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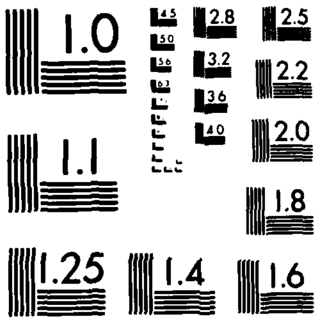

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The Army's Artificial Intelligence/Robotics Demonstrator Program (1), has resulted in expression of interest in a large number of potential autonomous vehicle applications within the Army Laboratory and TRADOC communities. In general this interest is based on the potential advantages of autonomous vehicle systems to improve efficiency of operations and to remove humans from hazardous environments on the battlefield. Examples of proposed autonomous vehicle applications are: intelligence collection, NBC reconnaissance, weapons platforms, transportation of supplies and material, and medical evacuation.

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TERRAIN NAVIGATION CONCEPTS FOR AUTONOMOUS VEHICLES (U)

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INTRODUCTION

The Army's Artificial Intelligence/Robotics Demonstrator Program (1), has resulted in expression of interest in a large number of potential autonomous vehicle applications within the Army Laboratory and TRADOC communities. In general this interest is based on the potential advantages of autonomous vehicle systems to improve efficiency of operations and to remove humans from hazardous environments on the battlefield. Examples of proposed autonomous vehicle applications are: intelligence collection, NBC reconnaissance, weapons platforms, transportation of supplies and material, and medical evacuation.

DESIRABLE AUTONOMOUS VEHICLE FUNCTIONS

The pacing problem for developing autonomous vehicles that can efficiently move to designated locations in the real world in the performance of Army missions will deeply involve aspects of machine intelligence for terrain navigation. A system must know where it is with respect to its destination, it must have knowledge of the terrain conditions which affect its movement in the area, and it must have the capability to develop plans for safe and efficient locomotion to its destination. While traveling along the planned route it must be capable of recognizing natural and man-made terrain features which coordinate with the plan. It must know its capabilities and limitations and the state of its operating system. It must be capable of recognizing obstacles and plan detours when necessary. It must be able to anticipate and detect active threats and actions, and plan accordingly for its own offensive/defensive actions. It must have a rationale for recognizing and dealing with real world activities such as operational characteristics of humans and other vehicles. And above all else, it must know when to ask for help in dealing with a problem for which it cannot solve. These autonomous functions can serve as general terrain navigation requirements for our discussion of autonomous vehicles.

Can we build a vehicular system that will autonomously perform these functions? The answer is "Yes, but definitely not today." Explanation of this answer requires reasons why today's technologies will not support autonomous vehicles and rationale for expecting these capabilities in the future. The paper presents these reasons and rationale by first defining functional requirements for an autonomous vehicle and its subsystems. Then the functional requirements are linked to technologies, the state of todays technologies and those expected in the future are outlined. Planned Army and DARPA programs in semi-autonomous and autonomous vehicles are outlined and shown to be the basis for optimism for the future of autonomous vehicles in the Army. Particular emphasis is given to terrain navigation concepts that will be generic for any type of autonomous ground vehicle.

The ideas presented in this paper are those of the author and not necessarily represent the policies or opinions of the U.S. Army Engineer Topographic Laboratories.

DEFINITIONS

The dictionary defines the noun "navigation" as the act or practice of navigating; especially, the science of locating and plotting the course of ships and aircraft. And the verb "navigate" means to steer, or direct, a ship or aircraft. Of course, for our purposes we will substitute "land vehicle" for "ship or aircraft" in these definitions. Thus within the intent of these definitions, terrain navigation for autonomous vehicles must involve the self-location of the route to be traveled and the self-steering along the selected route. For an autonomous military vehicle in a combat area, the system will have added requirements associated with its mission and the enemy that must be satisfied in the planning and conduct of the navigation process.

MISSION SCENARIO

The general terrain navigation requirements for an autonomous vehicle were outlined above; now those concepts will be recast into a mission scenario which will provide insight into the systematic nature of the required operations. The scenario will have two phases; the first phase will involve premission planning to select the route and the second phase will involve the movement of the vehicle to accomplish its mission. This is a rational division of the autonomous vehicle operations and conforms to the above definitions for autonomous navigation.

PREMISSION PLANNING

An autonomous vehicle can be expected to be given mission directives from some superior, human or machine. These directives will be coded for security purposes and provide mission goals rather than step-by-step instructions. Supplementary intelligence about the enemy and weather may be provided when available and when considered necessary for successful accomplishment of the mission. The vehicle's planning system must integrate this information with available data base information to formulate an operational plan as to how it will accomplish the mission goals given the constraints of the terrain, the enemy, the weather, time and the system's operational capabilities.

Global route planning must be sensitive to a number of factors. In general, a selected route must be vehicle dependent (e.g., tanks can go where jeeps cannot go and speed of travel is vehicle dependent). The selected route will be terrain dependent (e.g., steep slopes, selected soil conditions, water bodies, and natural and man-made obstacles can impede or deter movement). Inclement weather may reduce operational capabilities and thus decrease the degrees of freedom in route selection (e.g., reduce traction on slopes, result in flooded areas, and/or reduce visibility). The route selection must be mission sensitive (e.g., routes for direct fire engagements will be different than those for covert reconnaissance or rear area supply). The route must be threat sensitive (e.g., rear area routes planned differently than those near the FEBA or in areas of reported enemy activity; cover and concealment from airborne and ground threats need to be considered to improve survivability in combat zones). The route location might need to be communication sensitive for selected missions (e.g., signal propagation as a function of terrain and weather may need to be considered when the mission requires frequent reporting).

Following the route planning process, the system interrogates its internal sensors to ascertain if the mission can begin with the likelihood of successful completion. For example, given the planned route, the volume of fuel available, mission time constraints, and expected operational efficiency, the system can then determine its likelihood of success.

Next, the system activates its external sensors to verify operational capability and to ascertain if vehicle movement can be initiated safely. And finally, the vehicle system communicates acknowledgment to the supervisor along with information of its planning and status checks. These premission operations should only require a few seconds following receipt of the mission directive.

VEHICLE MOVEMENT

When all prior conditions are satisfied, the system initiates mission movement according to the global route plan. Vehicle position, determined by an internal position/navigation device, instanciates the route. Integration of vehicle position information, location of the planned route, and the associated terrain data base data with the appropriate interpretations of imaging sensor data provides data necessary for local path selection that leads to control signals for vehicle speed and steering. If the vision subsystem determines that the path is clear, the vehicle continues as planned using its steering controls as necessary to keep it on the selected route. If a potential obstacle is detected along the desired path by the vision system, the control system attempts to identify the obstacle and evaluate its significance. Based upon this evaluation, it proceeds or circumnavigates the obstacle after accomplishing local replanning. If the obstacle is judged to be a major barrier, then global replanning will determine a new route. During movement the vehicle communicates with the supervisor as required by the mission directive and it requests assistance if problems are encountered for which no solutions are available.

SYSTEM LEVEL FUNCTIONAL REQUIREMENTS

At the systems level for the autonomous vehicle system there are three major components: a Supervisor System, a Communications Relay System, and the Vehicle System. The Supervisor System is required to issue coded mission directives to the Vehicle System, provide current intelligence data to the Vehicle System relevant to the mission, monitor vehicle operations via a periodic and infrequent coded transmissions from the Vehicle System, and provide assistance to the vehicle when requested. The Communications Relay System is required to maintain line-of-sight links between the Vehicle and Supervision Systems in rugged terrain and/or when security of the supervisor's location is important, otherwise its use is optional.

The major functions required of the Vehicle System are: (1) reception and decoding of mission directives and intelligence data from the Supervisor System, (2) planning the "best" global route to accomplish the given mission, (3) checking vehicle status and operational conditions against the planned route, (4) acknowledging the Supervisor System message and providing information on the planned route and operational status via coded message to the Supervisor System, (5) acquiring images and external sensor data relevant to vehicle movement, (6) understanding sensor data in terms of the operational environment and mission objectives, (7) generating control signals to the steering actuators and speed controls, (8) monitoring internal sensors indicating operational performance and vehicle status, (9) reporting to the Supervisor System as required by the mission directive, and (10) requesting Supervisor System assistance when required.

SUBSYSTEM LEVEL FUNCTIONAL REQUIREMENTS

Only the major subsystems associated with the Vehicle System will be considered here. There are five such subsystems; each will be briefly described and its major functions outlined. Note that the vehicle chassis, although a very important component, is not addressed.

VEHICLE COMMUNICATIONS SUBSYSTEM

This subsystem provides an on-board message passing link between the Supervisor and Vehicle Systems. It is required to perform three roles: (1) receive and decode messages from the Supervisor System, (2) likewise, vehicle messages originating in the Vehicle Control Subsystem must be coded and interfaced to the transmitter, and (3) the Vehicle Communication Subsystem, acting as a mailman, must handle internal message querying and distribution of messages and data between processors within the vehicle.

EXTERNAL SENSOR SUBSYSTEM

External sensors associated with the Vehicle System need to include imaging and non-imaging sensors that collect information from the real world external to the vehicle. Imaging sensors should provide high resolution raw data from which information is extracted for local navigation. Selection of the imaging sensor type must be predicated upon the combined performance of the imaging system and the information extraction algorithms in the Control Subsystem to provide information for local navigation. In general, the sensing system must provide three-dimensional information, and have spatial resolution and spectral sensitivity necessary for rapid recognition of natural and cultural terrain features that affect vehicle movement. The non-imaging sensors should serve to expand the vehicle's awareness of its environment by collecting intelligence for purposes other than local navigation. In military systems these could include threat sensors which enhance vehicle survivability.

The External Sensor Subsystem also must include the mechanisms to point the imaging sensors and perhaps selected non-imaging sensors.

INTERNAL SENSOR SUBSYSTEM

The internal sensors are of two types: (1) a position/navigation device and (2) on-board sensors for monitoring vehicle status and operating conditions. All sensors should provide preprocessed data to the Control Subsystem upon demand.

The position/navigation device should provide geographic position information at a resolution and accuracy commensurate with the resolution of the vehicle's terrain data base. Additionally, this device must provide data for determining vehicle heading, and roll and pitch angles.

The on-board sensors for monitoring vehicle status and operating condition should provide preprocessed data that includes fuel status, measurements of engine parameters such as torque and oil temperature, and movement performance such as vehicle speed and engine torque.

CONTROL SUBSYSTEM

The Control Subsystem must provide capabilities for all on-board planning, control, and monitoring of the Vehicle System operations throughout all phases of its mission. In the planning and monitoring of the actions, the following functional requirements can be defined: (1) interpret Supervisor System mission directives and integrate information into the knowledge base, (2) accomplish global route planning from terrain data bases, mission directive, and vehicle performance capabilities, (3) check vehicle status and operational conditions with internal sensors against planned route requirements, (4) generate vehicle start-up plan, including starting engine, and collecting initial external sensor data, (5) monitor execution of global route plan during vehicle operation and generate subplans for minor corrections when deviations are detected, (6) plan data collection with external sensors, analyze sensor data using terrain data bases and knowledge bases for context, and generates information for local locomotion plans, (7) assess movement situation based upon planned route, sensor information, and vehicle status, (8) recognize and evaluate obstacles and accomplishes local route replanning when necessary, (9) generate contingency plans for operations when vehicle's internal sensors indicate vehicle status is abnormal and diagnostics confirm conditions, (10) monitor collected external sensor data for threats and plan appropriately when threats are detected, (11) plan and monitor execution of plan for recalibration of position/navigation device, and (12) prepare and format messages to Supervisor System.

Additionally, the Control Subsystem must control locomotion of the vehicle according to plans it generates. This is accomplished by preparing and sending messages to the actuators that control steering and speed. Pointing signals for external sensors and the vehicle's transmitter antenna are controlled in like manner.

ACTUATOR SUBSYSTEM

The Actuator Subsystem contains the electro-mechanical interfaces and mechanical actuators that respond to formatted messages from the Control System to manipulate steering and speed of the vehicle and pointing of its external sensors and the transmitter antenna.

TECHNOLOGY ISSUES ASSOCIATED WITH SUBSYSTEM FUNCTIONAL REQUIREMENTS

Each subsystem will be revisited with a brief description of the technological issues associated with the functional requirements. An estimate of the state of the technology and the expected progress will be provided for the requirements. This information will be used to generate implications for the time progression of autonomous vehicle system capabilities presented in the following section.

The functional requirements outlined in previous sections for an autonomous vehicle indicate the need for very powerful on-board digital computing capabilities. These systems are not available today, however they will be addressed within the DARPA Strategic Computing Program which will be outlined subsequently.

VEHICLE COMMUNICATION SUBSYSTEM

Reception and decoding of encrypted messages and the inverse of encoding and transmitting coded messages is well within the communications state of the art. However, if images must be passed by external communication channels, image bandwidth coding techniques are usually employed to reduce high bandwidth channel requirements. Image coding techniques using an average of a few bits per pixel are possible if some quality degradation can be tolerated. Transmission and reception of terrain data base data presents no special problems other than relatively long message lengths.

It is assumed that the Communication Subsystem would have one or more dedicated microprocessors to handle decoding, coding, and message handling tasks.

EXTERNAL SENSOR SUBSYSTEM

Real time acquisition of three-dimensional image data for an autonomous system presently restricts sensor systems to be of the active ranging type, e.g., a scanning laser ranging system such as the system ERIM is developing for the DARPA Adaptive Suspension Vehicle Program. This system can provide four-dimensional data: three dimensions, when calibrated, for spatial coordinates and one dimension for reflectance intensity which can be likened to an imaging single channel spectrometer. Present specifications for the ERIM sensor include: frame rate, 2 per second; scan range vertical, 60 deg; scan range horizontal, 80 deg; instantaneous field of view, 1 deg; range resolution, 8 bits; ambiguity interval, 32 ft; wavelength, 0.82 micrometers; weight, about 75 lbs; power, about 300 watts; and size, 26"x24"x14" (2). Reflectance data is not being used in the present sensor application.

Three-dimensional data extraction from passive sensors requires stereo imaging, e.g., dual imaging systems or extraction of pseudo-stereo from movement of a single imaging system. These techniques are presently too computationally intensive to be of value for an on-board data reduction system without VLSI/VHSIC computing resources. However, the DARPA Image Understanding community is actively addressing software and hardware for extraction of depth information from stereo images (see (3) for several articles).

Non-imaging sensors of value for threat detection and proximity sensing are found in acoustical sensors. Spectral analysis of passive acoustic sensor data can be used for source identification and arrays of these sensors provide directional information for locating noise sources (4). Low power active acoustic sensors provide means for proximity sensing for ranges of about 30 meters. If these acoustic sensors were employed on the autonomous vehicle, each would require digital processing facilities for threat detection and priority interrupt capabilities for emergency communication with the Control Subsystem to report the crisis.

INTERNAL SENSOR SUBSYSTEM

There are a number of techniques applicable to vehicle position determination and in-route navigation devices ranging from combined odometer and compass, on the low end in terms of cost and accuracy, to an aided inertial navigation system which is relatively expensive but very accurate. In between there are techniques such as GPS and PLRS coupled with a compass to provide the minimum requirements of vehicle position and heading. Each technique will have its own source of error, e.g., the inertial navigation systems have errors that are time dependent; therefore appropriate schemes for error correction or recalibration may be required.

Sensors for monitoring internal vehicle parameters and conditions appear to be well in hand. These can be coupled with fault detection diagnostics and performance prediction algorithms through micro-processors.

CONTROL SUBSYSTEM

As we have structured the subsystems for the autonomous vehicle, the Control Subsystem harbors the machine intelligence capabilities. There are two major pacing items of machine intelligence technology required for successful operation of an autonomous vehicle. They are planning and machine vision. Planning (often referred to as problem solving) is required at several levels. For example, interpretation of the mission directive in terms of mission goals and constraints; delineating a global route plan from the goals and constraints and a priori information of the terrain and enemy; navigating along the planned route using information obtained from external sensors for local navigation; replanning local routes around minor obstacles and invoking the global planner to circumnavigate major barriers; and planning in event of detected threats. If any portion of these planning functions are weak, then the system will have degraded operational capabilities that may lead to aborted missions if not provided assistance from the Supervisor System. Progress has been accomplished in machine planning, but the capabilities fall well short of requirements for an integrated system of planners needed for the autonomous land vehicle (5).

Likewise, machine vision has proven to be a very difficult problem area. While research in computer vision capabilities are progressing (5), the vision requirements for an autonomous vehicle system are not satisfied with todays technology and must be considered a pacing technology for autonomous vehicles. Perhaps, however, for the autonomous vehicle problem, a goal-oriented approach that is a subset of a total image understanding capability can be employed effectively to provide the required information within the Control System. For example, if one accepts that the globally planned route is a good first approximation of the desired route which requires only local tweeking, then machine vision tasks can be restricted to recognition of obstacles and terrain conditions along the planned route and finding obstacle-free paths where local replanning is necessary. Obstacle recognition may be made relatively simpler by providing more available information from the sensors, e.g., multispectral ranging data rather than single band laser ranging data.

The present state-of-the-art of complete autonomous robotic vehicles can be put into perspective by briefly describing the research systems of Hans Moravec at Stanford University and Carnegie-Mellon University (CMU) (6). In the mid and late 1970's Moravec built and conducted research with the Stanford Cart, an electrically driven four wheeled cart carrying a TV camera and communication gear. An off-board computer drove the Cart through cluttered spaces gaining its knowledge of the obstacle world entirely from broadcast images. The program would extract depth and obstacle information for the path planner and system controller. The system was reliable for short runs of about 20 meters, but it was slow. The Cart moved in 1 meter lurches every 10 to 15 minutes. The system was computationally limited and this led to very long experimental periods and precluded software control extensions. At CMU Moravec has a redesigned Rover system with increased mechanical and control system flexibility to support a wide range of research in perception and control. Rover is shaped like a barrel and has an omnidirectional steering system, a dozen on-board processors for essential real-time tasks, and a large remote computer and a high performance array processor. Internal communications are accomplished by message passing in a distributed control system (7). Expert modules control the operation of the sensors and actuators, interpret sensory and feedback information, build an internal model of the robot's working environment, devise strategies to accomplish proposed tasks and execute these strategies. Rover's research is just beginning and should be watched for future development in methods for handling autonomous vehicle control problems.

There are technology issues associated with on-board terrain data bases that require resolution prior to successful operation of a semi-autonomous or autonomous vehicle. For example, the optimum representations for spatial data, the amount of spatial data, and the quality of spatial data required for autonomous operations will need to be specified. The source of terrain data and its maintenance in terms of temporal variations will need to be addressed. Likewise, the representations of obstacle information in spatial data bases in a manner that facilitates a more efficient vision recognition capability, also is presently an open question.

One could argue that with a perfect terrain data base and a perfect inertial navigation system, there would be no need for a vision system. This is a mute argument, however, because no terrain data base is perfect at all times and the inertial navigation systems of today are also not without errors of their own. It can be said that the terrain data bases must be of higher quality early in autonomous vehicle development to make up for inabilities in the image understanding capabilities. As image understanding capabilities improve, terrain data base requirements can be relaxed.

Communication with an autonomous vehicle will require message understanding and preparation by the Control Subsystem. This will not be a pacing item, even though a natural language understanding capability will be needed in the future, because communications into and out of the vehicle can be required to be formatted with a limited vocabulary to obtaining an initial operational capability. These restrictions can be relaxed as our capabilities improve for natural language understanding.

ACTUATOR SUBSYSTEM

There appear to be no pacing items in the Actuator Subsystem. The technologies are well in hand, as demonstrated by results with teleoperated vehicle systems wherein vehicle actuators have been controlled via radio links for maneuvering remote vehicles (8,9).

PRESENT CAPABILITIES

ARMY AI/ROBOTICS - THE ROBOTIC RECONNAISSANCE VEHICLE

In the latter part of 1981 an AI/Robotics Steering Committee was established by the Assistant Director of Army Research Programs in the office of the Deputy Chief of Staff for Research, Development and Acquisition, HQDA, with representatives from the Army laboratory community and TRADOC (1). This lead to the preparation of plans for five AI/Robotic

Demonstrators, one of which was a Robotic Reconnaissance Vehicle with Terrain Analysis (10). These plans were evaluated and prioritized by the Army Science Board Ad Hoc Subgroup for AI/Robotics and the Robotic Reconnaissance Vehicle received highest priority (11). Funding for the AI/Robotics Demonstrators was removed from the FY84 budget, however, the Robotic Reconnaissance Vehicle is a line item within the FY85-86 budgets.

The purpose of the Robotic Reconnaissance Vehicle demonstration is to show the capability to plan and conduct reconnaissance vehicle operations for representative battlefield missions. The demonstration will center around a remotely controlled reconnaissance vehicle and its teleoperating control systems (12). Control of the vehicle for its battlefield tasks is divided into (1) operation of the vehicle and (2) performance of battlefield reconnaissance functions. The teleoperated vehicle will have remote controlled reconnaissance imaging and non-imaging external sensors, stereo cameras for remote navigation, a position/navigation system, remote control systems, and associated communication systems. Control of the reconnaissance vehicle will be accomplished from two teleoperator stations in a remote van. The reconnaissance station will have sensor displays, microcomputers, remote controls, sensor signal processor controls, and a military intelligence data base. The vehicle teleoperator station will have a stereo-image display, terrain graphics displays for route planning operations and monitoring vehicle location, microcomputers, teleoperator controls, and terrain data bases. Both stations will have provision for voice actuated displays.

Teleoperated systems are required to control remote vehicles today because the human-in-the-loop precludes the need for autonomous planning and vision technologies that are not yet mature for combat operations. Line-of-sight vehicle teleoperation technologies are well understood (9), however none of the approaches have effectively handled non-line-of-sight in the manner employed in the Robotic Reconnaissance Demonstrator. The new approach employs terrain data bases and a position/navigation device with computer graphics to indicate position of the remote vehicle at all times.

In addition to the Demonstrator plan, two studies related to the Robotic Reconnaissance Vehicle have been accomplished by the Jet Propulsion Laboratory: (1) a conceptual design of the terrain-navigator subsystem (13) and (2) a study that addresses research required for evolving the teleoperated system to an autonomous system (14).

OTHER VEHICLE EFFORTS

There are several other on-going R&D activities leading to autonomous vehicles. When taken separately, none have a critical mass to be successful in a significant degree of autonomy, mainly because the problems are too difficult to be solved with small isolated efforts. When taken together, these efforts indicate interest at the laboratory level from where operational systems will develop to meet future user requirements. For example, the Marine Corps has been supporting generic autonomous vehicle research at Naval Ocean Systems Center (15), the U.S. Army Missile Laboratory has been researching a remote missile launcher (16), the Ballistic Research Laboratory is exploring mobile mines (17). Several universities are researching autonomous vehicle techniques (16) and a number of industrial laboratories are into or positioning themselves for future semi-autonomous and autonomous vehicle programs.

FUTURE POTENTIALS

DARPA STRATEGIC COMPUTING PROGRAM

In October 1983 DARPA unveiled its Strategic Computing Program (18) that is designed to seize an opportunity to leverage recent advances in AI, computer science, and microelectronics to create a new generation of "machine intelligence technology." The program focuses on military applications requiring machine intelligence technology in a manner that requirements for technology stimulate or "pull" the creation of the technology base and provides ready environments to demonstrate prototype systems as technologies evolve. The initial program has three military applications: an autonomous land vehicle, a pilot's associate, and a carrier battle group battle management system. The program is structured so that technologies support the applications. Intelligent functional capabilities, such as vision, natural language, expert systems, navigation, speech, planning and reasoning, are emphasized. Hardware and software system architectures for high-speed signal processing, general purpose systems, symbolic processors, and multi-processor programming and operating systems are supported with VLSI microelectronics. The total program could amount to $600 million over the first five year period.

AUTONOMOUS LAND VEHICLE DEMONSTRATOR

The purpose of this demonstrator is the development of a broadly applicable autonomous navigation technology base rather than vehicle development. Yearly demonstrations are scheduled to showcase the evolving technologies. These demonstrations begin modestly and then build in a manner that "pulls" significant capabilities from the supporting technologies. For example, in 1985 the demonstration stresses automated navigation of 20KM of paved road with no obstacles at a speed of 10 KM/hr; in 1986, road following with obstacles at 20KM hr; in 1987, cross-country route planning in desert terrain; in 1988, road network route planning and obstacle avoidance and off-road maneuvering to avoid obstacles; in 1989, cross-country traverses with landmark recognition in desert terrain at 10KM/hr with replanning to circumnavigate impassable obstacles; and in 1990, mixed road and open terrain, 20KM of wooded terrain with isolated obstacles, and 50KM of paved road at 50KM/hr.

IMAGE UNDERSTANDING

Vision or image understanding research in the DARPA Strategic Computing Program directly supports the autonomous land vehicle demonstrator. This research has the long range goal to achieve passive navigation and reconnaissance capabilities for autonomous vehicles in the field. Incrementally, the goals of this program progress from modeling and real-time recognition of simple terrain with crude objects, to real-time recognition and navigation in complex terrain, to real-time reconnaissance tasks in a dynamically changing environment.

OTHER SUPPORTING TECHNOLOGIES

The DARPA Autonomous Land Vehicle Demonstrator program will also benefit from other supporting technologies such as natural language understanding for man-machine interfaces in handling mission directives and communications from the vehicle. Expert systems technologies will support representation and inference techniques in very large knowledge bases and automated knowledge acquisition directly from experts, text, and data. Hardware and software systems architectures will significantly improve processing speed in multi-function processors with very large memories.

OPTIMISM FOR ARMY AUTONOMOUS VEHICLES

Those interested in Army autonomous land vehicles have every reason to be very optimistic about the future. The Army's Robotic Reconnaissance Vehicle Demonstrator will showcase todays combat mission capabilities in 1986. This system can evolve as the DARPA Autonomous Land Vehicle Demonstration program, with supporting technologies, spin-off capabilities to produce subsystems and techniques that can be transferred. The Army program thus provides a base and the DARPA program, having critical mass and world-class performers, provides the necessary research and development capabilities to solve the pacing problems that face us today in our quest of an autonomous land vehicle.

CONCLUSIONS

The Army's Robotic Reconnaissance Vehicle Demonstrator program will provide the base for evolving to an autonomous capability from today's manual techniques. Functional requirements for autonomous land vehicles can be defined in general terms and technologies can be related to the requirements. The pacing technologies are associated with machine intelligence and the major deficiencies are in the areas of planning and image understanding. At a lesser level there is concern with more powerful computing systems and system control techniques. There is reason to be optimistic about future progress in these technology deficiencies with the introduction of DARPA's Image Understanding and Autonomous Land Vehicle Demonstrator efforts in their Strategic Computing Program.

Autonomous land vehicles for combat operations are not possible today, but there is definite optimism that we will have the capabilities for Air/Land Battle 2000.

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