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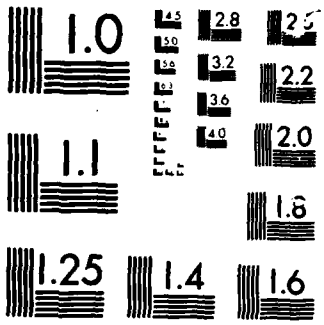

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To operate effectively under conditions characterized by AirLand Battle 2000, the Army must bring new technologies to the battlefield. Autonomous land vehicles represent one class of artificial intelligence and robotic systems employing new technologies of potential value to the Army. The DARPA Autonomous Land Vehicle (ALV) program focuses on key technology issues leading to a new generation of intelligent machines. This program will be described along with its status and future plans.

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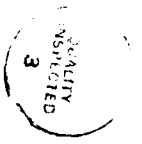

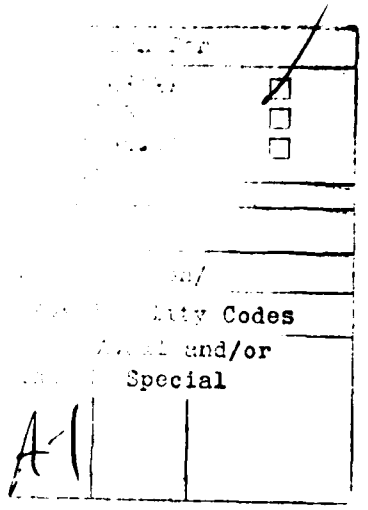

DARPA ALV SUMMARY

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INTRODUCTION

To operate effectively under conditions characterized by AirLand Battle 2000, the Army must bring new technologies to the battlefield. Autonomous land vehicles represent one class of artificial intelligence and robotic systems employing new technologies of potential value to the Army. The DARPA Autonomous Land Vehicle (ALV) program focuses on key technology issues leading to a new generation of intelligent machines. This program will be described along with its status and future plans.

DARPA STRATEGIC COMPUTING PROGRAM

The DARPA Strategic Computing Program was a new initiative in October 1983. 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. The application requirements of each demonstrator have been purposely structured to "pull" new capabilities from the technology base, rather than "push" available capabilities at the user. The Strategic Computer Program has a large built-in technology base research program that addresses 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 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 that affords the greatest flexibility to integrate and demonstrate the Strategic Computing Program technologies. Objectives of the ALV yearly demonstrations are:

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

1986 - Obstacle Avoidance Demonstration: 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 - Cross-country Route Planning Demonstration: 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 - Road Network Route Planning and Obstacle Avoidance Demonstration: 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.

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.

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. This can be factored into functional subsystems.

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 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 scenerio integrating these functionals may have a mission beginning 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. Then 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 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 circumnavigate the obstacle. If local planning produces no acceptable bypass, 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 Strategic Computing Program 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 as exemplified by the ALV applications. A system framework will be built to accomodate 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 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 accomodate 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 the development of higher-level knowledge to permit tracking of objects from scene to scene.

REAL TIME ISSUES (UofR, UMass, MIT, CU): Development of a parallel programing environment, common parallel processing algorithms, specialized parallel processing techniques for depth mapping, and the discovery of an integrated advanced architecture for parallel processing at levels of the computer vision process are the thrusts of these efforts.

ALV SUBSYSTEMS

The 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 system integrator contract was awarded in late August 1984, the vehicle was not available until late February, 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 inplace at the end of 1985 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 amplitude 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; (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 interval.

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 videotape 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 objectives of the yearly demonstrations. 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 presently 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. Postprocessing will produce 256x256 pixel images for each band, including range, that are in the vehicle coordinate system.

PERCEPTION: The primary near-range enhancements to the perception subsystem involve generalization of road following algorithms for faster travel along roadways with an increased range of variablity. Avoidance of road obstacles requires their recognition and segmentation from sensor data. Then offroad travel requires multispectral processing and segmentation to be modeled and transmitted to the reasoning subsystem. This necessitates integration of general representation schema for the computer vision primitives.

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-conditioning) 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 used 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 are developed, the WAPR-Butterfly combination will provide powerful parallel support for perception and reasoning. Both computer systems can be upgraded as additional capacity is required.

CLOSING

The DARPA ALV program brings a critical mass of effort and talent to bear on key technology issues for evolving autonomous land vehicle capabilities. The Army can then incorporate these capabilities into their plans and requirements for autonomous vehicle systems of the future.

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