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Research and Development Program Plan for the Center for Engineering Systems Advanced Research (CESAR)

C. R. Weisbin
J. Barhen
W. R. Hamel

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ORNL/TM-10232
CESAR-86/47

Engineering Physics and Mathematics Division

RESEARCH AND DEVELOPMENT PROGRAM PLAN FOR THE CENTER FOR ENGINEERING SYSTEMS ADVANCED RESEARCH (CESAR)

C. R. Weisbin, J. Barhen and W. R. Hamel*

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ABSTRACT

This document is the second issue of the Research and Development Plan for the Center for Engineering Systems Advanced Research (CESAR) at the Oak Ridge National Laboratory. The document is intended to provide a general framework for more detailed planning on an annual basis, both for DOE and for other sponsoring organizations. The charter for the overall intelligent machine research effort is presented along with programmatic and technological goals. A research implementation plan is provided through the FY 1989 horizon.

RESEARCH AND DEVELOPMENT PROGRAM PLAN FOR THE CENTER FOR ENGINEERING SYSTEMS ADVANCED RESEARCH (CESAR)

I. INTRODUCTION AND BACKGROUND

For a few years prior to 1984, there had been a growing awareness and belief that automation related technologies and intelligent machines should play an increasing role in Department of Energy programs. This trend was stimulated by a number of technical studies and conferences which concluded that automation technology can, to a large degree, increase the productivity and safety in the development and operation of DOE sponsored systems. Therefore, DOE management decided in FY'84 to initiate a research program to extend the body of knowledge underlying current engineering practice and satisfy perceived future requirements in the area of intelligent machine research. In support of these DOE objectives and of requirements by other sponsoring organizations, the Oak Ridge National Laboratory established the Center for Engineering Systems Advanced Research (CESAR) for the purpose of addressing fundamental problems of intelligent machine technologies.

A. Purpose and Objectives

The purpose of this document is to provide a framework and guidelines for research and development within ORNL's CESAR program in areas pertaining to intelligent machines. The specific objective is to present a CESAR Research and Development Plan for such work with a planning horizon of five to ten years, i.e., FY 1986 to FY 1990 and beyond. As much as possible, the plan is based on anticipated DOE needs in the area of productivity increase and safety to the end of this century.

B. Characteristics of Intelligent Machines

Intelligent machines, as envisioned in this plan, are artificially created operational systems which have capabilities of autonomous decision making and action. These capabilities are derived from their ability to reason based on acquired information and to learn from experience. Intelligent machines are able to govern themselves in accomplishing given objectives, as they manage their own resources and maintain their integrity. At the highest level of abstraction an operating intelligent machine consists of three elements.

1. Sensory System - The sensory system acquires data and information about the internal state of the intelligent machine, about its environment, and about its relationship to its environment.

2. Control Computer System - Based on newly acquired data through sensory input and/or a database (knowledge base) search, the control computer system assesses the current state of the intelligent machine system with respect to the desired goal state,

continuously updates the database and existing plans, and performs a planning process which results in a set of decisions for immediate and/or future actions, for control and for recovery from errors and faults.

3. Actuator System - The implementation of the decisions prepared by the control computer system is carried out by the actuator system, resulting in sensible and measurable effects within prescribed and controlled operational limits.

The ultimate setting of goals for, and supervision of, intelligent machines is done by humans. For simple systems this may be done directly by setting a switch or the like. For complex systems, such as an autonomous robot vehicle, the goal setting and supervision may be done by a team of operators with the help of an off-line or integrated computer system. The human operator(s) together with the supporting computer system and other peripheral equipment are collectively referred to as the "supervisory system." In general, one is dealing with a hierarchy of intelligent machines, where the higher level (echelon) elements are the supervisors of collections of elements at the next lower level. By extension, at the highest level in the hierarchy is (are) the human operator(s).

II. SCOPE OF THIS PLAN

The long-range research and development program of CESAR is shaped and directed primarily by prioritized research and available resources. The technical scope of this plan comprises not only the intelligent machine systems with various hierarchical levels, but also the automation of the corresponding supervisory systems, including the behavior of humans within man-machine systems. It also includes those aspects of related systems engineering, systems design and plant management that can be automated. "Peripheral technologies," such as data processing, power, propulsion, materials, structures, etc., are of concern here only to the extent to which they influence the operation of automated and intelligent machines.

The technology areas selected for research are oriented along lines of perceived requirements for two operational focuses of roughly equal priority, and which provide technical context relevant to the energy industry. The first focus for the development of intelligent machines is "robotic systems for identification, navigation and manipulation in unstructured environments." The concept "robotic system" is interpreted as a system consisting of a remote part and a proximal part, the latter serves as the supervisory system and includes the human operator(s). Applications include work in toxic, radioactive or physically uncomfortable situations such as those for nuclear plant emergencies, off-shore oil exploration, gas exploration, etc. These situations are particularly unique and central to the mission of DOE. To minimize risk to humans and to assure reliable performance in remote environments, there is a clear need for the expansion of the sciences and technology which would permit the exploitation of the capabilities of intelligent machines. The second

focus for the development of intelligent machines is "multi-purpose plant management and maintenance," where plant means an energy producing facility. The intelligent aspects include simulation, control, design, training, diagnosis, planning, repair and replacement. This system would have a design support subsystem allowing people to design plants, augment their models with feedback, perform simulations to evaluate alternative plant designs, diagnose problems that arise in operation, and set up training for people who are supposed to run the plant. The control portion of this system would utilize results of faster-than-real-time simulations to guide an actual running system which has to deal with real time operations. There would be automatic monitoring of instrumentation so that the system checks its behavior against expectations and audit trails of all control activities taken by the personnel. Faults occurring in the system would be analyzed and diagnosed. Based on such diagnoses, strategies and plans would be prepared for corrective action and would be implemented automatically or with the help of human supervision.

III. THE CESAR PERSPECTIVE AND ROLE

A. The DOE/ORNL Context

ORNL is a multipurpose laboratory primarily working on energy problems under the auspices of the U.S. Department of Energy. ORNL is operated by Martin Marietta Energy Systems; the technical program is determined by agreements established between ORNL and DOE with concurrence of the Oak Ridge Operations Office and Martin Marietta Energy Systems.

ORNL is a world leader in the development and use of remote operations and handling techniques in hostile environments; the Laboratory has many years of experience in this area. Building on this know-how and strong analytical capability, ORNL developed a research proposal to DOE in the area of "intelligent control systems," which has emerged as part of the Engineering Research Program of the Engineering and Geosciences Division of the Office of Basic Energy Sciences. A peer review committee was formed, and a steering committee (subsequently transformed into a permanent advisory committee) was appointed. In addition, a DOE/ORNL Workshop on Research Goals and Priorities in Intelligent Machines was held on November 2-4, 1983, (Ref. 1). The outcome of these activities has been the formation of the Center for Engineering Systems Advanced Research (CESAR). In addition to the CESAR Advisory Committee meetings, periodic reviews are held for the DOE Council on Energy Engineering Research.

B. The CESAR Charter

The Center for Engineering Systems Advanced Research (CESAR) is established at the Oak Ridge National Laboratory (ORNL) to address long-range energy-related research in intelligent control systems. These systems are intended to plan and perform a variety of tasks in unstructured environments,

given only qualitatively specified goals. Building upon extensive experience in remote operations and human engineering, the Center provides a framework for merging concepts from the fields of artificial and machine intelligence with advanced control theory. Emphasis is on interdisciplinary research for large-scale distributed processes applicable to many energy-related technologies. Research objectives stress the optimization of energy efficiency and the minimization of associated risks in its production and utilization. Potential applications include emergency situations, remote operations, resource exploration, transportation systems, and large-scale power generation systems.

CESAR is intended to be a national resource, and a major objective is to disseminate its accomplishments freely and comprehensively. Accordingly, results and technology are distributed through refereed journal publications, through the organization of specialists' workshops, and through the development of products which demonstrate concepts. CESAR cooperates with universities, laboratories, and industry, serving as a user facility to provide guests with access to modern computers, unique equipment, and a stimulating scientific environment.

C. Technical Discipline Areas of CESAR R&D

Within the scope of the CESAR Charter, various research elements are aggregated along disciplinary lines for program planning. The selected disciplines are those identified in the DOE/ORNL "Final Report on Research Goals and Priorities in Intelligent Machines," by the CESAR Steering Committee (Ref. 2). For each discipline its definition, evolution, importance to intelligent machines, and division into sub-disciplines are described. In addition, the nature and importance of research are discussed in relation to the energy industry and associated subareas.

The discipline areas for CESAR's intelligent machines research are:

1. Machine Intelligence
2. Mechanisms, Dynamics and Control
3. Sensors and Vision
4. Human-Machine Interface
5. Cross-Disciplinary Research

The first four areas are representative of the major subsystems of intelligent machines and, in particular, robotic systems. The last area addresses fundamental questions of system modelling and integration. While the work of this research and development program is primarily motivated by fundamental scientific questions, it also aims to satisfy basic development needs of real operating systems of the energy industry.

IV. TECHNOLOGY RESEARCH AND DEVELOPMENT PLAN

It is expected that intelligent machines will play an important role in the development of future energy systems. The CESAR program thus directs its efforts toward assuring that future complex energy related projects are affordable and cost effective, creating and maintaining a competent and vigorous R&D capability in related technical disciplines at ORNL, and assuring the transfer of technology to the applications sector.

A. Programmatic Goals and Objectives

To assure that the stated general directions can be accomplished, the CESAR research and development activities encompass the following programmatic objectives.

1. Fundamental research efforts will be sustained at the appropriate level to satisfy future demands and needs in machine intelligence; mechanisms, dynamics and control; sensors and vision; human-machine interface; and cross disciplinary research for intelligent machines.

2. Collaborative efforts in the above areas will be established with academic, industrial and government institutions to foster a free interchange of ideas, talents and capabilities.

3. Efforts will be sustained to understand continuing programmatic and technical needs in intelligent machine systems and technologies in the energy producing industry and to develop new approaches to meet these needs.

4. Initiatives will be undertaken to identify unique energy related applications of intelligent machines to provide context and effective utilization for methods development at the component, subsystem, and system level.

5. Programmatic initiatives will be undertaken to establish an intelligent machine technology base that will be made available to support the development of new and more cost effective reliable and safe systems.

B. Technological Goals

In establishing the technological goals of this plan, the DOE/ORNL Final Report on Research Goals and Priorities in Intelligent Machines by the CESAR Steering Committee has been reviewed and used as a point of departure. Other considerations are projected availability of research personnel, laboratory space, equipment, funding, etc. Hence, to start with, the technical goals concentrate mainly on areas oriented towards robotic systems for identification, navigation and manipulation in unstructured environments, the first focus identified in Section II. Work on the

non-overlapping areas of the second focus, multipurpose plant management and maintenance systems, will be phased into the CESAR program as resources become available.

The broad, long-term technical goals of this plan are to develop, within the next decade, the required science and technology for intelligent machines with capabilities to validate instructions from the supervisor(s) and reject those that would endanger the system's performance. Such machines would perform task planning to select satisfactory or optimal detailed plans for achieving high level goals, particularly in the presence of large environmental or system variations. The specific disciplinary goals are to develop the required technologies which will enable robotic vehicles with manipulators to operate effectively in unstructured environments representative of industrial facilities. Such technology involves the design and implementation of:

1. Machine Intelligence Systems with reasoning capabilities to do autonomous planning of robot operations within a domain of interest, and to solve problems which require a course of unforeseen actions as a result of operational requirements and/or self-diagnosis.

2. Mechanisms, Dynamics and Control Systems, which allow robotic vehicles to negotiate obstacles such as stairs, doorways and the like, to move obstacles out of the way as required, to perform precisely controlled manipulation of objects, and to do manipulation tasks with high dexterity.

3. Sensors and Vision Systems, which can obtain the necessary data in a suitable fashion to identify and plan a safe path for travel and positioning, to select target objects of interest, to identify and grasp objects safely, and to perform self-diagnoses.

4. Human-Machine Interface Systems, which make it possible for human operators to assume intimate control of the remote robotic system through realistic sensory feedback displays, proximal computer simulations, and effective control override capabilities.

In addition, it is a goal of this program to develop cross-disciplinary techniques as required in support of the major, long range goals in selected areas such as identification and estimation, sensitivity and uncertainty analyses, specialized computer architectures, and theoretical foundations for system integration.

C. Implementation Plan

1. Objectives and Task Description

The objectives and tasks have been updated in recognition of a number of constraints, such as available funding, talents and laboratory facilities.

A major consideration during the first two years has been the development of a laboratory capability in addition to theoretical investigations. Some aspects of the theoretical research have been tested experimentally in our developing laboratory. The specific objectives and tasks which follow are subdivided in agreement with the disciplinary areas identified in Section III.B.

(a) Machine Intelligence

(1) Design, construct, and maintain the HERMIES Robot series as experimental devices to test concepts of machine intelligence. This includes the mobile platform, manipulators, computing architecture, sensor array, controls, communications, and man-machine interface.

(2) Study and develop automated planning techniques for robotic systems with real time constraints; develop a HERMIES planner which considers sensor feedback, geometric reasoning, and capabilities for automated learning from experience.

(3) Develop and make operational an intelligent machine operating system using specialized computer architectures (hypercube ensemble machine). This includes development of concurrent computation algorithms (e.g., for time dependent planning and robot dynamics).

(b) Mechanisms, Dynamics and Control

(1) Develop and test real-time dynamic models for machines and manipulator systems using computer assisted techniques. These developments include rigid and flexible arms and single and multiple arm linkages.

(2) Develop and test advanced control concepts for intelligent machines including compliant manipulators, and cooperative systems.

(c) Sensors and Vision

(1) Study and develop computer software architectures for the integration of information from multiple sensors including consideration of knowledge bases, associative memories, parallel pattern processing, shell architecture, and multi-level data flow.

(2) Study theoretical problems and techniques related to the interpretation of information from multiple sensors considering contexts in dynamic environments, isomorphic matching of representations, merging of different representations, and automatic generation of higher level representations.

(3) Develop and test new transducers for single and multiple sensors using single and multimodal systems with specialized computers.

(d) Human-Machine Interface

(1) Develop techniques of planning for skill related operations considering human analogs; determine criteria for optimal human-machine task allocation.

(2) Design an experimental work station (control station) for remote control of robotic devices.

(e) Cross-Disciplinary Research

(1) Develop and validate a methodology for the automated generation of sensitivity coefficients to enable systematic model simplification and parameter identification.

(2) Develop theory for planning under uncertainty incorporating the advantages of the Dempster-Shafer methods, Fuzzy Sets, and Bayesian techniques.

(3) Conduct system integration studies and develop a test bed for robot technology demonstrations, human-machine performance research, and fundamental contributions to system design methodology and implementation.

2. Research Context

As framework for gauging the appropriateness of the various CESAR research and development projects, a reference problem has been selected. The reference problem involves the operation, diagnosis and repair of fluid control valves in various environmental settings. The operational requirements for this paradigm problem are deemed to be rich and comprehensive enough to cover most important aspects of autonomous robotic systems. A sequence of three phases of increasingly more complex valve-related system operation tasks has been developed, and corresponding subsystem characteristics have been derived as summarized in Fig. I.

	Phase 1	Phase 2	Phase 3
System Demonstrations	Operate Manual Valve 1988	.Remove/Install Flanged .Valve 1990	. Locate, Diagnose, and . Operate Valve 1992
Cognition and Planning	Non-Realtime Plan/Execute Known Simple Task	.Non-Realtime .Plan/Execute Known .Task	. Realtime . Human Supervisory Mode
Sensory Perception	Position Force-Reflection 2D Computer Vision	.Multiple 2D Computer- .Vision .Tactile Sensing	. Acoustic . Infrared . Radar
Manipulation	Single-Arm	.Coordinated Arms .Advanced End-Effectors .Simple Tools .Auxilliary Lift Capacity.	. Multiple End-Effectors . Adaptive Position/Force . Control
Mobility	Localized Navigation	.Localized (Navigation . in Unstructured . Environment)	. General World . Radio Link, On-Board . Power

Fig. I. Phased Reference Problem in Terms of System Operations and the Related Subsystem Characteristics*

*Each successive phase assumes capability of previous phases.

The overall problem (long-term) can be characterized with the following assumptions:

A. The absolute coordinates and orientation of the valve are uncertain (as-built drawings unavailable or obsolete).

B. The optical properties of the valve site are unknown a priori (valve may be clean or greasy, emergency lighting only).

C. The valve is one of multiple valves of this type located in this vicinity.

D. The current operability of the valve is unknown (may be corroded, slippery, etc.).

E. The robot's mobile platform is at a known initial condition and can move as required. At the valve site, the platform can elevate the manipulator sphere of influence to encompass the valve.

F. The valve access may be partially obstructed (e.g., a pipe may cut across the viewing angle). Only part of the valve can be viewed from any angle, but the degrees of freedom of the manipulator are sufficient to allow operation of the valve with the mobile platform positioned correctly in three dimensions.

G. There are several paths which the mobile platform may follow (through rooms, aisles, etc.), some of which may be obstructed by unanticipated objects.

H. Time is important for successful task completion but mobility and vision is not hampered by the emergency (no fire, smoke, etc.).

I. The total power available to the robot is limited, but may be replenished by returning to the starting point.

J. Communication with the robot can be effectively maintained throughout the plant by existing location of repeaters.

K. A world model exists including

- a complete description of the valve type (sufficient information to generate a view of the valve from any angle), and

- piping and other appropriate construction drawing information but not "as built" drawings, to establish the approximate location of the valve (including identification of end points of the line which it is located, such as vessels), and possible paths.

The global (long-term) paradigm problem is then to:

- Locate and approach the valve considering possible paths, obstacles, time, power requirements and monitoring, etc.
- Find the orientation of the valve and the handle position with respect to the robot platform.
- Evaluate the operability of the valve by inspection.
- Develop a strategy for actuation, replacement, repair, etc.

3. Schedule and Resources

The research schedule given in Fig. II has been developed based on the Objectives and Task Descriptions of Section 1, while considering the Research Context of Section 2.

The schedule covers a five year planning horizon from FY 1986 through FY 1990. It includes work sponsored by DOE and relevant work sponsored by other organizations. The milestones for each subtask indicate deliverable items which are called out at the end of this paragraph. They include capability demonstrations, pieces of hardware, or publications. The state of accomplishments as of February 1986 is presented in Ref. 3. Currently, the resources, both man years and funding, can reasonably well be estimated through FY 1987. The resources for FY 1988 through FY 1990 are approximate projections. Budgets and completed milestones corresponding to research in earlier fiscal years (e.g., FY 1985) are presented in Appendix A.

Milestones:

(2) Capability to do rudimentary machine learning.
(3) Scheduling of robotic tasks under hard-real-time constraints.
(4) Simulated annealing application to relational matching and sensor fusion.
(6) Theory of static load balancing of hypercube multiprocessors using simulated annealing.
(7) Virtual time distributed operating system with application to robotics.
(8) Theory of dynamic load balancing using generalized simulated annealing.
(10) Model and identify parameters of CESAR research manipulator.
(11) New control algorithm for compliant manipulator verified by performance testing.
(12) Control of one manipulator and mobile platform.
(13) Theory of human retinal models.
(14) Algorithms for vision guided manipulation.
(15) Human analog vision recognition using concurrent computing.
(16) Integration of laser range finder and vision.
(17) Concepts for optimum task allocation.
(18) Representation of tasks involving skill.
(19) Advanced teleoperated dexterous manipulation.
(20) Optimized work station design.
(21) Sensitivity analysis software validation.
(22) Simplified robot dynamics application using sensitivity analysis.
(23) Hardware validation of sensitivity tool.
(24) Uncertainty theory established.
(25) Incorporation in expert system of uncertainty analysis.
(26) Incorporation in planner of uncertainty analysis.
(27) Complete fabrication and assembly of CESAR research manipulator.
(28) Completion of testbed system.
(29) Upgraded testbed system.
(30) Algorithms for machine learning based on neural networks.
(31) CAD based knowledge base.
(32) Theory of cellular automata and neural networks for machine intelligence.
(33) Sensor driven dynamic knowledge base.
(34) Control of dual manipulators and a mobile platform.
(35) HERMIES demonstration including task planning, monitoring, replanning, object recognition, and manipulation.
(36) Machine vision system prototype based on principles at human vision.
(37) Dynamic task allocation with hierarchical communication and control.
(38) Hybrid statistical/deterministic uncertainty analysis capability.
(39) Parallel processing version of real-time expert system operating on the hypercube.
(40) Analysis of vehicle-manipulator dynamic interaction studies of MIT and technology transfer as appropriate.
(41) Integrated multi-fingered end effector for CESARM.

TASK AREAS	FY '86	FY '87	FY '88	FY '89	FY '90
a. Machine Intelligence					
(A) Planning and Learning	2	30	3	39	31 33
(B) Advanced Computer Sys.		6 7	32		8
Funding ($000)	700	1000	1400	1800	2000
Manyears	4.7	6.3	8.2	10	10.5
b. Mechan. Dyn. and Contr.					
(A) Dynamic modeling				40	
(B) Control structures		10	11	12	34
Funding ($000)	250	280	470	710	960
Manyears	1.7	1.8	2.8	3.9	5.0
c. Sensors and Vision Syst.					
(A) Human Analog Vision	13		15		36
(B) Sensor Guided Control		14			
(C) Sensor Integration			4	16	
Funding ($000)	250	500	700	1000	1110
Manyears	1.7	3.1	4.1	5.6	5.8
d. Human-Machine Interface					
(A) H/M Task allocation		17		18	37
(B) Work station design			19	20	
Funding ($000)	285	480	510	720	800
Manyears	1.9	3	3	4	4.3
e. Cross-Disciplinary Res.					
(A) Sensitivity analysis	21		22	23	
(B) Uncertainty analysis	24		25	26	38
(C) Systems integration *	27	35	28	29	41
Funding ($000)	470	785	825	910	830
Manyears	2	2	2.5	3.5	3.5
TOTAL RESOURCE PLAN — FUNDING ($000)	1955	3045	3905	5140	5700
TOTAL RESOURCE PLAN — WORKYEARS	12.0	16.2	20.6	27	29.1

*This item includes capital equipment and operating costs.
Estimated costs/manyear '86 (150 K), '87 (160 K), '88 (170 K), '89 (180 K), '90 (190 K).

Fig. II. Schedule and Resources: Circled Numbers Correspond to Milestones Listed on the Previous Pages

4. Facilities Plan

The research facilities for CESAR are undergoing a period of change. Reference 3 gives an overview of current facility and equipment developments. The major existing and planned facilities with accessories include:

(1) Two LISP Machines with LISP Upgrade (FY'85)

(2) General Access to ORNL Common Facilities (FY'85)

(3) Hypercube Parallel Processor with 64 nodes (FY'85)

(4) HERMIES-I Robot (FY'85)

(5) CESAR Research Manipulator (CESARM-I) (FY'85,'86)

(6) HERMIES-II Robot Upgrade (FY'86)

- Vision System
- Servo Sensory Platform
- Multiple Sensory Array
- Hypercube Interface

(7) NCUBE graphics facility (FY'86)

(8) Cellular Automata 256x256 Lattice Computer (FY'86)

(9) Second Hypercube Controller Board for Multiuser Access (FY'86)

(10) Upgraded IRI/NCUBE data link (FY'86,'87)

(11) Upgraded LMI/HERMIES communications board plus 8 megabytes memory (FY'86,'87)

(12) HERMIES-II NCUBE nodes on-board (FY'86,'87)

(13) Laser Range Scanner (FY'87)

(14) HERMIES-III Robot (FY'87,'88)

- High Speed Communication System
- Mobile Platform with Manipulator Torso
- Sensor Platform
  - Phased array sonar

(15) CESARM-II (FY'88)

(16) Utah/MIT Multifingered Hand (FY'88)

(17) Integrated Man-Machine Control Station (FY'88)

ORNL has designated a space of ~4200 sq. ft. to house the CESAR Laboratory which includes facilities and equipment for robot navigation experiments, manipulator development, advanced computing, sensor and signal transmission equipment, maintenance shops, etc. The space contains standard features including electric power and air conditioning, and was constructed as a second floor addition to Building 6010 at ORNL. A rough layout of the Laboratory is given in the following page, Fig. IV. The installation of this Laboratory is expected to be completed in July 1988. Finally, a large mobile manipulator robotics testbed is being assembled in behalf of the Human Engineering Laboratory of the U.S. Army.

5. Management Structure

The CESAR organization is generally structured along disciplinary lines as shown in Fig. V. Senior staff members and their associated technical interests are listed in Fig. VI. The cross-disciplinary activities are embedded within the the group activities. The permanent advisory committee provides periodic inputs to the annual planning and evaluation process of CESAR.

6. Reporting Structure

The operation of CESAR consists of a formal and an informal reporting process. The formal process requires annual submissions of DOE Form 5120.2, "Field Task Proposal/Agreement" including task descriptions, staffing, requested funding, milestone schedules, facility requirements, prior year publications and other detailed planning information necessary to allocate funding for the particular fiscal year. For other sponsoring organizations, formal proposals are prepared based on the particular requirements of the proposed work. Beginning in FY '86, annual reports are prepared abstracting the CESAR activities and accomplishments during the previous year.

The informal reporting consists primarily of publications in the open literature including books, refereed journals, conference proceedings and lectures, as well as a peer review process performed by the CESAR Advisory Committee and the Council on Energy Engineering Research.

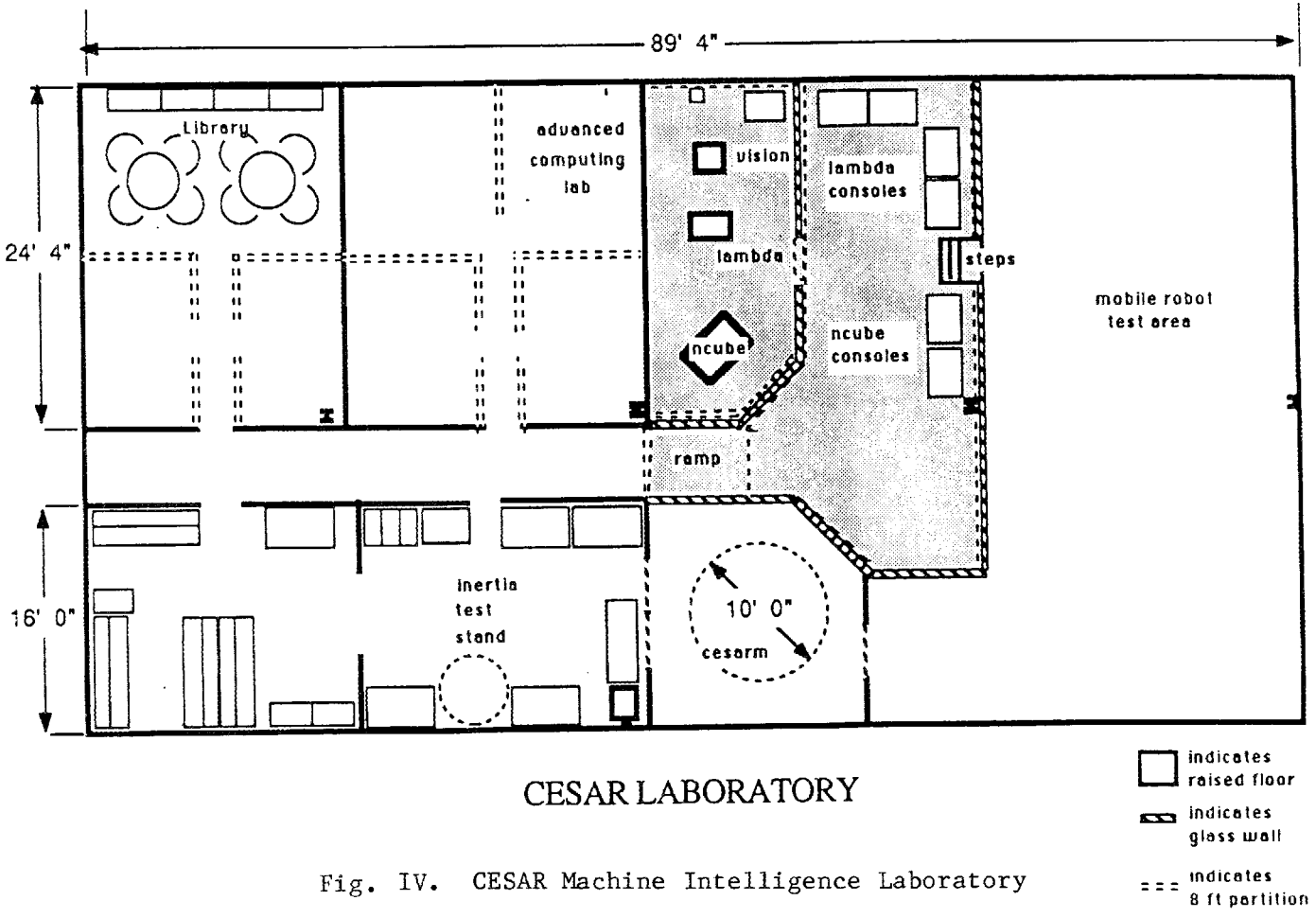

Fig. IV. CESAR Machine Intelligence Laboratory

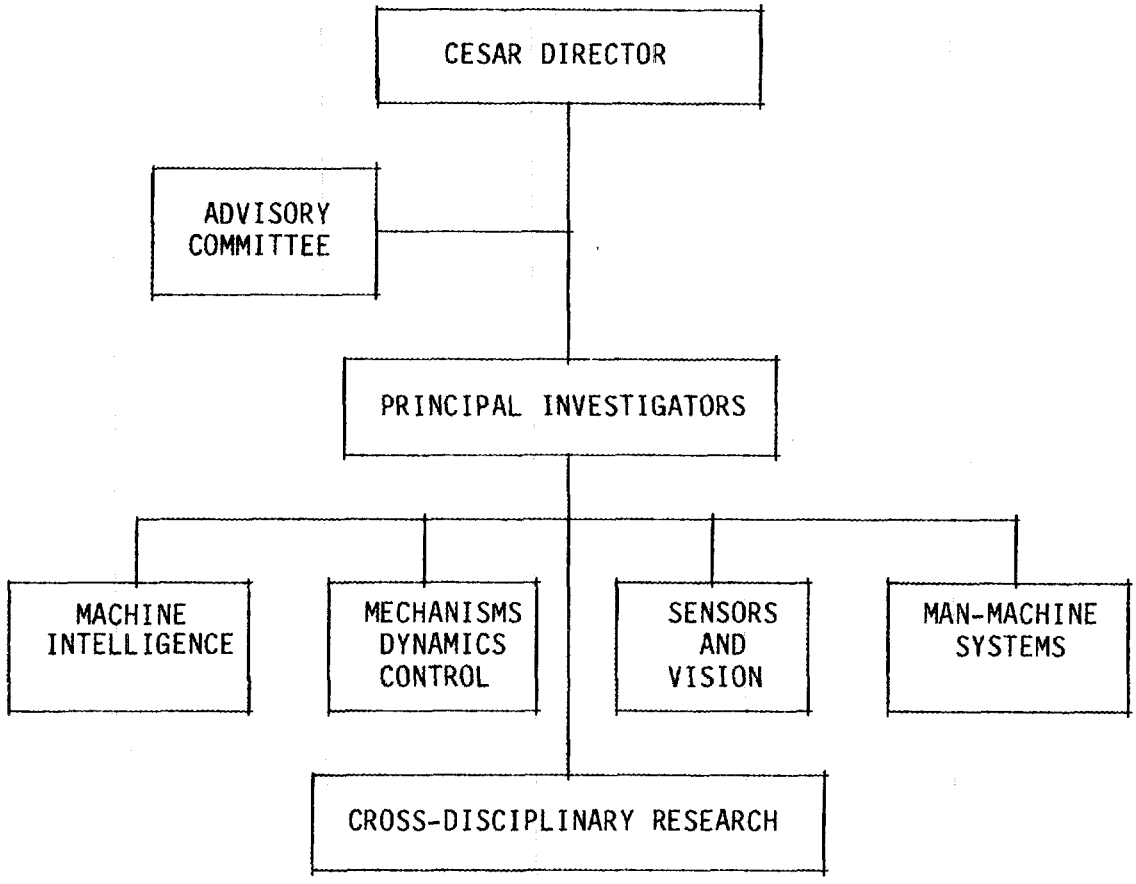

Fig. V. Organization Chart

C. R. Weisbin, Director

STAFF MEMBERS	TECHNICAL INTERESTS
S. M. Babcock	Dynamic Systems Analysis and Control
J. Barhen, Principal Investigator	Concurrent Systems and Algorithms, Cellular Automata, and Neural Networks
M. Beckerman	Sensitivity and Uncertainty Analysis in Decision Making
B. Burks	Mobile Robot Architecture and Operation
G. de Saussure	Strategy Planning and Machine Intelligence
J. R. Einstein	Concurrent Computation and Real-Time Operating Systems
C. Glover	Concurrent Computation and Multi-Sensor Integration
M. Goldstein	World Modelling and Path Planning
W. R. Hamel, Principal Investigator	Dynamic Systems Analysis and Controls, Manipulator Design, and Mechanical Nonlinear Systems Analysis
J. P. Jones	Concurrent Computation and Machine Vision
C. C. Jorgensen	Machine Learning and Neural Network Simulation
R. C. Mann	Concurrent Computation, Machine Vision, Pattern Recognition, Multi-Sensor Integration, and Systems Theory
E. M. Oblow	Sensitivity and Uncertainty Analysis in Decision-Making
L. Parker	Man-Machine Cooperative Problem Solving
F. G. Pin	Man-Machine Cooperative Problem Solving, World Modeling, and Machine Learning

Fig. VI. Senior Staff Members and Their Associated Technical Interests

V. REFERENCES

1. "RESEARCH NEEDS IN INTELLIGENT MACHINES," proceedings of a Workshop, prepared by the Select Panel on Research Goals and Priorities in Intelligent Machines, November 1984.

2. "DOE/ORNL FINAL REPORT ON RESEARCH GOALS AND PRIORITIES IN INTELLIGENT MACHINES," by the CESAR Steering Committee. (To be published.)

3. C. R. Weisbin, "CESAR RESEARCH IN INTELLIGENT MACHINES," Proceedings of The Second World Conference on Robotics Research, MS86-772, Scottsdale, Arizona (August 19-21, 1986). CESAR/86-12.

Appendix A. Budgets and Milestones from Earlier Fiscal Years
(CESAR milestones are circled)

TASK AREAS	FY '85 Budget $(000)
a. Machine Intelligence (A) Automated planning (B) Hypercube Oper. Systems	 1 5
Funding ($000) Manyears	630 4.5
b. Mechan. Dyn. and Contr. (A) Dynamic modeling (B) Control structures	 9
Funding ($000) Manyears	210 1.5
c. Sensors and Vision Syst. (A) Human Analog Vision (B) Sensor Guided Control (C) Sensor Integration	
Funding ($000) Manyears	30 0.2
d. Human-Machine Interface (A) H/M Task allocation (B) Work station design	
Funding ($000) Manyears	50 0.3
e. Cross-Disciplinary Res. (A) Sensitivity analysis (B) Uncertainty analysis (C) Systems integration*	
Funding ($000) Manyears	380 1.0
TOTAL RESOURCE PLAN FUNDING ($000)	1300
TOTAL RESOURCE PLAN WORKYEARS	7.5

*This item includes capital equipment and operating costs. Estimated costs/manyear '85 (140 K).

Appendix B. Completed Milestones

1. Capability to navigate in unstructured environment

C. C. Jorgensen, W. R. Hamel and C. R. Weisbin, **"Exploring Autonomous Robot Navigation,"** published in BYTE, January 1986, pp. 223-235. CESAR-86/04.

C. R. Weisbin, G. de Saussure and D. W. Kammer, **"A Real-Time Expert System for Control of an Autonomous Mobile Robot Including Diagnosis of Unexpected Occurrences,"** To be published in Computers in Mechanical Engineering, (October 1986). CESAR-86/25.

2. Capability to do rudimentary machine learning

S. S. Iyengar, C. C. Jorgensen, S. V. N. Rao and C. R. Weisbin, **"Robot Navigation Algorithms Using Learned Spatial Graphs,"** Published in ROBOTICA, Vol. 4, pp. 93-100 (1986).

S. V. N. Rao, S. S. Iyengar, C. C. Jorgensen and C. R. Weisbin, **"Robot Navigation in an Unexplored Terrain,"** To be published in Journal of Robotic Systems (December 1986). CESAR-86/28.

J. Barhen, **"Concurrent Algorithms for Asymetric Neural Networks,"** to be submitted to Hypercube Multiprocessors, '87. CESAR-86/32.

C. C. Jorgensen, **"Neural Network Recognition of Robot Sensor Graphs Using Hypercube Computers,"** to be submitted to Hypercube Multiprocessors, '87. CESAR-86/33.

5. Hypercube with 64 nodes operational

J. Barhen and J. F. Palmer, **"The Hypercube in Robotics and Machine Intelligence,"** published in Computers in Mechanical Engineering, V. 4, No. 5, pp. 30-38 (March 1986). CESAR-86/03.

J. Barhen, **"Hypercube Ensembles: An Architecture for Intelligent Robots,"** book chapter, J. Graham, Editor, Special Computer Architectures for Robotics and Automation, accepted for publication, (in press), Gordon and Breach, New York. (Summer 1986). CESAR-86/11.

J. Barhen and E. C. Halbert, **"ROSES: An Efficient Scheduler for Precedence - Constrained Tasks on Concurrent Multiprocessors,"** book chapter, M. T. Heath ed., Hypercube Multiprocessors, '86, SIAM Publishers, Philadelphia, PA, accepted for publication, (in press), (Summer 1986). CESAR-86/21.

6. Theory of static load balancing of hypercube multiprocessors using simulated annealing

J. Barhen, **"Combinatorial Optimization of the Computational Load-Balance for a Hypercube Supercomputer,"** Proceedings, Fourth Symposium on Energy - Engineering Science, pp. 71-80, DOE/CONF/8605122, Argonne National Lab (May 1986).

9. Model for rigid manipulator with compliant joints

M. G. Forest-Barlach and S. M. Babcock, **"Inverse Dynamics Position Control of a Compliant Manipulator,"** accepted for publication, IEEE Journal of Robotics and Automation (January 1987).

13. Theory of human retinal models

C. C. Jorgensen, R. Gawronski and F. Holly, **"Modelling Early Stages of Human Vision,"** ORNL/TM-10031, CESAR-86/05.

21. Sensitivity analysis software validation

E. M. Oblow, F. G. Pin and R. Q. Wright, **"Sensitivity Analysis Using Computer Calculus: A Nuclear Waste Isolation Application,"** published in Nuclear Science and Engineering, Vol. 94-1, pp. 46-65 (September 1986). CESAR-86/19.

24. Uncertainty theory established

E. M. Oblow, **"O-Theory: A Hybrid Uncertainty Theory,"** Accepted for publication to the International Journal of General Systems. ORNL/TM-9759, CESAR-86/02.

E. M. Oblow, **"Foundations of O-Theory: The Intersection Rule,"** Submitted for publication to the International Journal of General Systems. CESAR-86/10.

27. Complete fabrication and assembly of CESAR research arm

W. R. Hamel, **"Manipulator Technology: The Critical Element of Useful Autonomous 'Working' Machines,"** Intelligent Autonomous Systems, An International Conference, Amsterdam, The Netherlands (December 8-11, 1986). CESAR-86/43.

Appendix C. CENTER FOR ENGINEERING SYSTEMS ADVANCED RESEARCH PUBLICATIONS LIST

I. BOOKS AND REFEREED JOURNALS

I.1. S. S. Iyengar, C. C. Jorgensen, S. V. N. Rao and C. R. Weisbin, **"Robot Navigation Algorithms Using Learned Spatial Graphs,"** Published in ROBOTICA, Vol. 4, pp. 93-100 (1986).

I.2. E. M. Oblow, **"O-Theory: A Hybrid Uncertainty Theory,"** Accepted for publication to the International Journal of General Systems. ORNL/TM-9759, CESAR-86/02.

I.3. J. Barhen and J. F. Palmer, **"The Hypercube in Robotics and Machine Intelligence,"** published in Computers in Mechanical Engineering, V. 4, No. 5, pp. 30-38 (March 1986). CESAR-86/03.

I.4. C. C. Jorgensen, W. R. Hamel and C. R. Weisbin, **"Exploring Autonomous Robot Navigation,"** published in BYTE, January 1986, pp. 223-235. CESAR-86/04.

I.5. E. M. Oblow, **"Foundations of O-Theory: The Intersection Rule,"** Submitted for publication to the International Journal of General Systems. CESAR-86/10.

I.6. J. Barhen, **"Hypercube Ensembles: An Architecture for Intelligent Robots,"** book chapter #8 in Special Computer Architectures for Robotics and Automation, J. Graham, Editor, Gordon and Breach, New York, (January 1987). CESAR-86/11.

I.7. E. M. Oblow, F. G. Pin and R. Q. Wright, **"Sensitivity Analysis Using Computer Calculus: A Nuclear Waste Isolation Application,"** published in Nuclear Science and Engineering, September 1986, Vol. 94-1, pp. 46-65. CESAR-86/19.

I.8. J. Barhen and E. C. Halbert, **"ROSES: An Efficient Scheduler for Precedence - Constrained Tasks on Concurrent Multi-processors,"** book chapter, M. T. Heath ed., Hypercube Multiprocessors, '86, pp. 123-148, SIAM Publishers, Philadelphia, PA, (1986). CESAR-86/21.

I.9. C. R. Weisbin, G. de Sausure and D. W. Kammer, **"Self Controlled: A Real-Time Expert System for an Autonomous Mobile Robot,"** Computers in Mechanical Engineering, Vol. 5, #2, pp. 12-19 (September 1986). CESAR-86/25.

I.10. S. V. N. Rao, S. S. Iyengar, C. C. Jorgensen and C. R. Weisbin, **"Robot Navigation in an Unexplored Terrain,"** Published in Journal of Robotic Systems, December 1986, Vol. 3, No. 4, pp. 389-408. CESAR-86/28.

I. BOOKS AND REFEREED JOURNALS (cont'd)

I.11. J. Barhen, "Concurrent Algorithms for Asymetric Neural Networks," to be submitted to Hypercube Multiprocessors, '87. CESAR-86/32.

I.12. C. C. Jorgensen, "Neural Network Recognition of Robot Sensor Graphs Using Hypercube Computers," to be submitted to Hypercube Multiprocessors, '87. CESAR-86/33.

I.13. J. R. Einstein and J. Barhen, "Virtual-Time Operating-System Functions for Robotics Applications on a Hypercube," to be submitted to Hypercube Multiprocessors, '87. CESAR-86/34.

I.14. Reinhold C. Mann, "Analysis of Two-Dimensional Protein Patterns Using the NCUBE Hypercube," to be submitted to Hypercube Multiprocessors, '87. CESAR-86/35.

I.15. J. P. Jones, "Application of the NUCBE Hypercube Concurrent Processor to Image Processing and Artificial Vision," to be submitted to Hypercube Multiprocessors, '87. CESAR-86/36.

I.16. J. Barhen and J. R. Einstein, "Load Balance Algorithms for a Hypercube Supercomputer," to be submitted to Hypercube Multiprocessors, '87. CESAR-86/37.

I.17. M. G. Forest-Barlach and S. M. Babcock, "Inverse Dynamics Position Control of a Compliant Manipulator," accepted for publication, IEEE Journal of Robotics and Automation (January 1987).

I.18. J. Barhen, "On the Stability, Capacity Storage, and Design of Nonlinear Continuous Network," submitted to IEEE Trans. on Systems Man & Cybernetics (1986). CESAR-86/49.

II. PROCEEDINGS OF CONFERENCES - FULL PAPER REVIEWED

II.1. J. Barhen, S. M. Babcock, W. R. Hamel, E. M. Oblow, G. N. Saridis, G. deSaussure, A. D. Solomon, and C. R. Weisbin, **"Basic Research on Intelligent Robotic Systems Operating in Hostile Environments: New Developments at ORNL,"** Proceedings of the 1984 National Topical Meeting on Robotics and Remote Handling in Hostile Environments, pp. 105-116 (April 1984).

II.2. S. M. Babcock and J. Barhen, **"Real-Time Algorithms for Robotics Control of Teleoperators,"** Robots 8 Conference, Detroit, MI, pp. 1972-1987 (June 4-7, 1984).

II.3. C. R. Weisbin, G. deSaussure, J. Barhen, E. M. Oblow and J. C. White, **"Minimal Cut-Set Methodology for Artificial Intelligence Applications,"** The First Conference on Artificial Applications, Sponsored by the IEEE Computer Society in Cooperation with American Association for Artificial Intelligence, pp. 465-469 (December 5-7, 1984).

II.4. C. R. Weisbin, J. Barhen, T. E. Swift, G. deSaussure, C. C. Jorgensen and E. M. Oblow, **"HERMIES-I: A Mobile Robot for Navigation and Manipulation Experiments,"** Proceedings of the Robots 9 Conference, Detroit, MI, Vol. 1, pp. 1-41 (June 3-6, 1985).

II.5. M. G. Forrest and S. M. Babcock, **"Control of a Single Link, Two-Degree-of Freedom Manipulator with Joint Compliance and Actuator Dynamics,"** Proceedings of the 1985 International Computers in Engineering Conference, Boston, MA, pp. 189-197 (August 4-8, 1985).

II.6. J. Barhen, **"Robot Inverse Dynamics on a Concurrent Computation Ensemble,"** Proceedings of 1985 International Computers in Engineering Conference, Boston, MA, pp. 415-429 (August 4-8, 1985).

II.7. S. S. Iyengar, C. C. Jorgensen, S. V. N. Rao and C. R. Weisbin, **"Learned Navigation Paths for a Robot in Unexplored Terrain,"** Proceedings of the Second Conference on Artificial Intelligence Applications, Miami Beach, FL, pp. 148-155 (December 11-13, 1985).

II.8. M. G. Forest-Barlach and S. M. Babcock, **"Inverse Dynamics Position Control of a Compliant Manipulator,"** published in the Proceedings of the 1986 IEEE International Conference on Robotics and Automation, San Francisco, CA, Vol. 1, pp. 196-205, (April 8-10, 1986). CESAR-86/59.

II.9. S. V. N. Rao, S. S. Iyengar, C. C. Jorgensen and C. R. Weisbin, **"Concurrent Algorithms for Autonomous Robot Navigation in an Unexplored Terrain,"** published in the Proceedings of the 1986 IEEE International Conference on Robotics and Automation, San Francisco, CA, Vol. 1, pp. 1137-1144, (April 8-10, 1986).

II. PROCEEDINGS OF CONFERENCES - FULL PAPER REVIEWED (cont'd)

II.10. C. R. Weisbin, **"CESAR Research in Intelligent Machines,"** to appear in the August 1986 issue of ORNL Review, Proceedings of The Second World Conference on Robotics Research, MS86-772, Scottsdale, Arizona (August 19-21, 1986). CESAR-86/12.

II.11. J. Barhen, E. C. Halbert and J. R. Einstein, **"Advances in Concurrent Computers for Autonomous Robots,"** Proceedings of The Second World Conference on Robotics Research, MS86-771, Scottsdale, AZ (August 19-21, 1986). CESAR-86/14.

II.12. J. R. Einstein and J. Barhen, **"Virtual-Time Operating System for the Application of a Hypercube Supercomputer to Advanced Automation,"** to be presented at Advances in Intelligent Robotics System SPIE's Cambridge Symposium on Optical and Optoelectronic Engineering, October 26-31, 1986 in Cambridge, Massachusetts. CESAR-86/38.

II.13. C. R. Weisbin, G. de Saussure and D. W. Kammer, **"A Real-Time Expert System for Monitoring the Performance of an Intelligent Robot and Diagnosing Unexpected Occurrences,"** SPIE's 1986 Cambridge Symposium on Advances in Intelligent Robotics Systems, October 26-31, 1986, Hyatt Regency Cambridge, Cambridge, MA (Proceedings will follow). CESAR-86/44.

II.14. C. C. Jorgensen, **"Neural Network Modeling of Early Retina Vision Processes,"** Presented to Neurcom, San Jose, also to be TM (1986). CESAR-86/48.

II.15. M. Goldstein, F. G. Pin, G. de Saussure and C. R. Weisbin, **"3-D World Modeling Based on Combinatorial Geometry for Autonomous Robot Navigation,"** 1987 IEEE International Conference on Robotics and Automation. CESAR-86/51.

II.16. S. M. Babcock, W. R. Hamel, S. M. Killough, **"Advanced Manipulation for Autonomous Mobile Robots,"** International Topical Meeting on Remote Systems and Robotics, Pasco, WA (March 29 - April 2, 1987). CESAR-86/52.

II.17. N.S.V. Rao, S. S. Iyengar and C. R Weisbin, **"On Autonomous Terrain Model Acquisition by a Mobile Robot,"** Abstract to be presented at the JPL (NASA) Conference on Telerobotics (1987). CESAR-86/59.

II.18. N.S.V. Rao, S. S. Iyengar, C. C. Jorgensen and C. R. Weisbin, "On Terrain Acquisition by a Finite-Sized Mobile Robot in Plane," 1987 IEEE Robotics and Automation Confernce, Raleigh, NC. CESAR-86/60.

III. PROCEEDINGS OF CONFERENCES - SUMMARY REVIEWED

III.1. C. R. Weisbin, G. deSaussure, and J. Barhen, **"Automated Planning for Intelligent Machines in Energy-Related Applications,"** Proceedings of the Conference on Intelligent Systems and Machines, pp. 13-15, Oakland University, Rochester, MI (April 24-25, 1984).

III.2. J. Barhen, C. R. Weisbin and G. de Saussure, **"Real-Time Planning by an Intelligent Robot,"** ASME Conference on Computers in Engineering, pp. 358-360 (August 1984).

III.3. C. R. Weisbin, G. deSaussure, J. Barhen, T. E. Swift and J. C. White, **"Strategy Planning by an Intelligent Machine,"** First World Conference on Robotics Research: The Next Five Years and Beyond, Lehigh University, PA, MS84-501 (August 14-16, 1984).

III.4. J. Barhen and S. M. Babcock, **"Parallel Algorithms for Robot Dynamics,"** First World Conference on Robotics Research: The Next Five Years and Beyond, Lehigh University, PA, MS84-499 (August 14-19, 1984).

III.5. C. R. Weisbin, J. Barhen, G. deSaussure, W. R. Hamel, C. C. Jorgensen, J. L. Lucius, E. M. Oblow and T. E. Swift, **"Machine Intelligence for Robotics Applications,"** 1985 Proceedings of the Conference on Intelligent Machines, Oakland University, Rochester, MI, pp. 47-57 (April 23, 1985).

III.6. E. M. Oblow, **"A Hybrid Uncertainty Theory,"** Proceedings of the Fifth International Workshop: Expert Systems and Their Applications, Avigon, France, pp. 1193-1201 (May 13-15, 1985), (ask E. M. Oblow for copies).

III.7. W. R. Hamel, S. M. Babcock, M. C. G. Hall, C. C. Jorgensen, S. M. Killough and C. R. Weisbin, **"Autonomous Robots for Hazardous and Unstructured Environments."** Proceedings of the Robots 10 Conference, Chicago, IL, pp. 5-9 through 5-29 (April 20-24, 1986).

III.8. D. W. Kammer, G. deSaussure and C. R. Weisbin, **"A Real-Time Expert System for Intelligent Robot Control,"** Presented at 1986 Conference on Intelligent Systems and Machines, Oakland, MI (April 29-30, 1986). CESAR-86/20.

III.9. E. M. Oblow, **"O-Theory: A Hybrid Uncertainty Theory,"** will appear in the Proceedings of the International Conference on Information Processing and Management of Uncertainty on Knowledge-Based Systems held in Paris, France (June 30 - July 4, 1986).

III. PROCEEDINGS OF CONFERENCES - SUMMARY REVIEWED (cont'd)

III.10. J. R. Einstein, J. Barhen and D. Jefferson, "Intelligent Operating System for Autonomous Robots. Real-Time Capabilities on a Hypercube Supercomputer," to be presented in Pasco, Washington (1987). CESAR-86/57.

IV. INVITED TALKS

IV.1. C. R. Weisbin, J. Barhen, G. deSaussure, W. R. Hamel, C. C. Jorgensen, J. L. Lucius, E. M. Oblow and T. E. Swift, **"Artificial Intelligence for Energy-Related Applications,"** 1985 WATTEC Conference, Knoxville, TN (February 12, 1985).

IV.2. C. R. Weisbin, J. Barhen, G. deSaussure, W. R. Hamel, C. C. Jorgensen, J. L. Lucius, E. M. Oblow and T. E. Swift, **"Artificial Intelligence for Concurrent Computation for Robotic Applications,"** Transactions of American Nuclear Society Annual Meeting, Boston, MA, V. 49, pp. 310-311 (June 9-14, 1985).

IV.3. J. P. Jones, **"Image Processing on a Hypercube Concurrent Multi-processor,"** to be published in Proceedings of the RIMSIG Symposium, Sante Fe, New Mexico (October 22-23, 1986). CESAR-86/39.

IV.4. J. Barhen, **"Simulation of the Stochastic Dynamics of Neural Net-works on a Hypercube Supercomputer,"** to be published in Proceedings of the RIMSIG Symposium, Sante Fe, New Mexico (October 22-23, 1986). CESAR-86/40.

IV.5. J. R. Einstein and J. Barhen, **"Robot Control with a Hypercube: Virtual-Time Functions for the Node's Operating System,"** to be published in Proceedings of the RIMSIG Symposium, Sante Fe, New Mexico (October 22-23, 1986). CESAR-86/41.

IV.6. R. C. Mann, **"Quantitative Analysis of Two-Dimensional Protein Patterns Using an NCUBE Hypercube,"** to be published in Proceedings of the RIMSIG Symposium, Sante Fe, New Mexico (October 22-23, 1986). CESAR-86/42.

IV.7. G. de Saussure, D. W. Kammer and C. R. Weisbin, **"A Real-Time Expert System for the Control of Autonomous Robot Navigation in the Presence of Moving Obstacles,"** Pasco, WA (1987). CESAR-86/50.

IV.8. R. C. Mann, **"Multi-Sensor Integration for a Mobile Robot Using Concurrent Computing,"** to be presented in the Federal Republic of Germany (May 11-13, 1987). CESAR-86/53.

IV.9. J. R. Einstein and J. Barhen, **"Virtual-Time Operating System Functions for Robotics Application on a Hypercube,"** (M. T. Heath Meeting). CESAR-86/54.

IV.10. J. Barhen, **"Hypercube Supercomputer Methodologies for SDI Applications,"** SDI Research Plan for FY 1987-1989. CESAR-86/55.

IV. INVITED TALKS (cont'd)

IV.11. W. R. Hamel and S. M. Babcock, **"Manipulator Technology: The Critical Element of Useful Autonomous "Working" Machines,"** to be presented at the International Congress, Amsterdam, The Netherlands, (December 8-11, 1986). CESAR-86/56.

IV.12. W. R. Hamel and C. R. Weisbin, **"Human Scale Experiment in Mobile Autonomous Robotics,"** to be presented in Germany in May 1987). CESAR-86/58.

V. INVITED PAPERS

V.1. J. Barhen, **"Hypercube Concurrent Computation and Virtual Time for Robotic Applications,"** IEEE Workshop on Special Computer Architectures for Robotics and Automation, pp. 5.1-5.30. International Conference on Robotics Research, St. Louis, MO (March 25, 1985).

V.2. W. R. Hamel, **"Manipulators in Teleoperation,"** American Nuclear Society Conference on Remote Operations and Robotics in the Nuclear Industry, Pine Mountain, GA (April 21-24, 1985).

V.3. J. Barhen, M. C. G. Hall and J. R. Einstein, **"Robotics Applications on an Advanced Hypercube Multiprocessor: Initial Developments,"** IEEE Workshop on Special Computer Architectures for Robot Control, 1986 International Conference on Robotics and Automation, San Francisco, CA (April 7-10, 1986). CESAR-86/13.

V.4. C. C. Jorgensen, **"Control Algorithms for Autonomous Robot Navigation,"** Proceedings of the International Topical on Advances in Human Factors in Nuclear Power Systems, Knoxville, TN (April 21-24, 1986).

V.5. J. Barhen, **"Combinatorial Optimization of the Computational Load Balance for a Hypercube Supercomputer,"** Proceedings of the Fourth Symposium on Energy Engineering Sciences, Argonne National Laboratory, Argonne, IL. CESAR-86/30.

V.6. W. R. Hamel, **"Manipulator Technology: The Critical Element of Useful Autonomous 'Working' Machines,"** Intelligent Autonomous Systems, An International Conference, Amsterdam, The Netherlands (December 8-11, 1986). CESAR-86/43.

VI. WORKSHOP PROCEEDINGS AND ORNL REPORTS

VI.1. Select Panel on Research Goals and Priorities in Intelligent Machines, Proceedings of a Workshop (November 1984).

VI.2. ORNL/TM-9923, CESAR-86/01. Proceedings of a Workshop: Planning and Sensing for Autonomous Navigation, Edited by E. S. Howe and C. R. Weisbin, held Los Angeles, CA, August 17-18, 1985 (February 1986).

VI.3. ORNL/TM-9759, CESAR-86/02. **"O-Theory - A Hybrid Uncertainty Theory,"** E. M. Oblow, (October 1985).

VI.4. ORNL/TM-10031, CESAR-86/05. **"Modelling Early Stages of Human Vision,"** C. C. Jorgensen, R. Gawronski and F. Holly.

VI.5. ORNL/TM-9732, CESAR-86/06. **"Research and Development Program Plan for the Center for Engineering Systems Advanced Research (CESAR),"** C. R. Weisbin, W. R. Hamel, J. Barhen and M. C. G. Hall (February 1986).

VI.6. ORNL/TM-9782, CESAR-86/07. **"Robot Navigation Algorithms Using Learned Spatial Graphs,"** S. S. Iyengar, C. C. Jorgensen, S. V. N. Rao and C. R. Weisbin (December 1985).

VI.7. ORNL/TM-9987, CESAR-86/09. **"ROSES: Robot Operating System Expert Scheduler,"** J. Barhen, P. C. Chen and E. Halbert (September 1986).

VI.8. ORNL/TM-9983, CESAR-86/10. **"Foundations of O-Theory I: The Intersection Rule,"** E. M. Oblow (March 1986). (NOTE: see I.6)

VI.9. ORNL/TM-10232, CESAR 86/47. **"Research and Development Program Plan for the Center for Engineering Systems Advanced Research,"** C. R. Weisbin, W. R. Hamel and J. Barhen.

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68. Dr. M. J. Rabins, Dean, Mechanical Engineering Department, Wayne State University, Detroit, MI 48202.

69. Dr. Karl N. Reid, Dean, College of Engineering, Architecture, and Technology, Oklahoma State University, Stillwater, OK 74074.

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