determine candidate sets of alophones for vowel sounds in English.

The purpose of the robotics project is to investigate the feasibility of employing a mechanical arm for automated underwater tasks on an unmanned, free swimming vehicle. Techniques are being developed for the accomplishment of useful tasks without the use of television images or large complements of computers. Viable types of sensory feedback, dynamically alterable planning strategies, and information representations must be developed for this program to succeed. As an initial experimental tool for this research, we have acquired a model "MIT Robot Arm" such as the one shown in Figure 6. We will acquire, design and build sensors as needed.

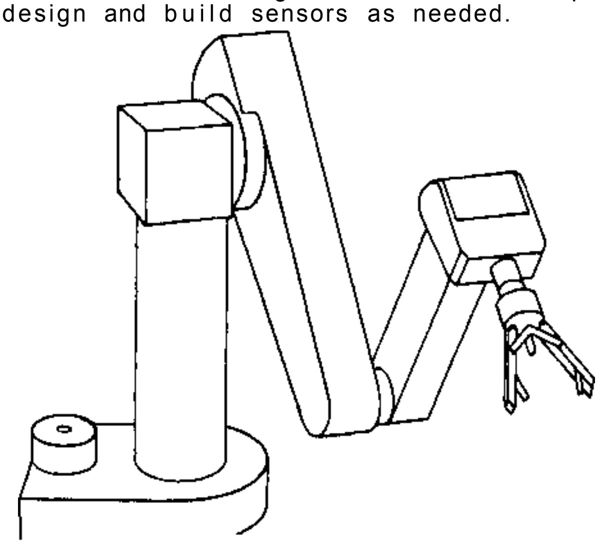

Figure 6, MODEL MIT ROBOT ARM

We are developing an intelligent knowledge-base management system with the following capabilities:

1. Ability to handle very large knowledge bases (order of a billion or more bits).

2. Ability to do both explicit and implicit (inferential) question answering.

3. Compact information representation.

4. Utilizes semantic (domain specific) information for both better control of the knowledge base search and inference processes and to assist in maintaining knowledge base integrity.

We are now in the process of "bringing up" the first version of the System for Parallel Representation of Knowledge (SPARK) on the DEC-10 Computer System at NRL. Experiments employing realistic Navy knowledge bases will be performed with the system to determine its utility and benefits.

We are investigating automatic clustering and pattern recognition from a basic research and applied point of view. Our main application is emission identification - the process of identifying unfriendly planes, ships, etc. by means of the passive acquisition of data such as their radar and radio signals. The objective of the automatic emission identification project is to employ clustering*and pattern recognition techniques to automate the process of identification of objects by class (that is to identify ships, for example, by their type but not by name) using data collected from a variety of remote sensing devices.

Reference

J. Slagle: Artificial Intelligence: The Heuristic Programming Approach, McGraw-Hill Book Co., New York, 1971. (ALSO available in German and Japanese translations.)

* Clustering is a procedure that assigns samples to sets called clusters in such a way that:

1. The members of a cluster are similar to one another.

2. The members of different clusters are dissimilar.

A sample is a list of parameters (features) for example, (THIN, BLUE, TALL) or (1.0, 2.5, 3.1, -1.0, -11.7, 10.5, 5.0) or (BROWN, 140, BLUE, 67, 36). Clustering may be used to get direct insight into the data (for example, taxonomy) or as a first step to automatic pattern recognition. It may be applied to many kinds of data, for example, emissions, personnel, chemicals, and ships.

ARTIFICIAL INTELLIGENCE RESEARCH FUNDED BY THE ADVANCED RESEARCH PROJECTS AGENCY

W. Gevarter

ARPA funds A.I. research in the areas of:

1. Natural Language
2. Knowledge-based Inferential Reasoning Systems
3. Computer Vision Systems

This research is largely university based.

1. Natural Language

In this area ARPA funds:

a. Story-understanding research
b. Better man-machine dialogue interaction research

2. Knowledge Based Reasoning Systems

Research in this area includes work on production rule formalisms (rule-based systems). Production systems they have helped support include MYCIN (a diagnostic system for identifying bacteria blood infections and antibody prescription) and DENDRAL (a qualitative chemical analyses system using mass spectronomy). Research continues on inference-based systems that can do reasoning and are self-documenting (indicating how results were obtained). Interest is also evolving on learning, whereby the computer can acquire its own models and rules empirically.

3. Computer Vision_Systerns

Research in this area is centered on trying to develop automatic recognition and extraction of features from scenes.