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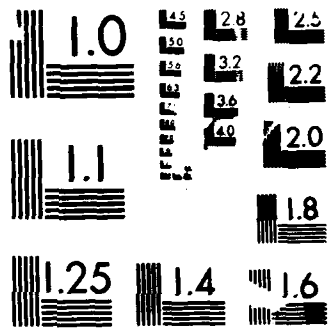
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DEVELOPING TECHNOLOGIES FOR ARMY
AUTONOMOUS LAND VEHICLES (U)

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INTRODUCTION

The battlefield, as described in AirLand Battle 2000, will be characterized by considerable movement, large areas of operations in a variety of environments, and the potential use of increasingly sophisticated and lethal weapons throughout the area of conflict. Opposing forces will rarely be engaged in the classical sense and clear differentiation between rear and forward areas will not be possible. To operate effectively under these conditions the Army must bring new technologies to the battlefield. In 1981 the Army commissioned a study to suggest applications of artificial intelligence (AI) and robotics technologies in Army combat and combat support functions [1]. One hundred applications were suggested and these were divided into ten categories. The technologies were indicated to be immature for a large number of the potential applications, but the number of key technology elements associated with AI and robotics is relatively small. Thus development of future Army systems that integrate AI and robotic capabilities to more effectively move, shoot, and communicate on the battlefield may depend on the maturity of relatively few key technology elements. Autonomous land vehicles represent one subclass of these systems which has been a subject of increasing Army interest [2]. The potential value of such systems for unmanned weapons platforms, reconnaissance, resupply, etc., has been recognized at all levels [3,4]. This has created a dilemma; the user community has initially expressed a need for these systems, while the laboratory community has indicated a present lack of technological maturity.

This paper describes research, development, and demonstration of robotic land vehicle technologies and a recent R&D partnership between the Defense Advanced Research Projects Agency (DARPA) and the U.S. Army

Tank and Automotive Command (TACOM). The partnership is significant because it addresses both horns of the dilemma. The DARPA program focuses on developing the key technologies for autonomous vehicle navigation and provides a critical mass of dollars and talent to meet these objectives, while the Army program integrates DARPA and other technologies to provide demonstrations of value to the user community.

DARPA STRATEGIC COMPUTING PROGRAM

The DARPA Strategic Computing Program (SCP) was a new initiative in October 1983 [5]. It was designed to seize an opportunity to leverage recent advances in AI, computer science, and microelectronics and create a new generation of "machine intelligent technology." The program focuses on three military applications of machine intelligence technology: (1) the Autonomous Land Vehicle, (2) the Pilot's Associate, and (3) the Battle Management Advisors. Each application has yearly demonstrations of prototype systems of increasing complexity and the requirements of each demonstrator have been structured to "pull" new capabilities from the technology base, rather than "push" available capabilities at the user. The SCP has a large built-in technology base research program addressing areas of advanced computing technologies such as image understanding, expert systems, voice recognition, natural language understanding, and microelectronics. These technology efforts are appropriately linked to the demonstrators. The expected expenditures of the SCP is $600 million over the five year period 1984-1988.

THE AUTONOMOUS LAND VEHICLE PROGRAM

The ALV focuses on development of a broadly applicable autonomous navigation technology base, and not vehicle development per se. The primary requirement of the ALV testbed is to provide a platform with flexibility to integrate and demonstrate the SCP technologies. Objectives of the ALV yearly demonstrations are:

1985 - <u>Road Following Demonstration</u>: Vehicle traverses a 2 km preset route on a paved road at speeds up to 10 km/hr. Forward motion only and no obstacle avoidance required.

1986 - <u>Obstacle Avoidance Demonstration</u>: Vehicle traverses 5 km road course at speeds up to 20 km/hr; must recognize and maneuver to avoid fixed objects that are small with respect to road width.

1987 - <u>Cross-country Route Planning Demonstration</u>: Vehicle plans and executes a 5 km traverse of open desert terrain at speeds up to 5 km/hr. Demonstrates soil and ground cover typing.

1988 - <u>Road Network Route Planning and Obstacle Avoidance Demonstration:</u>

Vehicle plans and executes a 20 km point-to-point traverse through a road network at speeds up to 20 km/hr using landmarks as navigation aids. Demonstration includes map updating and off-road maneuvering to avoid obstacles.

1989 - Cross-country Traverse with Landmark Recognition Demonstration: Vehicle plans and executes a 20 km traverse through desert terrain with obstacles at speeds up to 10 km/hr. Demonstration includes replanning when confronted with impassable obstacles.

1990 - Mixed road and Open Terrain Demonstration: Vehicle plans and executes a 20 km traverse in wooded terrain with isolated obstacles and a 50 km traverse on paved and unpaved roads at speeds up to 50 km/hr. Route planning includes multiple goals.

Martin Marietta Denver Aerospace, Denver, CO, won competitive competition as ALV integrating contractor in August 1984 and has responsibilities for all project research and development except vision algorithm development. In this regard, University of Maryland directly supports the ALV project and the Technology-based Vision contractors will provide vision algorithm support for the future. Martin Marietta is supported by two additional contractors; Hughes AI Research Laboratory provides planning software support and the Environmental Research Institute of Michigan (ERIM) is developing and supports the laser ranging imaging system. The U.S. Army Engineer Topographic Laboratories will produce the digital terrain data base for the Martin Marietta test area.

AUTONOMOUS LAND VEHICLE TECHNOLOGIES

FUNCTIONAL REQUIREMENTS FOR AUTONOMOUS LAND VEHICLES

Autonomous mobility in a dynamic unconstrained environment requires that a system sense its environment, model critical features from the sensed data, reason about the model to determine a mobility path, and control the vehicle along the path. Functional subsystems could be:

SENSORS: The sensors subsystem must have the capability to sense critical environmental features having impact on mobility.

PERCEPTION: The perception subsystem must be able to process sensor data to create a perceptive model of the environment.

REASONING: The reasoning subsystem must be capable of reasoning about the perceptive model and information from the knowledge base to determine appropriate mobility strategies.

CONTROL: The control subsystem must execute stable control to travel along the selected path.

KNOWLEDGE BASE: The vehicle system must have access to knowledge about the environment, the capabilities of the vehicle, the mission requirements, and characteristics of the environmental features.

VEHICLE: The vehicle system must have a stable platform capable of carrying necessary sensors, computers, electronics, and communications equipment at required speeds for on-road and cross-country travel.

HUMAN INTERFACE: The vehicle system must interface with a human operator to accept mission goals, report on system status, and assist in problem solving.

A general scenario for operation of the ALV platform integrates these functional requirements. The mission begins when a human operator specifies mission objectives and constraints to the vehicle system via a man/machine communications interface. The reasoning subsystem interprets mission goals and constraints and decomposes them into subgoals. From information in the knowledge base and the subgoals, the reasoning subsystem prepares a global plan of its route and actions. Upon completion of the global planning, the reasoning subsystem provides goals to the preception subsystem for decomposition into tasks to be accomplished by the sensors subsystem. Scene data acquired by the sensors subsystem along the proposed route is passed to and processed by the perceptual subsystem to produce a high-level symbolic model of the environmental features along the route. If no obstacles are detected, the reasoning system updates its position along the route and issues commands to the control subsystem to move along the route. If obstacles are detected, the reasoning subsystem initiates local data acquisition and planning to effect circumnavigation around the obstacle. If local planning produces no acceptable circumnavigation path, the global planning process is reinitiated from the current location. And if no acceptable route is found, the vehicle requests assistance from the operator.

DARPA TECHNOLOGY-BASE VISION FOR THE ALV

The Technology-base Vision efforts of the SCP are focused on issues that are impediments to real-time image understanding in outdoor environments. The research addresses the perceptual subsystem in above discussion and has issues that include development of: robust and general models for objects and terrain features; general representation schema for computer vision primitives and knowledge; the ability to generate 3D scene descriptions; spatial reasoning capabilities; massive computational speedups at all levels of the computer vision problem; sound theoretical foundations for vision process models; techniques for dealing with the dynamic aspects of rapidly changing environments;and integrated vision systems that can perform complex tasks in real time. The Technology-base Vision efforts address these issues with a substantial set of contractors which include: Carnegie-Mellon University (CMU); SRI International (SRI); Advanced Decision Systems (ADS); Stanford University (SU); General Electric Corporation (GE); Hughes AI Research Laboratory (Hughes); University of Massachusetts (UMass); University of Southern California (USC); Honeywell Corporation (Honeywell); University of Rochester (UofR); Columbia University (CU); and Massachusetts Institute of Technology (MIT). A brief description of the research responsibilities of these organizations follows.

New-Generation Vision System Development (CMU): A new-generation vision system is to be developed for dynamic image understanding environments for ALV applications. A system framework will be built to accommodate integration of component research tasks outlined below.

Common Vision Representation Schema (SRI): Different representation schema needed for various parts of the computer vision process and the construction of a spatial directory to provide a uniform means of handling differentiation models will be developed.

Visual Modeling (SRI, ADS with SU, and GE): This involves discovery of general models to represent objects and natural terrain for predicting and matching against real world observations. Also included is the application of reasoning techniques to improve geometric model construction and object identification.

Obstacle Avoidance (Hughes): Discriminatory techniques are investigated for distinguishing and evaluating obstacles in the path of a vehicle and the integration of those techniques with a planner to avoid obstacles along a planned path.

Dynamic Image Interpretation (UMass): This effort focuses on discovery of knowledge about dynamic environments and development of improved image recognition techniques that accommodate distortions arising from movement within the environment.

Target Motion Detection (USC): Motion analysis technology is studied to detect moving objects within the ALV field of view.

Object Recognition and Tracking (Honeywell): This effort involves discovery of improved object recognition techniques and higher-level knowledge to permit tracking of objects from scene to scene.

Real Time Issues (UofR, UMass, MIT, CU): Development of a parallel programming environment, common parallel processing algorithms, specialized parallel processing techniques for depth mapping, and integrated advanced architecture for parallel processing at all levels of the computer vision process are the thrusts of these efforts.

ALV SUBSYSTEMS

The May 1985 road following demonstration was accomplished by Martin Marietta with vision algorithm assistance from the University of Maryland. This was a significant accomplishment since the contract was awarded in late August 1984 and an initial demonstration, had the vehicle autonomously traveling along 1 km of road at 5 km/hr. Later in the year the vehicle traveled 2 km at a speed of 10 km/hr and required processing at 1.75 sec/frame to segment roads with commercially available computer hardware. The ALV subsystems in place at the end of 1985, when the vehicle attained 5 km at 10 km/hr, will be briefly outlined.

Sensors: The ALV sensor subsystem employs a RCA color video CCD TV camera and an ERIM laser range scanner. The video camera acquires 30 frames per second and delivers red, blue, and green intensity images in analog form to a VICOM image processor that digitizes the three color bands into 512x484 pixels with 8 bits/pixel. The perception subsystem controls a pan/tilt drive for this sensor. The laser range scanner is an amplitute modulated light source that is scanned over the area in front of the vehicle. Phase shift of reflected light from the scene features is measured with respect to an internal reference to determine range. The range data is processed on the VICOM in the form of a 64x256 digital array with 8 bit accuracy and requires 1 to 2 seconds to acquire and store as a range image.

Perception: The perception subsystem accepts sensor images and routes them to the appropriate processor. It has four major components: (1) a video processing component that extracts road edges and activates pan controls by cues from the reasoning subsystem, (2) a range data processing component that produces a set of 3-D points (in the sensor coordinate system) representing road edges, (3) a transformation component to correct video or range points to 3-D vehicle coordinates, and (4) an executive that switches between components, based on a measure of plausibility of the processed edge points, to transmit a set of 3-D road edge coordinates as the scene model.

Reasoning: The reasoning subsystem receives a plan script from a human test conductor and coordinates all ALV operations. It requests scene models from the perception subsystem and converts them into smooth trajectories that are passed to the pilot to drive the vehicle. It also provides the perception subsystem with cues about upcoming events or conditions along its path and is responsible for maintaining a knowledge base that contains a map and other descriptive data about the test track. The reasoning subsystem has three major components: (1) a goal seeker that directs and coordinates the activity of the reasoning subsystem from a decomposed plan script, controls information interchange with the perception subsystem, and monitors execution of the current activity until its completion when the next plan script activity is issued; (2) a navigator that receives a scene model and a goal position, queries the knowledge base about the road location, and computes a trajectory which is sent to the pilot; and (3) a knowledge base that maintains a map of the test area.

Pilot: The pilot subsystem converts the intervals of a trajectory into steering commands for the vehicle. It calculates steer right, steer left, and speed commands by first determining error values for speed, lateral position, and heading by comparing the current vehicle heading and speed provided by the land navigation system with the desired speed and heading specified by the current trajectory internal.

Knowledge Base: The knowledge base consists of a digital representation of the road net.

Vehicle: The vehicle subsystem has an undercarriage that is an eight-wheel hydrostatically driven unit capable of traversing rough terrain at speeds up to 29 km/hr and 72 km/hr on improved surfaces. Steering is accomplished by reducing or reversing power to one of the wheel sets. A 2-inch air tight fiberglass shell is large enough to house on-board computers, sensors, associated electronics, electric power, and air conditioning for interior environmental control.

Human Interface: The human test conductor directly inputs the plan script for the road following test. A deadman switch serves as a safety device for halting unexpected or out of control trajectories.

Hardware Architecture: The primary computer architectures include an Intel multiprocessor system which supports the reasoning subsystem and pilot, and a VICOM image processor which supports the perception subsystem. The multichannel controller provides an interface to the VICOM image processor and the laser scanner. In addition to the Intel multiprocessor and VICOM, the ALV's architecture includes a video tape recorder, a time-code generator, a Bendix land navigation system, left and right odometers, vehicle control and status sensors, and an ERIM laser scanner with an associated processor.

FUTURE ALV SUBSYSTEM DEVELOPMENTS

As indicated above, the development of the ALV capabilities is driven by the yearly demonstration objectives. As the demonstration requirements stress the performance capabilities of the methods and equipments, new approaches are necessary to continue the system evolution. In many cases the methods and equipments already employed are at or very near the state of the art and progress will require implementation directly from basic research in the technology base. Thus prediction of ALV subsystem developments is risky and subject to change. Nevertheless, it is instructional to indicate the major near-range subsystem plans, given the present state of the ALV system and the technology base program that supports it.

Sensors: A multispectral laser scanner, presently under development at ERIM, will replace the monospectral laser scanner now being employed. This scanner will use a YAG laser to develop six discrete wavelength beams which are detected as a range image and six reflected intensity images having 256x256 pixels.

Perception: The primary near-range enhancements to the perception subsystem involve generalization of road following algorithms to allow faster travel along roadways with an increased range of variability. Avoidance of road obstacles requires their recognition and segmentation from sensor data. Offroad travel requires multispectral processing and segmentation to be modeled and transmitted to the reasoning subsystem.

Reasoning: The reasoning subsystem must evolve considerably in the near-range to attain the demonstration goals. It must interpret a wide range of road, obstacle, and terrain object models; monitor the status of the vehicle; reason about its present and future location; and adjust speed and direction as necessary.

Knowledge-base: For 1986 models of roads and obstacles in the data base will be expanded. In 1987 a terrain data base will be added for apriori environmental information and terrain object models will be introduced. A "blackboard" memory structure will be used for maintaining cognizance of temporal activities and knowledge.

Vehicle: The vehicle chassis will not change through 1990, however the computers, electronics, and environmental accessories (e.g., power supplies and air conditionings) necessary for the demonstrations must be incorporated in the vehicle enclosure.

Human Interface: A user-friendly command module will be coupled to the vehicle with a communications interface.

Advanced Computers: At 10 km/hr the onboard VICOM processor is almost compute bound. There is not enough processing power to analyze both video and range data simultaneously, therefore the perception subsystem must choose the set of sensory data to process. Parallel processors are required for 1986 and beyond. To this end a 16-node BBN Butterfly parallel processor will be utilized for the reasoning subsystem and portions of the perception subsystem in 1986. Two onboard VICOM processors will be used for perceptual processing until mid-1986 and then these will be replaced by a CMU WARP computer, which is an advanced multistage programmable systolic array. Once an integrated hardware and software environment is developed, the WARP-Butterfly combination will provide powerful parallel support for perception and reasoning. Both computer systems can be upgraded as additional capacity as required.

Thus it is seen that the DARPA ALV program focuses significant efforts on key technology issues to meet the demonstration objectives leading to a new generation of intelligent machines. The following discussion will indicate how the Army plans to capture and use technology spinoffs to advance the state of the art of robotic vehicle systems capable of performing military missions.

ARMY ROBOTIC VEHICLE PROGRAM

The Army robotic vehicle program focuses on demonstration of state of the art robotic vehicle capabilities applied to combat missions of value to the Army user community. The program is structured to progressively demonstrate increasing degrees of autonomous capabilities in military missions as the technologies evolve. This program naturally complements the DARPA ALV program which is structured to demonstrate increasing capabilities of technologies associated with autonomous vehicles beginning with autonomous demonstrations of limited military value and increasing in military value as the technologies evolve. In the cooperative DARPA and Army programs the ALV provides the transfer of technology advances that enhance the Army program's degree of vehicle autonomy, while the Army provides military focus for the ALV. The Army robotic vehicle program is also a mechanism to transfer other DOD sponsored vehicle technologies and provides a test bed for evaluation of industrial Independent Research and Development (IR&D) in related efforts. Though the Army program is long-term it can provide short-term spinoffs with direct military applications.

The ultimate goal of the Army program is to demonstrate increased force effectiveness and/or improved soldiers battlefield survivability. Techniques such as remote management and multiple vehicle control will be primary tools used in the program.

ROBOTIC VEHICLE SYSTEM

Armor and Infantry type missions will be initially demonstrated with a system consisting of several robot vehicles and a Robotic Command Center (RCC). The vehicles and RCC will be coupled through communication subsystems under evaluation. Standard RF, microwave, and fiber optics links will be initially integrated.

The robot vehicles will have two sensor subsystems: The driving sensor subsystem and the mission sensor subsystem. The former will operate in two modes: (1) teleoperated extension of the operators eyes and ears through stereo and peripheral vision and stereo microphones and (2) supervisory and machine vision allowing operator management of vehicle actions while onboard image processors interpret images from the stereo cameras and laser scanners. The mission sensor subsystem incorporating thermal imaging, daylight video and laser rangefinders, shall be mounted on the mission modules. A telescoping mast will be employed providing 360° independent rotation.

Robotic vehicle machine vision processors will track those of the ALV, beginning with a VICOM image processor and advancing to WARP and Butterfly processors as the technologies and need evolves. Manual override of vision control provides added mobility in obstacle avoidance situations which may initially overburden the image processing system.

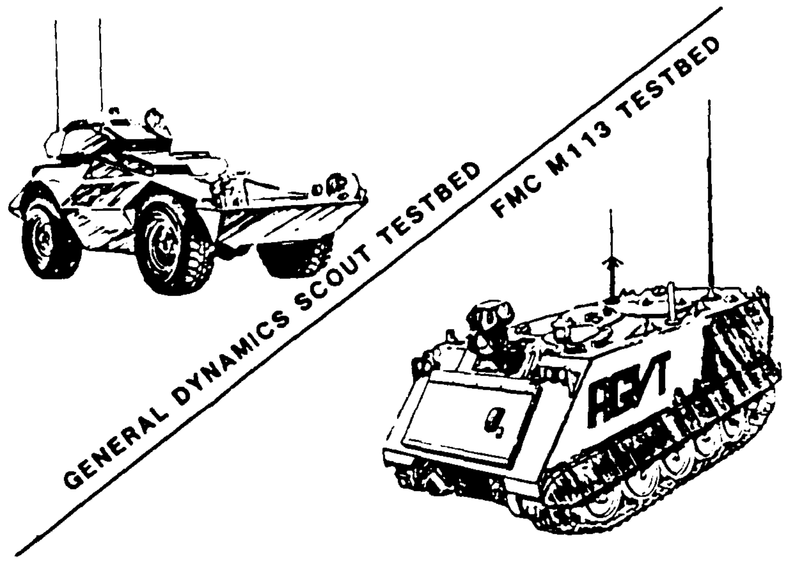
The vehicle payload will be modularized according to mission and permit mounting of modules such as weapon packages or manipulators for logistics material handling.

The RCC will be an adapted manned close combat vehicle and house all the robotic vehicle displays and operator controls. Displays will provide stereo vision, terrain data base, and peripheral and rear camera views for driving.

DEMONSTRATION PLAN

1986 - The first Army demonstrations will occur in August and September at the ALV test site. A route reconnaissance mission will be performed by two robotic vehicles under separate supervised control from robotic control stations. The supervised control will use both state of the art teleoperation and autonomous road following. The robotic vehicles under evaluation are built under IR&D programs by FMC Corporation and General Dynamics. The FMC vehicle is a tracked M113 and the General Dynamics vehicle is a 4 x 4 wheeled Commando Scout (Chassis is built by Cadillac Gage). These systems will integrate ALV software and perform military/combat type missions using both teleoperated and autonomous control. The teleoperation mode will be used in cross-country terrain and more difficult maneuvers now requiring man in the control loop. The autonomous road following algorithms are a product of the November 1985 ALV demonstration. Soldier/machine issues will be evaluated during the missions. Follow-on Army demonstrations are planned to show decreasing driver workloads leading to the ability of a driver to manage multiple vehicles simultaneously.

ADVANCED GROUND VEHICLE TECHNOLOGY (AGVT) TESTBEDS



1988 - A newly developed Army owned and operated robot vehicle system will be used to evaluate the performance of a more agressive route reconnaissance mission using ALV software demonstrated in 1986 and 1987. Route reconnaissance will be performed autonomously on the road at speeds up to 20 km/hr with obstacle avoidance and cross-country traverse at 5 km/hr. In addition to the ALV software integration, Computer Aided Remote Driving (CARD), which is a new robotic mobility technique, will be added to allow a driver to predrive a path via his display. Using a light pen and a light sensitive stereo display of the driver's sensor, the driver will designate a path for the vehicle to follow. CARD, presently being developed for the Army by JPL, is coupled to vehicle control with an onboard land navigation subsystem and optical tracking. Preliminary demonstrations of multiple robot control through teleoperation and fiber optics links will be evaluated.

1989-1990 - Improved multi-vehicle management at speeds up to 10 km/hr will be demonstrated. A platoon of vehicles will engage in both offensive and defensive missions to evaluate the potential increase in force effectiveness resulting from multiple vehicle control. One driver and one commander/mission specialist will maneuver and operate the vehicles. Initial site selection will be road networks and smooth terrain. Speeds will be limited to 10 km/hr. These demonstrations will result primarily from the 1987 and 1988 ALV software demonstrations in cross-country route planning and obstacle avoidance.

1991+ - Armored Family of Vehicles (AFV) robotic variants will execute missions singularly, in packs, or in concert with manned vehicles. As the ALV software provides higher vehicle speeds, more realistic combat missions can be demonstrated with increasing autonomy. Vehicles mounting weapon packages or other mission modules operating in concert with manned systems will demonstrate performance of military missions. The use of robotic vehicles in the AFV family is the major objective of the Army program.. AFV will use the robotic vehicle demonstrations to build follow-on requirements for singular robotic vehicles performing high risk or tasks for a platoon of robots in offensive type missions.

ARMY ROBOTIC VEHICLE REQUIREMENTS

The Army user community is very interested in the application of robotics to solve field problems and through a number of TRADOC Centers and Schools have identified potential robotic concepts. Concept requirements were formulated by a TRADOC General Officer Steering Committee (GOSC) for AI and Robotics managed by the U.S. Army Soldier Support Center (USASSC). USASSC released a broad requirements document for robotic vehicles which summarizes all submissions to the GOSC by the Schools and Centers. On 15 May 85, USASSC released a "Summary of TRADOC Requirements for Generic Robotic Vehicle Systems" which realizes the evolutionary process required to field robotic vehicles, i.e., teleoperation available now, while also being the first step in the evolution of autonomous systems.

Two leading TRADOC Schools that drove each end of the USASSC requirements were the U.S. Army Infantry School (USAIS) and the U.S. Army Armor School (USAARMS). USAIS requirements are for a teleoperated mobile platform that can mount a mission system to defeat enemy armor. An Infantry man with a control box will guide the Robotic Anti-Armor Systems (RAS) to a firing position and then locate, aim, fire, and guide the missile. Ultimately USAIS would like to product improve the RAS to provide autonomous mobility and automatic target detection and servicing.

USAARMS's Operational and Organizational (O&O) Plan for the Family of Robotic Combat Vehicles looks at using a common chassis with various mission module combinations. In normal mode of operation the robotic vehicles will receive mission guidance from a RCC in a manned close combat vehicle operating in concert with the robotic vehicles. This O&O desires autonomous operation, however, for near term applications would field systems directed by semi-autonomous control requiring only periodic manual inputs to execute a mission. User requirements have been integrated into the AFV Umbrella O&O Plan. Robot variant vehicles in the AFV are defined as (1) Tactical Reconnaissance, (2) NBC Reconnaissance, (3) Mine Detection, (4) Mine Breaching, (5) Anti-Armor, (6) Directed Energy Weapon, (7) Air Defense, (8) Rearm, (9) Refuel, (10) Smoke Dispensing, (11) Decoy, (12) Recovery, (13) Counter Obstacle, and (14) Obstacle Implacement.

ARMY TECHNOLOGY CHALLENGES

There are several key technology challenges that must be solved before the Army plans to field autonomous land vehicles. For discussion, a robotic vehicle system can be divided into seven major subsystems: (1) sensors, (2) intelligence, (3) controls, (4) platform, (5) mission module, (6) soldier/machine interface, and (7) communications. Significant developmental work is required in all areas before the Army can field a robotic vehicle providing capabilities beyond simple teleoperation. Current technology limitations, work in process and development yet required are summarized for each area below:

Sensors: Sensor technology specifically for robotic vehicles is being developed in the DARPA ALV program. A laser scanner provides range and intensity data of a scene that is processed and interpreted with color video data as basic sources of vehicle mobility information. Scanning and processing rates are current limiting factors, but improved processors will be integrated in 1986. Development of the ALV multispectral laser scanner should provide improved information needed for all terrain mobility.

Machine Intelligence Subsystem: Perception, reasoning, and knowledge bases for autonomous vehicles is being pursued in the DARPA ALV program and provides a significant focus for development of machine intelligence subsystems. Other related issues are being pursued in DOD. An Army program at TACOM is evaluating several architectures for combat vehicles and will lead to a common architecture for future combat systems. The Naval Ocean Systems Command has developed a blackboard knowledge base architecture that is being evaluated in their robot vehicle test bed. Ultimately a common architecture is required to be versatile enough to accept various mission modules without requiring restructuring.

Controls Subsystem: This subsystem includes servos for robotic vehicle actuation, i.e., steering, braking, acceleration, etc. Most controls used in robots today are commercially available. These may require militarization to ensure ruggedness and reliability for operation in dirty environments.

Platform: Initial robotic vehicles will be adaptations of current manned chassis, but in the future several classes of chassis will be used for AFV robotic vehicle variants. These chassis will be optimized for robotic applications with lower silhouette, reduced internal volume, less armor protection, electric drive, fuel cells, etc. The changes are primarily driven by the elimination of on-board vehicle operation. To date minimal work has been accomplished in this area.

Mission Modules: These are the "end effectors" for the robotic vehicle systems. They can be configured as a tactical reconnaissance sensor, a weapons platform mounting either a cannon or a missile, a robotic arm, etc. Work in this area is just beginning. The Armament Research and Development Center (ARDC) is investigating a robotic weapon station mounting a large caliber cannon and has developed several fire control concepts suitable for integration on a robotic vehicle test bed. Mission module development will be focused on the AFV robotic variants. The Army must focus on high payoff missions resulting in hands-on experience with available robotic technologies and spinoffs from the ALV program.

Soldier/Machine Interface (SMI): The SMI issues for robotic vehicles are as critical as those for manned vehicles and they are just beginning to surface. Operator sensors and displays must provide a presence through electronic transfer of information from the vehicle to the operator. Issues such as display size, color, control handles, telepresence, voice control, etc., need to be evaluated by human factors experts in the field. The command and control station will be packaged in a combat vehicle, this leads to an entirely new set of technological challenges required to miniaturize the control and displays for installation in an already confined crew compartment of a combat vehicle.

Communications: This is the weak link in a supervised robotic vehicle system. Little technology development is devoted to communications required to operate robots on the battlefield. Non-line of sight, jam proof, and secure communication are key challenges. Communication techniques employing repeaters, low frequency, packeted and preprocessed information must be developed and evaluated in field scenarios. Requirements to communicate with multiple robotic vehicles in a noisy and hostile battlefield environment could impede their fielding unless serious technology development is undertaken.

SUMMARY

Two associated research and development programs which together have the potential of great impact on Army vehicles of the future have been described. The DARPA ALV program focuses significant efforts on key technology issues leading to a new generation of intelligent machines and the Army robotic vehicle program focuses on demonstrating the state of the art robotic vehicle capabilities applied to combat missions of value to the Army user community. The Army has identified a need for robot variants in the AFV. Through user experience with maturing robotic vehicle technology, it is anticipated that follow-on requirements documents will be generated for engineering development of Army autonomous land vehicles. Timing for critical technology, such as the DARPA ALV software and hardware, will pace fielding of an Army AFV, however a progressive development program could be commenced to initially field a robotic vehicle that is remotely controlled with preplanned product improvements leading to an autonomous vehicle.

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