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TECHNOLOGICAL ASSESSMENT OF FUTURE BATTLEFIELD ROBOTIC APPLICATIONS

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INTRODUCTION

The process of applying robotics to the battlefield appears to be, to a certain degree, concept driven. That is, a concept for a robotic system is generated, then its value to the military is assessed. Alternatively, detailed applications may be specified, then the concepts are generated. Neither approach represents the thorough, integrated procedure necessary for the optimal application of robotics by the military. A different approach is to examine the military application of robotics from a technological viewpoint. In this paper, we have considered two aspects of robotics technology: the basic technologies involved in the application of robotics, and the application process itself.

As the first step in discussing robotics technology, we must define the terms robot and artificial intelligence. Although numerous definitions of both are available, we will use those of the Army Science Board (ASB). The ASB defines artificial intelligence thus: "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." To the ASB, a robot is essentially the embodiment of artificial intelligence in a mechanical system. Or, as the ASB states, a robot is "a programmable machine that displays cognitive behavior and performs mechanical and manipulative functions similar to those performed by humans."

Several potential applications of robotics to military tasks are in various stages of conceptual development. These are listed in Table 1. Some applications are weapons oriented, such as intelligent mines, robotic flame throwers, and sentries. Other applications are oriented toward combat support and reconnaissance tasks. Some are very large systems, others are quite small. This list also includes applications that are not truly robotic at all. For instance, the brigade planning aid is an artificial intelligence system, packaged to help field commanders make quick decisions. And a maintenance training aid may or may not be robotic. For many military applications, the distinction between robot and artificial intelligence has become blurred; few examples of applications of robotics to military purposes do not include some degree of artificial intelligence.

Table 2 lists some, but not all, of the technologies required for the robotics applications listed in Table 1. Some technologies are closely allied with artificial intelligence, such as vision, guidance, and sensor fusion. Others are related to "mainstream" digital technology sensor systems, such as computer hardware and communications (especially of the secure type). Still other technologies are hardware oriented, such as energy storage systems, mobile platforms, and lightweight structures. Some of these technologies are being pursued primarily because of robotic

TABLE 1. SOME POTENTIAL APPLICATIONS

Intelligent Mines	Robotic Smoke Generator
Chemical RPV	Robotic Flame Thrower
NBC Recon	Brigade Planning Aid
Smart EOD Robot	Gunner's Aid
Missile and Rocket Loader	Maintenance Training Aid
Rapid Excavator	Tactical Reconnaissance Robot
Countermine Vehicle	Approach Sentry
Forward Ammo Handler	Light Fighting Sentry
Container Handler	Street Walker Robot

TABLE 2. SOME ENABLING TECHNOLOGIES

Vision	Tactile Sensing
Guidance	Advanced Computer Hardware
Navigation	Mobile Platforms
Sensor Fusion	Energy Storage Systems
Communication	Lightweight Structures
Planning	Expert Systems
Human Factors	Information Representation
Actuators	

applications. Different applications make different demands on the development efforts for the enabling technologies.

The potential applications of military robotics are fairly diverse, as are the enabling technologies. Ideally, the technologies would be systematized to emphasize the ones that make many things possible. However, the most important thing is to make sure that the driving factors that are most important militarily have the greatest impact on setting the research agenda. In other words, we must concentrate on enabling technologies for those applications in which we are most interested.

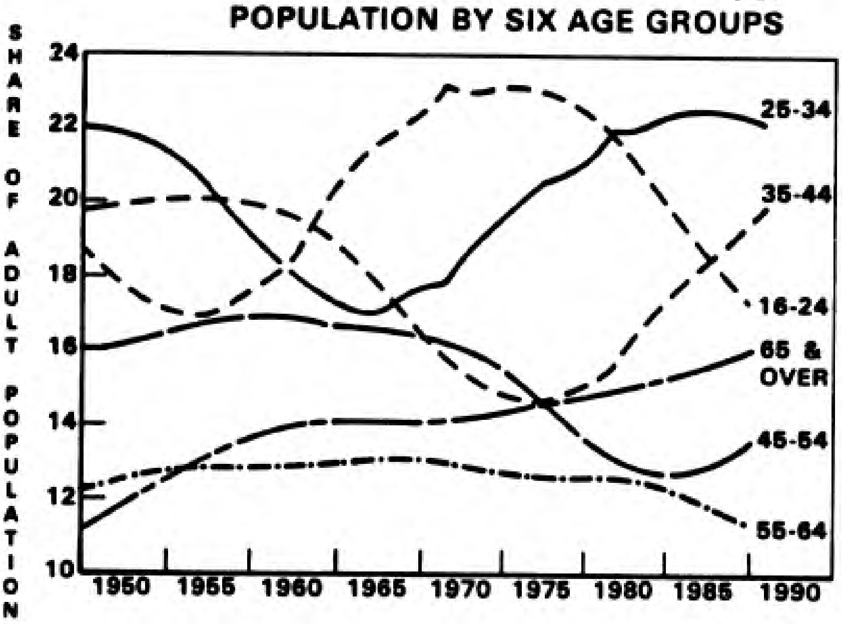
WHICH APPLICATIONS ARE IMPORTANT?

Battlefield robotics has two basic driving factors. The first is the substitution of high technology for people. The second is the overcoming of mismatch in mass. The first factor can be expressed in a number of ways, such as "reduced manpower intensiveness" or "increased tooth-to-tail ratio". These expressions acknowledge the fact that a battlefield is really no place for a human being.

The second factor reflects the large amounts of money required to field an army large enough to match a potential adversary's. We have finite quantities of personnel and money, which we would rather not have destroyed in combat, for reasons both humanitarian and economic.

Figure 1, which illustrates trends in the composition of the population as a function of age group, reveals one coming problem; the declining availability of potential military

FIGURE 1. AGE COMPOSITION OF THE ADULT POPULATION BY SIX AGE GROUPS



personnel. This figure shows that the number of people in the 16 to 24 age group, and to some extent in the 25 to 34 age group, will be declining toward the end of this century. Thus, it will be increasingly difficult to get the number of soldiers that might be needed, especially if our society does not change its conscription techniques.

From the economic standpoint, many demands will arise between now and the end of the century. For instance, a great deal of money will be required to convert present manufacturing techniques into computerized processes. Money will also be required for the service and the information sectors of our economy. In short, as Table 3 shows, our economic system is going through changes that will require massive capital expenditures. And capital expended on warfare or on building large standing armies is diverted from the economic sectors. Each soldier trained from the army represents a significant investment; therefore, the substitution of robots for soldiers will also be driven by future economic considerations.

Based on these long-term considerations, we have developed priorities for applying robotics to the battlefield. First, robotics must replace people in hazardous jobs, such as combat, since those people can be killed. Second, robotics should replace people in military jobs that may not be hazardous, such as in logistics, to decrease the overall investment in the armed forces. Third, robotics should be used in those applications, particularly in combat, that can overcome the disadvantage in numbers of personnel. Considering these priorities, we will next look at potential applications and what, in terms of technology, is required to bring them to actuality.

TECHNICAL PERSPECTIVE

Future battlefield applications of robotics can be evaluated on the basis of levels of complexity of the

TABLE 3. PER WORKER INVESTMENT

Current Levels of Per Capita Capital Investment by Economic Sector		Projected Per Capita Capital Investment By 1990	Projected Expenditures For Increased Automation Through 1990
Agricultural Sector	$55,000-$85,000	$55,000-$85,000	-0-
Industrial Sector	$25,000-$35,000	$35,000-$45,000	$180 Billion
Service Sector	$5,500-$6,500	$7,500-$8,500	$70 Billion
Information Sector	$2,000-$2,500	$8,000-$8,500	$360 Billion
			$610 Billion Total

applications. Each level requires certain technological attributes. And each higher level will require new attributes in addition to many of the attributes of the lower levels.

Level I: Computation, Storage, and Retrieval

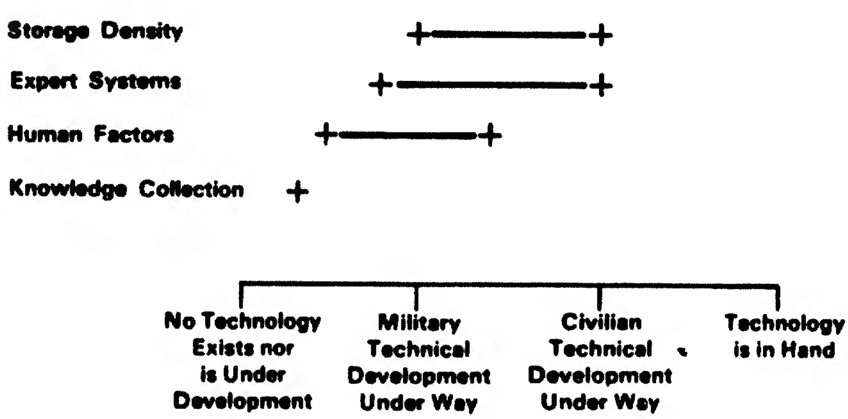
The first level applications include decision support systems and other such concepts that require improvements in computer technology, and in information storage and retrieval. We define a "decision support system" as a convenient, rapidly accessible source of information that provides assistance in analyzing or planning military operations. It is a very high speed source of reference information that can help a battlefield commander make decisions that he may not have time to make using a more traditional approach. An example of such a system is a tactical decision aid that is being developed at Battelle. This aid will assist wing commanders in selecting sensors and weapons on the basis of particular targets to be attacked.

Decision support systems require a number of technologies: storage density, expert systems (that is, artificial intelligence geared towards representing and utilizing expertise from human beings), human factors (the ability to provide a friendly interface between machines and users), and the ability to collect knowledge so that it can be used systematically.

Figure 2 displays these four technologies against a scale that reflects their relative level of development. At the low end of the scale, the technology does not yet exist; at the high end the technology is off-the-shelf; and in the middle the technology is either under development for military applications or for civilian uses. Development for civilian use is slightly better than development for military applications from the standpoint of minimum risk.

We see from this figure that storage density and expert systems are being worked on quite broadly. In the human factors area, the need for development is somewhat greater; that is, less directly applicable technology exists. Above all, however, improvements are needed in knowledge collection, which is crucial for this particular application. We have to be able to codify information such that it can be used by an automated system. That information has to be obtained from military

FIGURE 2. LEVEL 1—COMPUTATION, STORAGE, AND RETRIEVAL



experts, panels of skilled individuals, and so on. Thus, knowledge collection is a very important area of research, needed to make a reality of decision support systems that would be of use on the battlefield.

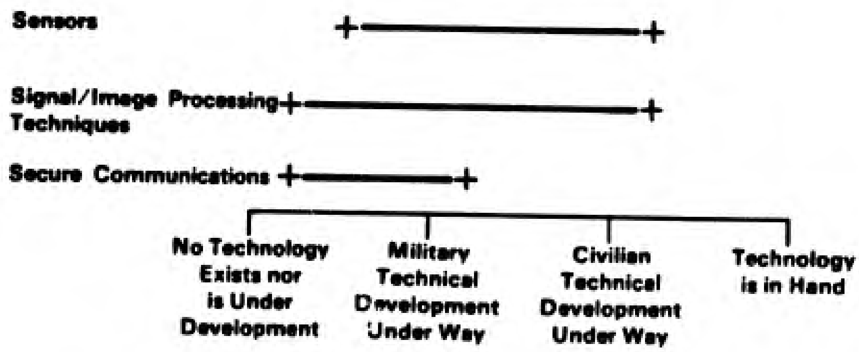
Three observations can be made with respect to Level I applications. The first is that the application is not of primary importance with respect to the selection criteria we set forth, although it may assist a commander in more efficiently utilizing his human resources. The second is that most of the technologies involved in making decision-support systems a reality for military applications are being worked on for other reasons. Finally, the major need is to understand the knowledge base involved; that is, to know what information a battlefield commander would have to have at his disposal in order to be more effective in the field.

Level 2: Sensing, Signal Processing, and Communications

Level 2 includes such applications as remote information collectors, which are capable of sensing, processing the information received by the sensors, and sending that information to some other location so that decisions based upon the information can be made. One example is a remote monitoring device for detecting vehicles. Another example is a package capable of sensing nuclear, biological, or chemical hazards, recognizing them, and recording the information so that the appropriate action can be taken. Key technology needs for such systems fall into the areas of sensors, signal and image processing techniques, and secure communications. The status of these technologies are summarized in Figure 3.

Sensors represent a very broad technology. In some cases, sensors are available off the shelf; in other cases, depending on the phenomena to be sensed, technology is at an infant stage. Signal and image processing techniques likewise cover broad areas. In some areas, we have very well-developed capabilities in processing data. In others, our capabilities are not as well-developed; for example, in visually recognizing certain objects as threats. The area of secure communi-

FIGURE 3. LEVEL 2—SENSING, SIGNAL PROCESSING, AND COMMUNICATIONS



cations, under intensive development for military applications, is the key to many important AI/Robotics applications.

Two observations can be made with respect to Level 2 applications. The first is that the application itself does spare people from hazardous jobs. Hence, the application is valid with respect to our overall requirements. The second observation is that some of the technology is available, but real gaps exist, particularly with respect to signal processing.

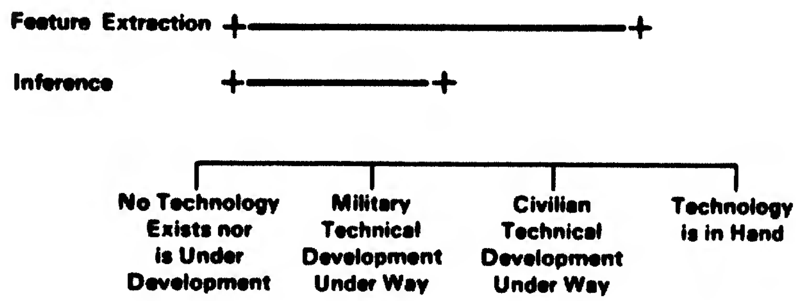
Level 3: Feature Extraction and Inference

Level 3 includes such applications as smart reconnaissance aids. These aids not only can sense information, but they can recognize features in the data that it acquires and it can infer from those features what the threat might be. That is, it makes higher-level decisions than a remote sensing package does. This aid can be defined as a device capable of filtering sensor data and, working with incomplete information, recognizing the presence of specific situations, based on sound, vision, or whatever other phenomenon is useful.

Figure 4 illustrates the state of the art of the key technologies. Feature extraction is the processing of sensor data to the point where specific signatures can be identified and recognized. This is a very broad area that is being addressed in the civilian sector for applications such as medical diagnosis and nondestructive testing. Inference is actually a broad series of techniques that interprets information to build a "mental image" of the situation being faced, even though all of the facets of that environment have not been observed directly. This also is an area that is under development, though primarily for military applications.

Two observations can be made on Level 3 applications. First, such applications are applicable to the selection criteria because they take

FIGURE 4. LEVEL 3—FEATURE EXTRACTION AND INFERENCE



the place of people in hazardous situations. Second, many technology gaps exist in this level, some of which will be very difficult to fill.

Level 4: Sensor Fusion and Decision Making

Level 4 is characterized by such systems as remote sentries and onboard diagnosticians. Here, the traits of interest are sensor fusion and decision making. Sensor fusion refers to the integration of data from a variety of sensors and the subsequent development of high level conclusions regarding the source of the stimuli. That is, if it looks like a tank, sounds like a tank, exhibits the electromagnetic interference of a tank engine, and so forth, then it probably is a tank. Such systems are capable of collecting a variety of data, of synthesizing information by analyzing and combining the data collected, and of making decisions as to the actual situation based on this information. The decisions have to be made in contexts that differ greatly from application to application.

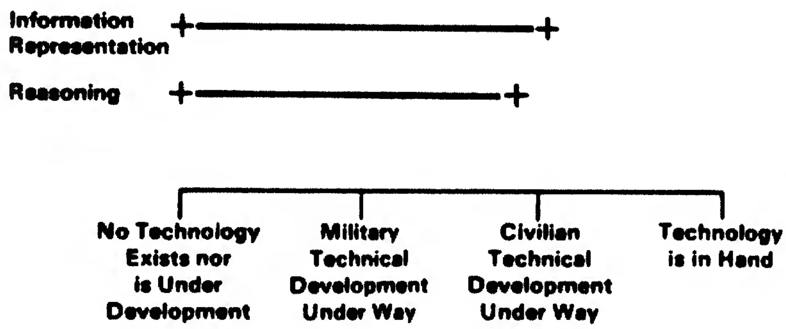
There are two main technological needs at this level: information representation and reasoning. As shown in Figure 5, both are subjects of a great deal of basic research. Information representation relates to how information can be represented and organized in a computer so that the kind of symbolic processing that is required can be conducted. Information representation techniques currently being applied are often restrictive and specialized due to computational limitations; hence, they are not as flexible as more generic schemes would be. Reasoning approaches as will need to be developed to deal generically with the information.

Three observations can be made with respect to Level 4. First, of our two examples, the remote sentry better fits our criteria than the diagnostician, but both are quite useful. Second, some technology is available for application. Third, to address the needs in the near future, it will be necessary to work on specific applications, rather than concentrate on generic solutions.

Level 5: Actuation

Level 5 encompasses, or adds actuation to, the suite of characteristics that we have described thus

FIGURE 5. LEVEL 4—SENSOR FUSION AND DECISION MAKING



far. It is exemplified by the concept of an autonomous weapon. An autonomous weapon can be defined as a device capable of identifying, locating, and locking on a target and firing. An example of such a system is the Navy Phalanx, which is a ship mounted, last ditch, air defense device that detects and tracks a large number of targets, categorizes threats, and launches weapons.

The principal difference between Level 5 and Level 4 systems is the inclusion of actuation. As shown in Figure 6, actuation is a very broad area. For advanced weapon system concepts, actuators do not exist. A second area in the technology is that of intelligent control. That is, the real time aspects of analyzing sensed information and directing actuation to take effective action. This is a technology that is not very far advanced.

Three observations can be made about Level 5. First, the technology needs tend to be application dependent, just as the actuator or the weapon system are application dependent. Second, energy-efficient controlled actuation could be improved. Third, the Level 5 applications, the autonomous weapons, are applicable to our selection criteria in that they enable military operations without as large an expenditure of manpower.

Level 6: Mobility

Level 6, the final level to be considered, incorporates mobility with the other aspects to produce devices of which an example is a "robotic warrior." A robotic warrior is a mobile, autonomous system, capable of carrying out a variety of military operations. Such systems could be designed for different media: air, land, sea, and undersea. Each would be capable of identifying threats and conducting military operations. Such systems may have to be "briefed" electronically prior to the start of an operation so that an excessive amount of onboard intelligence would not be required. This level clearly is the ultimate high payoff area, but it is an area in which a great many needs exist at present, and one in which progress will be incremental.

Some of the technology needs are shown in Figure 7. These relate to the areas of guidance, navigation, and

FIGURE 6. LEVEL 5—ACTUATION

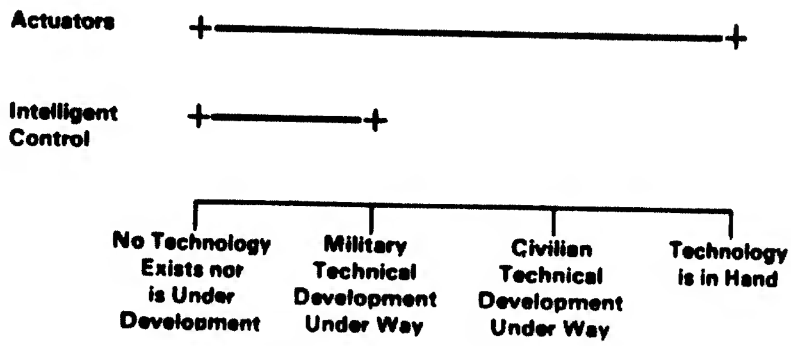
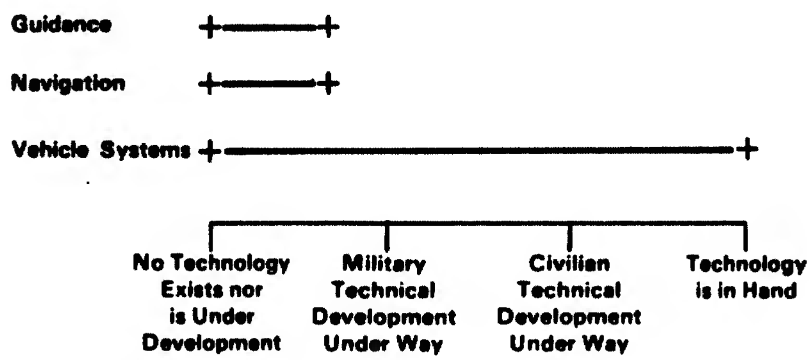


FIGURE 7. LEVEL 6—MOBILITY



vehicle systems in general. Guidance and navigation can be considered together in the sense that navigation is the ability to control one's path over a large scale while guidance is the ability to avoid short-range obstacles and to maintain one's attitude. The technology in both of these areas is at an infant stage, compared with what is required by the robotic applications. Ultimately robotic warriors will require guidance and navigation systems that are wholly self-contained and not dependent on satellite position systems or the like in order to be truly reliable. Although most approaches that would permit these robotic systems to navigate are related to the various mapping data bases currently under development, a great deal of basic work needs to be done.

Vehicle systems encompass a large area in that a robotic warrior may be a fully autonomous version of an existing military vehicle or it may be an entirely new vehicle system, which would have to be developed, possibly requiring different energy systems and propulsion systems.

Two observations can be made on Level 6 application. First, this is the ultimate payoff area; it is the complete removal of people from hazardous situations. Second, significant research needs exist, some of which can be handled generically, such as autonomous approaches to guidance and navigation. Others need to be considered specifically, particularly in the case of vehicle systems and some of the supporting technologies.

APPLICATIONS PERSPECTIVE

For the most part, current efforts to develop robotic military systems are driven by selected applications which have specific technology needs. This is an important first step in the implementation of robotics in the military, but it is a near-term approach. By assessing robotic battlefield applications by generic levels of technical complexity, a different perspective on future applications of robotics is achieved. The generic applications levels reviewed in this paper have identified basic technology gaps that will impact the future implementation of robotics. Both of these approaches however, tend to interface robotics into current military strategies.

Initial industrial applications of robotics were similar in approach. Robotics were assessed with regard to their application to existing processes and equipment. The benefits of applying robots were increased substantially, however, in those cases where it was possible to modify the environment to take advantage of all of the robot capabilities. This involved such efforts as the design of work stations around the robot and the design of the product to facilitate robotic fabrication.

The current applications of robots are, without a doubt, important to the upgrading of our military forces. Not only do they increase the efficiencies of current systems, but they provide an initial mechanism for interaction between military strategy and robotics. The technologies developed for each application also impact future applications. However, as in the industrial applications, military application of robotics, particularly in the battlefield, should be assessed in the long-term. Current military strategies are based on the capabilities of the current soldiers. Implementing robots to replace soldiers in roles that have been designed around the soldier should be considered a short-term strategy.

Assessing future military strategies now in terms of both current and potential capabilities of robotics would allow the development of systems that fully utilize the capabilities of robots. Removing the soldier from the tank drastically changes the system requirements for the tank. This assessment should be a joint effort of both military strategists and technical experts in robotics and associated fields. This interaction would permit the evolution of concepts for applying robots directly to military needs, without preconceived biases based on the utilization of soldiers.

CONCLUSIONS

Projected shrinking of available manpower and funds for the military over the next twenty years will drive the military application robotics. The primary criteria for the application of robotics should be:

1) Replace soldiers in hazardous jobs;
2) Replace soldiers in non-hazardous jobs;
3) Increase the effectiveness of the individual soldier.

Current military applications of robotics, driven by specific identifiable needs, are intended to assist and support existing manpower. Future applications must be directed toward replacement of the soldier with fully autonomous systems.

Technologically, the military application of robotics can be classified by level of complexity, ranging from decision support aids to robot warriors. Each of these generic levels can be assessed with regard to their primary technologies, technology gaps and their potential suitability to a future criteria of soldier-replacement. Such an analysis indicates a need for future R & D in such areas as knowledge collection, signal and image processing, feature extraction, inference, information representation, reasoning and mobility. Basic research efforts in these areas will be necessary to effectively implement robotics in the battlefield.

Finally, battlefield robotic systems can have a significant impact on our military strategies. The true value of automation in the industrial setting is not realized until the design of the product reflects how it will be manufactured. In a similar manner, the application of robots on the battlefield will be enhanced by analyzing the missions in terms of robot capabilities, not in terms of the capability of robots to imitate soldiers.