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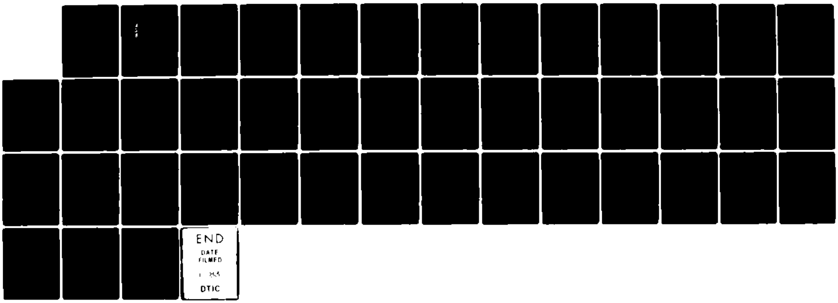

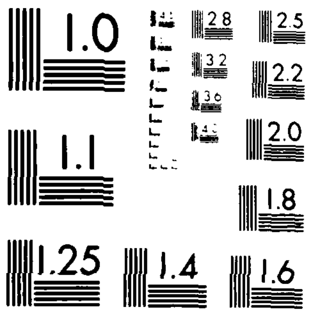
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DEPARTMENT OF THE ARMY
ASSISTANT SECRETARY OF THE ARMY
RESEARCH, DEVELOPMENT, AND ACQUISITION
WASHINGTON, D. C. 20310

ARMY SCIENCE BOARD

AD HOC SUBGROUP REPORT

ON

ARTIFICIAL INTELLIGENCE AND ROBOTICS

SEPTEMBER 1982

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This report examines the state-of-the-art in artificial intelligence and robotics technologies and their potential in terms of Army needs.

Assessment includes battlefield technology, research and technology insertions, management considerations and recommendations related to research and development personnel, and recommendations regarding the Army's involvement in the automated plant.

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ARMY SCIENCE BOARD

REPORT OF

ARMY SCIENCE BOARD AD HOC SUBGROUP

ON

ARTIFICIAL INTELLIGENCE AND ROBOTICS

SEPTEMBER 20, 1982

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September 20, 1982

Dr. Richard A. Montgomery, Chairman
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(Research, Development and Acquisition)
Washington, D. C. 20310

Dear Dr. Montgomery:

The attached report of the Army Science Board Ad Hoc Subgroup on Artificial Intelligence and Robotics is transmitted for your review.

The Subgroup was established in accordance with Ms. Hoeber's letter to you of October 30, 1981. It has been our intention to provide an assessment of the state of the art of these fast-track technologies and their potential in terms of Army needs. Not only are the technologies themselves evolving rapidly, but in addition there has been an escalation of Army interest and internal activity over the course of this study. Accordingly, the Subgroup has concentrated its efforts on those aspects with which it could deal rapidly and relatively completely. They include battlefield technology, research and technology insertion, management considerations, and some recommendations related to the automated plant. As noted in the body of the report, several important areas of application are addressed only briefly or incompletely. For this reason, the Subgroup strongly favors a follow-up study and recommends for your consideration that applications of artificial intelligence and robotics to training and to the hybrid human/robot system be given emphasis in such a study.

The Subgroup hopes that the report will be of value to the Army and to the Board and will be pleased to discuss it with you are your request.

Sincerely yours,

Irene C. Peden

Irene C. Peden, Chairwoman
Ad Hoc Subgroup on Artificial
Intelligence and Robotics

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PREFACE

The initial meetings of the Subgroup were devoted primarily to overviews of Army needs and current programs, to briefings on the current status of artificial intelligence and robotics, and to a summary of other Department of Defense programs in these technologies. Primary centers of academic research activity were visited somewhat later in the study, namely Carnegie Mellon University, the Massachusetts Institute of Technology, and Stanford University; the Stanford Research Institute Artificial Intelligence Laboratory was also visited. A day at the National Science Foundation resulted in information exchange regarding the nature and goals of currently supported research in these areas. The Subgroup observed factory robots in action at the Westinghouse Industry Automation Division, and also visited the Northrop Corporation (Factory of the Future), and the Hughes Aircraft Corporation. Records of Subgroup meetings are found in Appendix B. Appendix C summarizes an interim report to the Army Science Board, made approximately midway in the study.

The Subgroup organized itself in clusters early in its deliberations in order to carry out parallel studies in important areas of application, namely - robotic or semi-autonomous weapons, automated recognition and supported C^3I, human interface, and the automated plant environment. The first four studies comprise the background for the Subgroup recommendations, or examples, portion of Section III on Battlefield Technology. More detailed information is found in Appendix E which contains a set of cluster area reports.

The Army demonstrator programs came to the attention of the Subgroup after the study was underway. They were evaluated as an additional feature, with results that can be found in Section III.

The Subgroup would like to express its thanks to all the briefers identified in Appendix B and to members of the Army staff who provided valuable assistance throughout.

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REPORT OF THE ARMY SCIENCE BOARD AD HOC SUBGROUP
ON ARTIFICIAL INTELLIGENCE AND ROBOTICS

* Appendices not attached. Available from the Army Science Board upon individual request.

INTRODUCTION

The partnership of artificial intelligence (AI) and robotics offers a unique potential for changing the way the Army would fight if called upon to do so. New weapons which seek out, recognize, discriminate and attack targets unseen by conventional means would give a capability with important strategic implications. Military missions not previously feasible because of high or absolute human risk would become possible. A high priority class of applications involves operations in the NBC environment, and this is only one example. Weapons with even limited cognitive abilities suggest that new operational and tactical doctrines could be established in response to new military challenges that have been identified but not yet adequately met. Further, the personnel and support requirements brought about by these complex weapons could actually be reduced by means of AI and robotics. Thus, the opportunities are seen to be substantial.

Several factors will influence realization of the potential of such entities as the intelligent (autonomous) robot, its predecessor/companion the teleoperated vehicle, and the AI-enhanced soldier decision support system. These are evolving technologies, not a single discrete step nor weapons concept, and this must be recognized if plans to utilize them effectively are to be successful. The first stage must be remote control by human operators, and pre-planned product improvement (P^3I) must be an important ingredient of future technology insertion. The fact that step increases in operational capability can be realized suggests change in the traditional "doctrines-requirements-systems" approach to materiel development. Well-directed management actions can bring the materiel and doctrine developers together to make best use of the new technologies in Army applications.

It is the opinion of the Subgroup that the expert system aspect of artificial intelligence, at least, has considerable potential for Army missions in the 1980s. For example, expert systems have the potential to accelerate training, to provide important assistance to people who are not well trained, and to increase the output of well trained people. The expert system has developed to a point that makes it accessible to these and other Army applications. In this sense, the promise of AI is not being oversold at the present time, a contrast to the uneven history of the development of this field.

Because of the pervasive nature of the AI and robotics technologies and the wide impact they are expected to have on the broad and disparate activities of the Army, it is the opinion of the Subgroup that they must be diffused throughout the system and incorporated into the doctrines, tactics, and programs aggressively, but without establishment of a single Army Center for Artificial Intelligence and/or Robotics.

The Subgroup has carried out its investigations in terms of the following questions:

> What is the present state of the art in AI and robotics? What can the Army do now? What new starts should it make to prepare to take maximum advantage of the opportunities offered by these technologies? Where should the Army be in five years, and how should it get there? What about the longer term?

The outcome is contained in the report that follows. Operating on a limited time scale, some important applications of the artificial intelligence and robotics technologies were necessarily left uncovered because they could not be addressed rapidly or in sufficient detail. Two such areas recommended by the Subgroup for Army Science Board follow-on study are: 1) the applications of AI and robotics to the teleoperated vehicle, a hybrid human/robot system that involves remote operation with advanced computer systems and wide use of artificial intelligence, and 2) applications to training.

The report does contain an assessment of existing and potential advantages to battlefield technology in terms of automated recognition, semi-autonomous weapons, supported C^3I, and some possible solutions to Army staffing problems in critical skill areas. The proposed Army demonstrator projects are evaluated, Subgroup-generated recommendations are included that address short, intermediate and long-term battlefield and support systems that could be developed to the Army's advantage. There are research recommendations, management recommendations, recommendations related to research and development personnel, and recommendations regarding the Army's involvement in the automated plant. These are found in the body of the report together with their individual supporting narratives, but isolated notationally for easy reference by means of a bullet (●) at the left margin of the page. Expanded write-ups on selected study areas are found in separately available appendices.

SCENARIO AND DEFINITIONS

Scenario

The scenario for Airland Battle 2000 describes a substantial increase in the pace of battle. The doctrine envisions essentially continuous combat, possibly carried out in widely separated places. There must be a capability to defeat forces in contact while at the same time delaying, disrupting, and reducing the numbers of those expected in the next 12 to 72 hours. It must be possible to recognize forces that are of the order of 12 hours away, to assess the threat they present, and to act rapidly. Artificial intelligence (AI) and robotics could contribute to the Army's advantage in several ways. They could force a potential enemy to introduce second echelon forces prematurely, achieving this by means of faster processing of our intelligence information and associated decision making, and by the delivery of robotic weapons to incapacitate enemy forces more rapidly than losses could be replaced. This would introduce confusion into the enemy battle plan and disrupt its forces. Directed action against command centers, supply points, and launching sites becomes more feasible with these technologies, even when such critical nodes are not located. Further, AI and robotics promise reduction in manpower intensity and life support requirements. These opportunities are available both in conventional Mideast or European war scenarios and in unconventional scenarios as well.

Definitions

Definitions abound within the technical community for both AI and robotics. Since the Army's needs are best served in the context within which the Army operates, the Subgroup adopted definitions relevant to its specific charge, concentrating much of its effort in areas that primarily involve the joint use of AI and robotics. Applications of AI in decision support systems (DSS), designed to assist but not to replace the battlefield decision-maker, are viewed as high priority areas, although they did not receive the main focus of the Subgroup's attention. AI/Robotics hybrid systems that appropriately integrate human and machine behavior are viewed as worthy of as much of the Army's attention, including R & D support, as autonomous automated machines.

The following definitions provide the framework for this report:

ARTIFICIAL INTELLIGENCE: A programmable machine exhibits artificial intelligence if it can incorporate abstraction and interpretation into information processing and make decisions at a level of sophistication that would be considered intelligent in humans.

ROBOTICS: The study and application of artificial intelligence to manipulative mechanical devices.

ROBOT: A programmable machine that displays cognitive behavior and performs mechanical and manipulative functions similar to those performed by humans.

BATTLEFIELD TECHNOLOGY

The capability of the AI/robotics partnership to revolutionize land warfare during the 1980s bears a relationship to advances provided by modern communications and electronics during the last two decades. There is now a potential to make conventional weapons ultimately as effective as tactical nuclear weapons in destroying military targets under special conditions of target exposure. Intelligent robotic weapons can seek out, recognize, discriminate, and attack previously invisible targets. With even limited cognitive abilities, these complex weapons will allow establishments of new operational and tactical doctrines in response to new military challenges. The opportunity also exists to reduce the personnel, direct-support and general-support requirements they engender. It is important to recognize that AI and robotics form a set of evolving technologies, not a single weapons concept. They can bring about substantive changes in battlefield technology during the 1980s; in addition, current research promises results achievable in the field by 1990 and before.

The principal recommendations of the Subgroup are summarized on the two pages that follow. Three basic categories are identified, namely hybrid and autonomous (robotic) weapons (AW) and equipment; automated recognition; and the expert support system (ESS) which is not necessarily associated with robotics. Examples within each category are listed in the tables. The Army Demonstrators have been assigned to the same three categories and evaluated by the Subgroup, with the results indicated in Table 1. Table 2 is an assessment of the time scale associated with each example.

The recommended approach is evolutionary. The present obsolescence rate of some items, e.g. system architecture, partitioning, protocol and programming language, required for a complete application, tends to be one-third or less that of sensor and processor components or pattern recognition algorithms. Similar remarks can be made regarding the mechanical, optical, and power elements indicated by the application. Consequently, new ideas involving important elements having the lower obsolescence rate and technical risks acceptable at the time of the original concept are recommended. Such preplanned product improvements (P^3I) are important where large benefits can still be obtained from later increases in sensor and processor capability, as is the case with target detection, classification and identification.

Where hazard to human operators is a primary consideration, the first applications of AI and robotics should involve the remote control of machines by human operators. Such teleoperators can reduce the danger to personnel without demanding the presently unattainable degree of AI required by the completely autonomous robot. It is also emphasized that full autonomy of a robotic device is not necessarily the most effective end product in all cases, even when the state of technology would permit this choice.

Table 1

TECHNICAL RECOMMENDATIONS

CATEGORY	DEMO	LONGER TERM: EXAMPLES
(1) Close combat vehicles (initially remotely operated and evolving into vehicles with increasing autonomy)	Reconnaissance vehicle with terrain analysis	Reconnaissance including NBC (radiation hardening implied) NBC decontamination Perimeter defense MOUT robot Weapons platform Combat engineering vehicle (bridges, excavation, etc.) Explosive ordnance disposal
(2) Battlefield sensing, recognition and image processing (includes both robots and human operated systems)	$V(INT)^2$	Autonomous weapons (AW) Automated recognition (imagery, signals, non-visual identification) Reduced tank crew
(3) Combat service support (expert support system that can go on a robot or stand alone)	Automated Supply Point Training* Medical Aide*,**	Expert support system (ESS)

*must be recast
**needs MD proponent

Table 2

TECHNICAL RECOMMENDATIONS BY CATEGORY AND PROJECTED YEARS TO PRODUCT

	PROGRAMMATIC	SCIENTIFIC AND TECHNICAL NON-PROGRAMMATIC
SHORT TERM 1-3 years to product	Demonstrators Battlefield remotely operated platform (1) Combat engineer (1)* Air-delivered AW (2) *category (1), pp. 5 & 10	Application of Current work Automated recognition (pattern recognition and automatic target cueing) (2)
INTERMEDIATE TERM 2-5 years to product	Recon vehicle (1) CP finder/destroyer (2) ESS: electronics *maintenance* heavy vehicle maintenance automation specialist (3)	6.2 and 6.2A Explosive ordnance disposal (1) *Automated recognition* (sensor fusion, pattern recognition and cueing, speech recognition) (2) ESS: AI in data base management (3)
LONG TERM 5+ years to product	New starts Reduced tank crew (2)	6.1 and 6.2 MOUT robot (1) Automated recognition (2) Adaptive sensing (2) Heuristic programming (3)

As another aspect of the evolutionary process, the Subgroup advises the use of existing vehicles as platforms where possible. A case in point is the M551 Sheridan tank proposed as the platform for the robot reconnaissance vehicle, with its associated terrain analysis and soldier-machine interface features.

Army Demonstrators

Brief assessments of the demonstrators are presented below. The priority ordering falls into two major categories, namely, Category A - proceed as is; and Category B - proceed subsequent to modification. There is further priority ordering of the demonstrators within these categories.

Category A:	Priority 1.	Robotic Reconnaissance Vehicle with Terrain Analysis
	Priority 2.	Automated Ammunition Supply Point (ASP)
	Priority 3.	Intelligent Integrated Vehicle Electronics [V(INT)^2]
Category B:	Priority 1.	Intelligent Maintenance Tutor
	Priority 2.	AI/Robotics Medical System Development

Robotic Reconnaissance Vehicle with Terrain Analysis: This project, which in fact involves a hybrid, or combined human-robot system, is considered to be of highest priority as a test bed for alternative sensors and control-communications means. It is further recommended that:

- An existing vehicle platform (M551) be employed.
- Provisions for testing varying reconnaissance EW and navigation sensors, plus a variety of aimed and "smart/brilliant" weapons be incorporated.
- Emphasis be placed on minimizing data link bandwidth for the navigation, sensor data, and control functions.
- A separate program be planned for development of sophisticated low probability of intercept (LPI) and anti-jam (AJ) communications, and for automated fusion, in the context of this effort. These features are important, but separately very difficult.

Automated Ammunition Supply Point (ASP) Demonstrator: The plan presently outlined provides for an AI/robotics demonstrator for rapid loading and unloading of ammunition, now done mostly by hand, fork lifts, and other manually operated devices. The concept is to create an "Ammunition Issue Module" (AIM) including resupply, unloading, replacing, and uploading.

The Subgroup rated this as the second highest priority demonstrator of the five, with the strong recommendation that the concept must be expanded to include other aspects of supply and loading in addition to ammunition. These should include POL (petroleum, oils, and lubricants) refuelers and handling and heavy cargo loaders and unloaders for lifting, moving and replacement tasks.

$\underline{V(INT)^2}$: A successful program offers the potential for dramatic improvement of target servicing capabilities while improving survivability due to lessened exposure to enemy fire. It may also increase real-time, two-sided target servicing rates by an order of magnitude, permitting the Army to realize successful rates which approach the technical capabilities of tank main guns and major anti-tank weapons. Another significant potential involves synergistic internetting for target acquisition and assignment, plus optimized electronic warfare and extraformation C^3, including communication relays.

- It is recommended that a high priority be given to an application of AI to the $V(INT)^2$ program, developed around a test bed. A candidate vehicle (TACOM portion) should be an improved tank with sensors having the following features.

  - A man-machine subsystem to identify how to use AI in the soldier-machine interface to best display information and interact with the user (ARI portion).

  - Automated imagery recognition capabilities (ERADCOM portion).

  - Storage and display of terrain data on demand (USAETL portion).

  - Position location and communications equipment to transfer data between vehicles (CECOM portion).

  - Fire and maneuver coordination aids (ARI portion).

- It is strongly recommended that a learn-by-doing program be implemented soon. The things which can be achieved immediately ought to be emphasized. These should include:

  - Use of existing passive and active NVL sensors and current imagery recognition as input to the AI-based system.

  - Use of capabilities from range instrumentation to provide a local over-the-horizon capability as was demonstrated at CDEC.

  - Current interactive displays which can be adapted to the add-on turret of the TACOM test bed.

The objective of the effort should be to involve the user from the beginning and to demonstrate operationally useful results as soon as possible, with controlled evolution to a totally integrated $V(INT)^2$ system built on a solid base of AI technology.

Intelligent Maintenance Tutor: The Subgroup would recommend the computerized tutor for a high priority if there were a change in the approach. The desired tutor would demonstrate its capabilities in a specific narrow area of high Army need such as heavy vehicle maintenance. This recommended change results from the following considerations:

- There is a belief that a "generic" system may be better developed and tested around a specific subject area and data base.

- It would be to the Army's advantage to have such a fielded training/maintenance system.

- A successful demonstration is likely to be more persuasive if a specific Army need is met.

Medical System Development: In its present form, the medical system demonstration presented by USAMRDC cannot be supported by the Subgroup. The plan does not outline specific program objectives, actions, activities, constraints, and/or critical resources. The project could be recommended if:

- A proponent within the Office of the Surgeon General were identified.

- A specific function could be demonstrated that would benefit from AI and/or robotics, i.e.

  ..remote and intelligent triage of CW/BW casualties and/or blunt trauma victims;

  ..critical care support using expert nursing systems that utilize AI/robotics.

- The demonstrations were coupled with programs at a civilian or military trauma or burn center.

- The demonstration were considered within the mid-term, i.e. two to five years.

Subgroup Recommendations (Examples)

The examples tabulated in Tables 1 and 2 were developed by the Subgroup as outcomes of special investigations of the major areas addressed in the course of this study. These include: automatic (robotic) weapons, supported C^3I, autonomous recognition, the Army's staffing problems and the soldier-machine interface, automated plant environment, research, and technology insertion. Background material and rationales for the first four topics are found in Appendices E1 through E5. The three broad categories into which all examples fall are:

(1) The automatic (robotic) weapon, a vehicle with autonomy, or minimum bandwidth remote control, regarding its destination and various functions.

(2) Automatic pattern recognition and sensor fusion, i.e. its mission enroute and upon arrival.

(3) Expert system to support Army personnel in its maintenance.

The key technology needs for producing autonomous weapons are sensors, processors, algorithms, guidance capabilities, flight controls, warheads, and fuzing which produces lethal results. There are types of targets that can be successfully attacked efficiently with simple area munitions, with current autonomous target detection and tracking capabilities. Others are borderline given the current state of the art. There are more difficult problems that would require advances for which there is a substantial dependence on VHSIC (very high speed integrated circuits) plus follow-on advances in microelectronics, computer architecture and compounded software. Improvements of algorithms, very great increases in currently available affordable microprocessing power, and integration testing are needed. The recommendations apply equally to close combat, indirect fire, and interdiction missions.

There are a number of high leverage areas in which AI can support the command and control process. Command posts (CP) have grown in size as a result of their growth in functions so that it is now virtually impossible to disguise the signatures of a major command post. In terms of the Airland Battle 2000 doctrine, there is thus a need for greater survivability and endurance, with substantially lower signatures plus capabilities that will permit fast assessment of rapidly unfolding situations, evaluation of courses of action, rapid decision making and dissemination of information in sufficient detail to carry out all necessary combat operations in a timely manner. These requirements apply to all hierarchies of decentralized command from the smallest group to the whole front. The state of the art in AI offers opportunities to develop these capabilities, and this is also reflected in the set of examples.

Expert support systems hold a prominent place among the examples. Those aspects of AI referred to as knowledge engineering and expert systems have developed to such a level that they should be strongly cultivated and broadly utilized by the Army. Areas of application include equipment and medical diagnostics, data and information fusion and exploitation systems, C^3I, terrain-related situation evaluation and training.

RESEARCH AND TECHNOLOGY INSERTION

Research

Issues: Microelectronics is the primary component technology that will drive robotic system developments in the future. Developments in microelectronics, large-scale integrated circuits, computers, and/or microprocessors have been extensive during the last ten years and there is no end in sight. In particular, VHSIC activities will provide processing capabilities to implement even more advanced robotics systems. The Army is thus provided with many new opportunities ranging from enhancement of the existing defense production base to developing brilliant weapons and robotic vehicles for reconnaissance, mine clearing, etc.

In spite of the spread of microelectronics technology into numerous applications, the present state of the art in the AI/robotics-related component technologies is not sufficiently mature from a systems perspective to field stand-alone robotic fighting elements. Army R & D efforts should be initiated in the relevant component technologies, and feasibility demonstrations begun, using existing technology to provide directions for future R & D efforts as well as to aid in the development of applications concepts.

In order to utilize AI/robotics in the near term, it will be essential for the Army to use a combined human-robot system in many cases. The best near-term solution will be a balance of human and machine capabilities, with the understanding that the balance can shift over time. This approach allows for early introduction of robotic elements in Army maneuver forces with existing technology, and a gradual and natural transition to more autonomous intelligent robot systems, where these are viewed as the most effective end states.

It is the opinion of the Subgroup that the Army should work on all aspects of the intelligent robotic system in order to make it apply to the broadest possible range of military and industrial applications, developing the technology for the next generation robotic systems in terms of the best of the advanced technologies associated with sensing, microprocessors, precision encoders, computer architecture, etc., to achieve an integration far superior to that presently available.

The Subgroup further believes that the limited availability of adequate numbers of scientific and engineering personnel (S & Es) trained in the relevant emerging technologies will be a primary pacing factor on the successful development of Army AI/robotics applications. The number of such individuals who are currently experienced enough and qualified to do research and development in AI and robotics is a very small portion of the national S & E workforce. Nationwide competition for appropriately trained S & Es will be increasingly keen as a result of the high payoff promised by these technologies to a wide spectrum of the defense and non-defense sectors of the economy. The Army will be highly vulnerable to the effects of this very limited national supply and capacity to educate S & Es trained in the emerging AI/robotics technologies. It has not had any ongoing AI/robotics research and development either in-house or with the private sector, including the Universities.

Current AI/robotics efforts at such Army locations as USAETL, CECOM, ARI, and the Army Model Improvement Program (AMIP) are all very recent and are experiencing difficulty in acquiring adequately trained S & Es. Although there is willingness to retrain new and experienced personnel, there is a lack of coordinated know-how and long term support to accomplish such retraining effectively. The Army needs a more focused plan than it presently has for the development of the needed human resources as part of its AI/robotics program.

Recommendations: In broad terms, the Army is encouraged to support the development of human resources in the areas of computer science and engineering, microelectronics, and information systems. Sensor technology, especially automated imaging, is the key to advancing the capabilities of smart machines and weapons. Improved data link technology will be another fruitful area for investigation. Although artificial intelligence is still in an early stage so far as successful applications are concerned, the knowledge-based expert systems show promise for the intermediate term. It would appear that the area with the quickest short-term payoff would be medical diagnosis followed by chemical identification.

Other AI areas with promising leverage in Army systems include: (1) pattern recognition, including automatic target cueing, (2) speech recognition, (3) adaptive sensing, (4) heuristic self-adaptive programming. Area (1) is closest to fruition within this group. Speech recognition (2), i.e. hands-off operation for weapons systems, would be extremely valuable on the battlefield and in complex vehicle system environments if it could be made close to error-free. This area is in an early stage of development. Adaptive sensing (3) is a systems concept with the possibility of future AI growth. A multi-sensor system is envisioned that would encompass a range of the electromagnetic spectrum in addition to acoustics, chemical, radiological, etc., and would provide the best combination for systems knowledge through changing conditions, deception and clutters. These systems bear a relation to heuristic programming (4), an exciting and still nebulous concept.

In addition to sensor technology (machine vision, etc.), locomotion is an aspect of robotics in which the Army has special interest. Efforts in reconnaissance vehicles (ground and air forward observers) are especially appropriate.

- We recommend that the Army support:
  - the DARPA project on Adaptive Suspension Vehicles,
  - the Marine Corps Robotic Program, NOSC/Hawaii in reconnaissance vehicles.

Artificial intelligence and robotics involve four of the five major Army research thrusts, namely VISTA, distributed C^3I, brilliant munitions, and the soldier-machine interface. It is assumed that there will continue to be rapid development of imaging array, millimeter wave and VHSIC/VLSI technologies. Given this, and the fact that many aspects of artificial intelligence are still in their early technical growth stages,

- It is recommended that the Research Subgroup of the Army Science Board be charged with monitoring the progress of AI in its various research aspects through the development process.

Table 3 comprises a display of potentially productive research areas, together with their relationships to the Army research thrusts. The best proposals received in these areas should be the ones funded to develop the Army technology base in AI and robotics. The Tables primarily address the hardware side of the soldier-machine interface. It is worth pointing out again that research directed at the human side must be supported as well, if the full potential is to be realized.

The research effort that must be mounted if AI and robotics are to be incorporated into a broad spectrum of Army programs in a timely fashion calls for the earliest possible release of 6.1 monies to the Army laboratories and to the academic community within which these problems are already being addressed in basic research form. In the latter case, it is noted with concern that both AI and robotics research are presently buried in the Electronics Section of the Army Research Organization (ARO) where they must compete for funds with numerous other programs.

- It is strongly recommended that an infusion of funds specifically allocated to AI and robotics research be made available to ARO at the earliest possible time to be directed to institutions having established programs of expertise in these fields.

Personnel: In order to address the human resource problems through Army-sponsored research, the Subgroup further recommends that:

- ARO contracts with Universities require institutions to accept responsibility for the development of the talent pool as well as for technical contributions. In particular, such contracts should include:

  - liberal funding of research assistantships for graduate students, part-time work opportunities for undergraduates, and grants for both instructional and research equipment;

  - encouragement for non-Army graduate and undergraduate students to find temporary employment (summer, co-op, part-time) with Army AI/robotics oriented R & D organizations;

  - encouragement for full-time faculty in the projects to spend

Table 3

FUNCTIONAL ELEMENTS OF ROBOTIC/AI SYSTEMS	ROBOTICS/AI RESEARCH RECOMMENDATIONS FOR TECHNOLOGY BASE DEVELOPMENT		RELATIONSHIP TO MAJOR ARMY RESEARCH THRUSTS
SENSORS Collect information pertaining to the environment.	• Fine resolution 2-D imaging sensors • 3-D imaging sensors • Sensors for smart hands (tactile, force-torque, artificial skin) • Multispectral sensors	• Range sensors (acoustic, laser) • Robot joint position sensors • Inertial reference sensors • NBC sensors • Temperature	• VISTA • Distributed C^3I • Brilliant munitions • Soldier-machine interface
SENSOR/PREPROCESSOR Extraction of key information.	• Gray-scale preprocessing • 3-D data processing	• Filtering • Integration of "chip" technology at sensor	• VISTA • Brilliant munitions • Distributed C^3I
MACHINE VISION Interpretation of visual images.	• Statistical models for scenes and images • Shape recognition algorithms • Image restoration • Image segmentation	• Multispectral feature extraction • Model matching • High speed computer architecture • Motion detection • "Chip" technology	• VISTA • Brilliant munitions • Distributed C^3I • Soldier-machine interface
CONTROL SYSTEM Simultaneous management of command signals and control variables.	• Quantitative modeling of robot systems • Integration of real time vision with manipulation • Algorithm development for structuring multi-dimensional robot sensor data • Hierarchical controls and control logic systems	• Robot task modeling • Intelligent controls (integrate speed, recognition, image analysis, data base analysis, decision making, and learning) • Dynamic control for manipulation • Fault tolerant control techniques for robotic systems	• VISTA • Brilliant weapons • Soldier-machine interface
OUTPUT/EFFECTORS Devices that produce certain types of motion and perform specific tasks.	• Manipulator arms • Intelligent legs	• Intelligent hands • Direct end of arm sensing	• VISTA • Brilliant weapons

Table 3 (continued)

FUNCTIONAL ELEMENTS OF ROBOTIC/AI SYSTEMS	ROBOTICS/AI RESEARCH RECOMMENDATIONS FOR TECHNOLOGY BASE DEVELOPMENT		RELATIONSHIP TO MAJOR ARMY RESEARCH THRUSTS
MANIPULATION Use of mechanical arms and hands to move objects.	● Lightweight/high torque materials for electric motors ● Integration of AI in prime mover design ● Kinematic geometry of multi-robot systems	● Manipulator kinematics ● High speed manipulation ● Improved power transmission devices	● VISTA ● Brilliant weapons
MOBILITY/LOCOMOTION Navigation and propulstion.	● Visual obstacle avoidance/ navigation ● Feedback control for legged machines ● Teleoperation techniques ● Active suspension	● Propulsion techniques for high mobility vehicles ● Programming languages for control of locomotion	● VISTA ● Brilliant weapons
COMMUNICATION Transmission of information of the status and actions of robot elements to and from the control system and to and from a master station.	● Teleoperation ● On-board processing/bandwidth reduction ● Human monitoring of robot actions	● Interaction of sensory information and data bases ● Improved data link technology (LPI/AJ/relays)	● VISTA ● Distributed C^3I ● Brilliant weapons ● Soldier-machine interface
ARTIFICIAL INTELLIGENCE The interpretation of information by a machine at a level of sophistication that includes the ability to abstract.	● Knowledge representation (data/ doctrine, procedures, assumption) ● Acquisition/Integration of new knowledge	● Reasoning/Deduction ● Heuristic search techniques for solutions	● VISTA ● Distributed C^3I ● Brilliant weapons ● Soldier-machine interface
APPLICATIONS R & D	● Reconnaissance vehicle with terrain analysis capability ● Intelligent integrated vehicle electronics - $V(INT)^2$ ● Automated supply point for rapid loading/unloading ammunitions	● Intelligent/Autonomous weapons ● Intelligent maintenance systems	● VISTA ● Distributed C^3I ● Brilliant weapons ● Soldier-machine interface

summers and/or sabbaticals and do consulting as staff members of Army R & D organizations with AI/robotics responsibilities.

The present highly constrained supply of S & Es trained in AI/robotics is an example of the broader problem addressed by the Army Science Board in its 1982 Summer Study of Science and Engineering Personnel. The Subgroup endorses those recommendations as applied to AI/robotics. Specifically,

- Army R & D organizations assigned responsibilities for the various recommended AI/robotics applications should be strongly linked with the ARO-funded academic research programs for both technology transfer and S & E resource development.
    - Assign and physically relocate if necessary current Army personnel qualified to do AI/robotics research so that they can become part of the University-based project staff.
    - Give educational leaves-of-absence and organizational support to junior level Army S & Es as graduate degree-seeking students within these projects.
- Some Army scholarships, both civilian and ROTC, which carry a required period of Army employment upon graduation should be designated for students majoring in AI/robotics technologies.
- Industrial contractors associated with AI/robotics-tasked Army R & D organizations should be encouraged to fully exercise DAR (Defense Acquisition Regulations) cost recovery positions for employee educational cost and equipment gifts.
- Army R & D organizations with developing AI/robotics expertise should form liaisons with regional Universities to expand the total size of the technical community with emphasis on use of Army S & Es as faculty.

Factors Affecting the Introduction of New Ideas into the Army

Credible scenarios are needed to frame the uncertainties and deficiencies of Army capabilities, which must then be evaluated in terms of their importance to the success of the Army's missions. Airland Battle 2000 was used as a background for the study described in this report; it will be to the Army's benefit to view AI and robotics from the perspective of such others as might be developed by its own experts.

New ideas must take into account the tremendous investment of resources and ongoing momentum of existing inventories, if they are to be useful to the Army. These include platforms, sensors, and communication links, as well as logistics support, training, etc. In considering the value of a new idea, very substantial calculated benefits should be demonstrated in contrast with the cost of not using the idea. The cost/effectiveness should be at least three to one, unless it can be shown that the situation is desperate and hence cost/effectiveness superiority is not necessary in the face of a proposed solution that gives reasonable hope of producing an acceptable mission. The ultimate exchange ratio should be measured in terms of campaign objectives, i.e. "What is the cost of stopping a Pact attack on NATO versus the cost of losing Western Europe?"

Preplanned Product Improvement (P^3I) is seen as an important ingredient of successful technology insertion, as is the selection of high priority problems capable of best solutions by means of AI/robotics technologies. The recommended Army Demonstrators and the examples selected for the technical recommendations of this report fall into this class of problems.

MANAGEMENT CONSIDERATIONS

Criteria and Approach

The rapid introduction of appropriate technology into weapon systems rests heavily not on the innovation of entirely new systems, but rather (a) on the enunciation of requirements that lead to efficient modernization and production closer to the state of the art, and (b) on the orderly implantation of evolving AI technology into the weapon system development cycle. Long term technology introduction, in contrast, rests heavily on consideration of new doctrines and tactics in light of the new military opportunities offered by AI and robotics. Table 4 is illustrative.

Table 4

FUNCTIONS	STRUCTURES: OLD	STRUCTURES: NEW
OLD	Cost and Personnel Risk Reduction Short Term	Usually Difficult to Justify Intermediate to Long Term
NEW	New Operational Concepts Cost/Risk Reduction Short to Long Term	High Payoff Needed to Justify Cost and Delay Long Term Only

The introduction of these new systems should be guided by the potential performance of new and enhanced warfare functions, on the one hand, and by reductions in critical and high-risk manpower demands on the other. Improved warfare performance with the simultaneous lowering of demands for personnel, at constant or reduced life-cycle cost, is an achievable objective provided that the resulting efforts do not involve the development of new platforms.

The entire wealth of options and recommendations available, even within these constraints, is too large for meaningful priority ordering. Specific programmatic recommendations are therefore based upon review and judgement.

Table 5 presents a set of criteria governing the consideration of AI/robotics in the context of military acquisition. The dominant criteria for weapon systems appear to be: (1) force multiplier per weapon, and (2) percentage skilled manpower saved per weapon, assuming again that new platforms are not needed. Command and support personnel are presumed to be included in the requirements, a partially quantifiable concept to the military operations analyst, given some weighting factors for scarcity of skilled resources and personal hazard on the part of the personnel. Therefore, numerical assessment of the marginal cost/effectiveness of many of the alternatives and options should ultimately be possible, at least in part.

Table 5

PRINCIPAL CRITERIA FOR AI/ROBOTICS INTRODUCTION

1. New operational concepts, perhaps not previously feasible, and requiring a discrete step in doctrine and tactics, though not necessarily new hardware.

2. Technological leverage: solution of a problem with multiple and significant application in military systems.

3. Personnel cost savings, either in operations or support, resulting in reduced life-cycle costs. This would also allow moving personnel to other assignments.

4. Reduced workload for skilled MOS categories. Simple reductions of personnel are not satisfactory if they increase the required skill levels, particularly those in short supply, such as intelligence analysts, electronic maintenance specialists and missile maintenance specialists.

5. Reduced exposure for dangerous duties, such as ammunition handling, rescue decontamination, evacuation, and intelligence collection.

6. Improved decision-making under tactical stress conditions, including the introduction of AI assistance (but <u>not</u> usurpation of the Commander's judgement ability), including collection, analysis and fusion, execution and elaboration of decisions, and dissemination.

7. Avoidance of the introduction of new support problems in the process, including additional needed operational skills, mobility, support and maintenance.

Management Issues

Considering Army management issues in the light of weapon system acquisition, the facts are that (1) a technological generation now spans about 4 years, and (2) a single weapon system development program now spans about 8-15 years, or 2-4 technological generations.

The Army has been both diligent and consistent in training at all levels, to assure that each individual has minimal qualifications and a personal knowledge base for his or her job. However, it is noted that with a few exceptions, officers and civilians are not trained in how to write requirements. It appears that expertise in performing a mission is taken as equivalent to expertise in specifying future requirements. This is particularly untrue when the technology is considered not merely as a means to a pre-specified end, but rather as a contributor to the operational options themselves.

The lengthy development cycle exhibited by most major Army weapon systems is partially a product of the intensive and expensive work needed to test and qualify the mechanical elements (platforms, launchers or barrels, weapons) under severe worldwide environments and terrains. It is also a product of a management structure whose origins, although certainly incrementally rational and responsive to perceived needs, has the net effect of guaranteeing some degree of obsolescence. This problem is particularly acute in the case of such fast-track technologies as AI and robotics. In contemplation of technology-driven changes which may involve wholly new warfare options over the twenty-plus year life-time of a weapon system, the drafting of operational requirements is an art that must be learned and which must be supported by a solid and continuing appreciation of future threats and future technology by its authors.

Recommendations

The principal problems are managerial. The Subgroup thus makes the following recommendations:

- Establish a dedicated interim proponent and action officer, minimum level 06, for AI/robotics to implement and follow through the exploitation of these technologies in new and existing Army programs, the activity to be shaped by the success of present Army efforts in the field, including planned demonstrations. The activities should include:

  - information transfer to TRADOC about AI and robotics, and support to consider new requirement opportunities opened by the field;

  - recognition by the Department of the Army that a weapon system program occupies 3-4 generations of this technology, and the Program Managers must be instructed to utilize P^3I;

  - incorporation of AI and robotics annexes in JMSNS (Justification for Major System New Starts) and other key documents in the weapon system procurement cycle, with an eye toward utilizing P^3I as a vehicle.

- Establish a similar interim dedicated proponency for AI and robotics in DARCOM and TRADOC to determine mission priorities, define requirements, and develop doctrine and tactics.

- In the case of new and present requirements utilizing AI and robotics, give preference to the use of existing and current-development platforms, sensors, communication links, etc.

- Give preference to semi-autonomous, hybrid and supervised autonomous systems, with evolution to full autonomy only when indicated on a cost/benefit basis.

- Provide that the Army Model Improvement Program (AMIP) and other modeling programs incorporate the options of new operational concepts made feasible by AI and robotics.

- Establish an oversight committee consisting of representatives of the Army's materiel developer and user communities who have policy making responsibility, and consultant members of the Army Science Board, possibly Chairpersons of its functional Subgroups. The committee charge should include:

  - regular communication to TRADOC, DARCOM, DCSPER, Corps of Engineers, and the Office of the Surgeon General regarding present and projected AI and robotics trends;

  - coordination and communication regarding de facto user needs and developer capabilities before important decisions are made regarding the insertion of AI and/or robotics technology into weapon systems, training, doctrine, logistics support;

  - examination of the soldier-machine interface for each significant application to determine whether autonomy or support for human decision-makers (DSS) is the most effective goal of the system development.

The $V(INT)^2$ test bed and related activities highlight the need to consolidate major capabilities from several laboratories. AI and robotics may ultimately lead to a need to matrix manage, as well as to program manage the resources needed to assure successful programs. It is not appropriate to consider an AI Center, or even separate commodity management or program management structures organized purely for these pervasive technologies, but rather to incorporate them into the doctrines, tactics, and programs of the Army. <u>Designation of a single Army laboratory as the sole repository of its AI and robotics programs is specifically not recommended</u>.

AUTOMATED PLANT RECOMMENDATIONS

The commercial robotics industry is robust and can be expected to provide many devices that can be incorporated into manufacturing operations to provide high gains in productivity. It would thus be inadvisable to spend Army resources on specific factory-type AI/robotics developments. However, it is noted that the Department of Defense spends billions of dollars annually for a wide range of U. S. manufactured products and that inflation in the defense segment of industry exceeds that of industry as a whole. Contractor procurement and investment policies that would lead to reasonable utilization of robotics to reduce end costs should be encouraged by the Army.

The emphasis of this study was on the field rather than on the plant. Still, a strong, modern manufacturing technology base must be a valuable asset to DoD to acquire upgradable modules for continuing improvement of its materiel. Through its tight coupling to the nation's manufacturing sector, the Army can play a key role in diffusing smart weapon technology, particularly AI/robotics technology, to that sector while continuing its development for fighting purposes. It will be to the Army's ultimate advantage to determine whether any field equipment developed in-house has manufacturing plant applications, and subsequently to facilitate the transfer of such systems to the private sector. This implies de facto availability, i.e. security classifications at the lowest possible level. Examples of Army-developed systems that might be candidates for transfer to the manufacturing plant include expert support systems (ESS) such as those that might be designed for troubleshooting heavy vehicles or sophisticated electronic equipment, and aspects of the automated supply depot.

- It is recommended that the Army:

  - continue to support the Manufacturing Methods and Technology (MMT) programs that involve Flexible Manufacturing Stations;

  - assess Army-developed systems for their potential industrial value and facilitate the transfer of such systems to Defense contractors;

  - encourage procurement and investment policies that would result in reasonable utilization of robots to reduce final costs;

  - stress the development of such robotic components and systems as are unique to Army needs, coupling development of expert systems to support Army maintenance with expert systems to support Army manufacturing.

BRIEF SUMMARY OF RECOMMENDATIONS

APPENDIX A
TERMS OF REFERENCE

DEPARTMENT OF THE ARMY
OFFICE OF THE ASSISTANT SECRETARY
WASHINGTON, D.C. 20310

SARDA

30 OCT 1981

Dr. Richard A. Montgomery
Director of Corporate Development
R&D Associates
Post Office Box 9695
4640 Admiralty Way
Marina del Rey, California 90291

Dear Dr. Montgomery,

It is requested that you empanel an ad hoc sub-group of approximately eight Army Science Board members to examine Robotics programs and potentials for the Army. Robotics and artificial intelligence would appear to offer overall cost and manpower savings in production, tactical operations, and support.

The sub-group should review Army plans, the theory and technology base, and near term applications in both the public and private sectors. Specifically, the sub-group should address the following Terms of Reference:

- What opportunities exist for the Army to use commercially developed/modified industrial production machines in government owned facilities (e.g., ammunition plants, arsenals)?

- How could tactical applications of robotics and artificial intelligence increase combat capabilities and decrease personnel requirements (particularly in very hazardous tasks)? To what extent might overall costs be reduced?

- What applications of robotics and artificial intelligence should be made in the training, personnel, and logistics support areas? To what extent might machines be substituted for support forces?

I have asked Dr. Robert Norwood to be the cognizant deputy in OASA(RDA) for this sub-group. Dr. Frank Verderame, ODCSRDA, is the DA Staff point of contact.

It would be appreciated if this sub-group could complete their work and provide a final report and briefing by the end of July, 1982. An interim report should be planned for the Spring general membership meeting in March.

Sincerely,

Amoretta M. Hoeber
Deputy Assistant Secretary of the Army
(Research and Development)

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