# Overview of the UGV / Demo II Program

**John R. Spofford, Raymond D. Rimey, Steve H. Munkeby**

Lockheed Martin Astronautics[1]
P.O. Box 179, M/S H8380
Denver, CO 80201

## Abstract

The UGV / Demo II program, begun in 1992, developed and matured those navigation and automatic target recognition technologies critical for the development of supervised, autonomous ground vehicles capable of performing military scout missions with a minimum of human oversight. The program culminated with a highly successful series of field exercises performed by soldiers at Ft. Hood, Texas over three weeks in May/June 1996. This paper provides an introduction to the UGV / Demo II program.

## 1. UGV / Demo II Program Concept

The objective of the UGV / Demo II program was to develop and mature those navigation and automatic target recognition technologies critical for the development and demonstration of supervised, autonomous ground vehicles capable of performing military scout missions with a minimum of human oversight. The intent was to focus on and exploit the artificial intelligence, computer vision, and advanced processor developments sponsored under the Defense Advanced Research Projects Agency's (DARPA) science and technology program. The developed autonomous navigation and automatic target recognition technologies were then transitioned to the principal Department of Defense agencies that were responsible for and supported the acquisition of unmanned ground vehicles. This objective led to a balance of the program emphasis between technology development and military application, which was adjusted over the course of the program. A scenario-based approach to technology development activities and program-wide coordination was used throughout the program, and the scenarios increased in complexity and realism over time.

The UGV / Demo II initiative was a suite of related contracts in which various contractor organizations were each responsible for developing key component technologies. Lockheed Martin Astronautics was the system integrator. The UGV / Demo II system is composed of four semiautonomous surrogate vehicles (SSVs) and a mobile operator workstation. The program focused on scout missions. The major navigation emphasis of the program was to robustly drive off road and on arbitrary roads, plan and execute safe driving paths, and perceive and avoid obstacles. The major mission sensing emphasis of the program, called Reconnaissance, Surveillance and Target Acquisition (RSTA), was to provide a sensing and processing system that detects, tracks, identifies, and reports on military targets in the field of regard of each SSV. Three interim demonstrations -- Demo A, B and C held in 1993, 1994 and 1995 -- illustrated the incremental progress leading up to the Demo II field exercises held at Ft. Hood, Texas in May/June 1996. The program began in 1992.

### 1.1. Military Relevance (Scenarios)

A military scenario was used for the UGV / Demo II program because: (1) It provided those outside the program with a clear conception of the application orientation of the program, thereby avoiding the perception of "technology for its own sake"; (2) It assured that the developers kept in mind from the beginning the application and military utility of the technology; and (3) It helped to clearly define system requirements which

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Figure 1. The UGV / Demo II program concept developed autonomous technologies for the military scout mission.

otherwise may have remained vague as long as the program was technology oriented.

Today's soldier must have the ability to perform a myriad of tasks including self-camouflaging, maneuvering, maintaining equipment, understanding electronics and sensors, working cooperatively, communicating, and firing weapons. These individual capabilities are applied to fit the assigned combat mission. Combat missions performed today take many forms but some of the performed tasks include the following, which are also candidates for UGV employment:

- Intelligence gathering
- Counter reconnaissance
- Route and area reconnaissance
- Target acquisition
- NBC surveillance and monitoring
- Channeling an enemy attack
- Ambushes
- Decoy and deception
- Obscurant dispensing
- Establishing obstacles
- Breaching obstacles
- Communications relay
- Remote sensors deployment and monitoring
- Deploying mines
- Forward area resupply

The scout mission was selected as the focus for the UGV / Demo II program, and includes the first few tasks in the list above. Figure 1 shows several SSVs beginning a mission, with the operator and the operator console shown in the foreground. The scout mission is inherently hazardous due to the forward deployment into uncertain situations. Scout units generally sustain high loss rates during a conflict, as they are lightly armed and contact the enemy first. Protective gear for man-made obstacles, such as nuclear, biological, and chemical (NBC) contamination is bulky and reduces the scouts' effectiveness. The scout mission emphasizes observation, rather than employment of weapons, thus avoiding issues about whether experimental robots are ready to carry weapons. Observation results are sent up the chain of command, where a human makes the decision regarding use of force. These factors combine to make the scout mission a strong candidate for robotic systems to supplement human capabilities.

Scout functions are mobility and reconnaissance, surveillance, and target acquisition (RSTA).

Autonomous RSTA is necessary to perform remote scout function without requiring unacceptable image transmission bandwidth and operator loading. Similarly, vehicle mobility must be accomplished without high communications data rate and high levels of operator involvement. When remote scout systems are fully fielded, several will be within communications range on the battlefield. They will have to share a finite asset -- communications bandwidth. The more that remote systems are employed, the more efficient they will have to be.

For the first three annual demonstrations, the maturity of the technology drove the development of the mission scenarios used. Scenarios were developed by technologists as a showcase for the results of the prior year's development. These scenarios grew in duration, difficulty of terrain, and mission complexity over the years. For Demo II, it was known that the complexities and uncertainties of the Ft. Hood environment would have to be accommodated. Therefore, robustness was a very high priority when determining if a capability was prepared and used at Demo II. The program plan for that final year was developed to facilitate integration of the technical capabilities specifically needed for the vignettes.

The level of user involvement in UGV / Demo II program activities steadily increased during each year of the program.  An aggressive plan to increase user involvement was instituted prior to Demo C, in preparation for field exercises to be held at Ft. Hood, Texas, for the culmination of the Demo II program. A major objective of Demo C was to elicit the views of the military as to which scenarios should be the focus of Demo II in 1996. The target audience of Demo C was a group of military concept developers and "users" representing a wide cross section of mission areas. Demo C was the first step in a cooperative effort between the research and development community, TRADOC, and other services to shape the vision of robotics on the future battlefield. As part of the demonstration week, a four hour workshop was held with selected users and technologists to focus the robotic research and fielding efforts. The workshop had three objectives:

- Acquaint concept developers and potential users with the current state-of-the-art in robotics technology. These individuals were asked to develop between five to six applications that could be demonstrated during the final DARPA Demonstration II effort at Ft. Hood in June of 1996. These inputs would have an impact on the applications demonstrated at Demo II.
- Acquaint concept developers and potential users with the current fielding efforts of the unmanned ground vehicles/systems joint project office (UGV/S JPO).
- Solicit cooperation with TRADOC's Robotic Technology Integration Activity (RTIA) to develop a TRADOC vision for robotics on the battlefield.

Concept worksheets were provided to the military audience on the first day of Demo C. The concept worksheets were used to generate vignette ideas as the individual pieces of robotic technology were demonstrated. Therefore, when the workshop occurred on the last day of Demo C, the participants already had some concepts prepared. The military participants had also informally brainstormed among themselves as they were shown the technology. During the workshop, four breakout sessions were held -- combat arms, combat support, combat service support, and special operations / operations other that war. Each group prepared suggested vignettes for Demo II and presented these concepts in a group session. These vignettes were used by the UGV / Demo II community as the starting point for Demo II planning.

The selected vignettes were as follows: For offensive operations, three cooperating UGVs would initiate a movement-to-contact scenario using bounding overwatch over semiarid terrain, a single UGV would be used to direct artillery fire onto an enemy convoy, and three cooperating UGVs would perform reconnaissance of a mock, European village. In addition to autonomously moving over the terrain, avoiding obstacles, and limiting their exposure to suspected enemy positions, RSTA modules would be used to observe threats and to locate, detect, assess, and designate for friendly use. For defensive operation, the vehicles would conduct a counter-reconnaissance scenario. The three cooperating UGVs would monitor enemy reconnaissance efforts during darkness and provide the friendly commander with the intelligence necessary to inflict damage on the advancing enemy force.

The Demo II audience was a small, select group of individuals from potential user organizations and other organizations responsible for the direction of future UGV efforts. These individuals were taken to the field locations where the vignettes were taking place. As the vignette scenarios were performed, the observers were able to see the technology in-work in a less formally structured field experiment. The word "experiment" was used extensively during Demo II because each vignette had never been attempted prior to arrival at Ft. Hood. Additionally, with the Army soldiers executing the vignettes, the actual vehicle routes and sensor activities were continuously changing due to the soldier desires.

Demo II was not a "canned" demonstration, but actual military "force-on-force" missions performed with supporting UGVs. The scenarios were actual training missions routinely performed by troops, with UGVs inserted to perform the scout role. Standard Army training doctrine and tactics, techniques, and procedures were used. These will undoubtedly change with the routine use of UGVs in the field. Evaluations and feedback from the soldiers who operate UGVs will serve to focus future development to improve the real-world performance of these systems.

The Unmanned Ground Vehicles / Systems (UGV/S) Joint Project Office (JPO) is charged with transitioning UGV technology into fielded systems. It has been utilizing technology created prior to the UGV / Demo II program. Near-term robotic systems rely on teleoperation -- direct control of vehicle subsystems by a remote human operator. While simple and inexpensive, there are two significant drawbacks to this approach: large communications bandwidth and large operator workload. Now that the Demo II program has concluded, the UGV/S JPO will begin to utilize Demo II technology.

## 1.2. Technology Push Issues

The technology base for the UGV / Demo II program has its heritage in a number of DARPA programs in strategic computing, image understanding, planning, and robotics, including the autonomous land vehicle (ALV) program 1984-1990, the CMU NAVLABs [Thorpe, 1990] starting in the mid-1980's, the Demo I program 1991-1992, and the Image Understanding program's development of stereo throughout the 1980's.

The UGV / Demo II program was designed to: (1) Bring the technology further out of the lab towards maturity; (2) Provide a user to fine-tune requirements; (3) Change the technology development and maturation process from universities to the field and from concept to evaluation; (4) Increase system-level synergies.

Three core technology areas were addressed by the UGV / Demo II program: (1) autonomous mobility; (2) planning and user interfaces; and, (3) reconnaissance, surveillance and target acquisition (RSTA).

Autonomous mobility included the following technology capabilities:

- Road following
- Waypoint teleoperation
- Multivehicle cooperative mobility
- Formation driving
- True unmanned operation
- Semi-autonomous turnaround
- Reverse path following
- Obstacle map sharing
- Stereo obstacle detection
- Negative obstacle detection
- Field-of-regard control
- Stereo FLIR at night
- Navigation LADAR
- Multi-spectral terrain classification
- Obstacle avoidance
- Route history maintenance
- Sensor-based hill cresting
- Advanced inertial navigation

The planning and user interfaces area included the following technology capabilities:

- Military plan specification language
- Military plan decomposition
- Route planning
- Formation planning
- Plan editor
- Multivehicle plan execution and monitoring
- Multivehicle operator workstation
- Portable multivehicle control unit
- Replanning of robotic plan
- Field-of-view and other RSTA planning
- Terrain-based reasoning
- Communication planning
- Cooperative teleoperation
- Overflight visualization

RSTA included the following technology areas:

- Adaptive FLIR target detection
- FLIR clutter suppression
- Color stationary target detection
- Acoustic target detection / cueing
- Image stabilization
- Moving target detection from moving platform
- Target detection and classification using polarization sensors
- Passive cooperative ranging
- Cooperative target verification
- Target recognition with FLIR
- Target identification with LADAR
- Sensor fusion (video, FLIR, LADAR)
- ATR algorithm selection
- Call for fire; adjust fire

Additional description of these areas and the work of associated contractors is provided in Section 2.2 below.

## 1.3. Demonstration Strategy

As an applied research and development program and by direction from DARPA, the UGV / Demo II program had flexible technical and schedule goals. The fundamental program organization used annual incremental steps to build on technology and experience from the previous year. These steps transitioned the technology from development to demonstrations to field exercises, by integrating the technology as soon as possible so it could mature via regular field experience and associated on-going development and refinement.

The benefits of this approach are: (1) It provides the option to refocus program-wide efforts along the way; (2) It provides annual evaluations of the technologies within the integrated system using user-centric metrics and as isolated technologies; (3) It provides the best and most flexible way to convince DOD end users, specifically in the Army and Marines, of UGV utility; and finally, (4) It reduces risk.

The UGV / Demo II program utilized the flexibility of this approach extensively. Leaps in technology and commensurate system capability occurred from the start of the program through Demo C. Leading up to Demo C, a new shift in user-focus was planned to help prepare for the final Demo II, meaning that the program switched from a technology-community emphasis (government, academia, industry) to a military emphasis. The Demo II activities and accomplishments were a quantum leap beyond those planned at the start of the program.

The UGV / Demo II program was organized around a series of four proof-of-concept demonstrations for cooperating semiautonomous vehicles in a tactical application. The four demonstrations incrementally developed those perception, mobility, control, and target recognition technologies required to achieve an automated scout capability. The top-level objectives of these demonstrations (Figure 2) were described as follows:

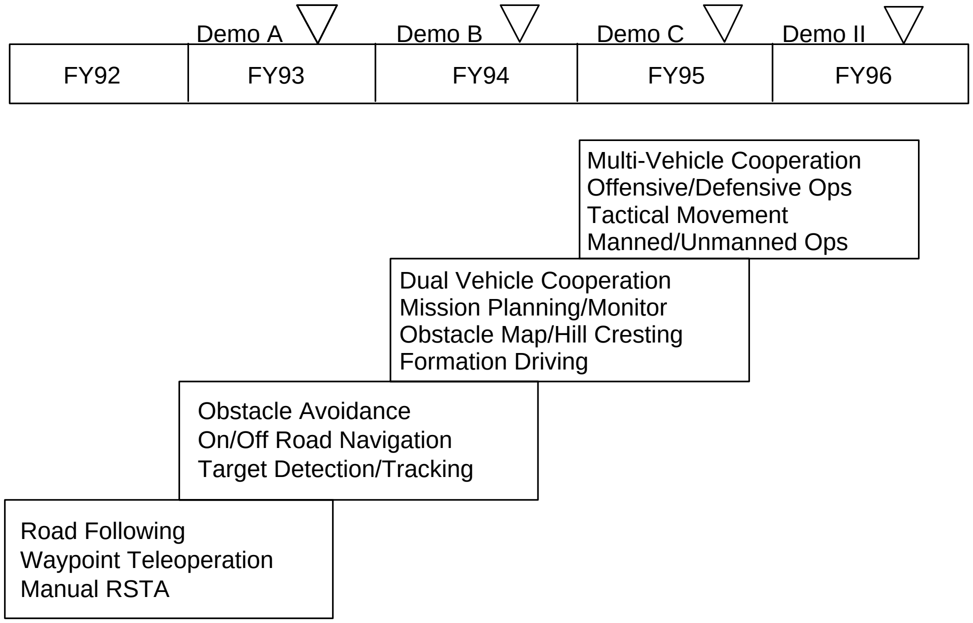


Figure 2. Program overview schedule.

- Demo A would demonstrate a working vehicle and operator workstation infrastructure and early integration of road following and teleoperation capabilities.
- Demo B would demonstrate on-road and off-road navigation, obstacle avoidance, and target detection using forward looking infrared (FLIR).
- Demo C would demonstrate dual cooperating SSVs, target detection and tracking capabilities, mission planning and monitoring, and exercise the system in militarily relevant scenarios.
- Demo II would demonstrate three cooperating SSVs in a military environment at Ft. Hood, Texas.

Demo A and Demo B were used to highlight specific UGV technology, and were oriented towards a general audience of people from the government, contractor organizations, and academia. Those demonstrations placed emphasis on showing an integrated set of technology. Since this did not always demonstrate the full individual technology capabilities, Demo C emphasized a new approach that highlighted the individual technology capabilities, demonstrated each capability's state-of-the-art, and offered an explanation of how the technology could be used to address user applications. The audience for Demo C was a group of military concept developers and potential users of UGV technology. Demo II used another new approach. It was not a "canned" demonstration. Demo II placed the technology developed during the previous demonstration periods into the Ft. Hood-user hands and asked them to perform three real-world scout missions. Except for following a general scenario, the actual activities required to be performed by the SSVs during the vignettes were unknown until they were executed. The Demo II audience was a small, select group of individuals from potential user organizations and organizations responsible for the direction of future UGV efforts.

## 2. Program Organization and Roles

The UGV / Demo II program represented a contractually-unique collection of government, industrial, and research institutions coordinated through an DARPA focal point. Co-contractors, working under separate DARPA contractual agreements, were responsible for the development of key component technologies. Lockheed Martin Astronautics was the system integrator. Commensurate with DARPA ground vehicle robotic technology goals, co-contractors iteratively provided research-grade software modules for integration into the SSV system. Due to the non-binding relationship Lockheed Martin Astronautics, the system integrator, had with each of the co-contractors, Lockheed Martin Astronautics was required to accept co-contractor software as delivered. As the UGV / Demo II program matured and at the request of the associated sponsors, co-contractors' scopes of work sometimes changed. Several organizations joined or departed the community during the course of the program. The community functioned primarily through working groups, workshops, and direct one-on-one contacts. This section enumerates the members of the community (Figure 3) over the years and their roles or areas of contribution.

## 2.1. DARPA / OSD Sponsorship

The UGV / Demo II program is part of the Joint Robotics Program (JRP) centrally coordinated by the Office of the Secretary of Defense. The introduction of the latest JRP Master Plan [UGV MP, 1996, page 1] provides an excellent overview of the program:

"The goal of the Joint Robotics Program (JRP) is to develop and field a family of unmanned ground vehicle systems in accordance with user requirements for a range of military applications. The program has been structured to mature critical technology and to progress from teleoperation -- where a remotely located human directly controls the functions of the UGV -- to autonomous performance of UGV functions with the operator in a supervisory role who is able to control multiple UGV concurrently.

The current Joint Robotics Program investment focuses on the following:

- Near- and mid-term advanced system development (ASD) projects that have strong Service support with requirements that are approved or are well along in the approval process.
- Technological barriers that impede fielding first-generation UGVs and the evolution of autonomous capabilities.

Key projects that are underway are the following:

- Tactical Unmanned Vehicle (TUV) for reconnaissance, surveillance, and target acquisition (RSTA) missions.
- Vehicle Teleoperation Capability (VTC) to insert optional remote operation capability into existing combat engineer and other military vehicles.
- Robotic Excavation Vehicle System (REVS) for remotely detecting, removing, and disposing of buried unexploded ordnance (UXO).
- Remote Ordnance Neutralization System (RONS) for securing exposed UXO by attaching and operating render-safe tools.
- UGV Technology Enhancement and Exploitation (UGVTEE) program to mature technologies for incorporation into UGV systems.
- Joint Architecture for Unmanned Ground Systems (JAUGS) to develop a common hardware / software open architecture to ensure UGV systems' interoperability with cost savings to the user."

From 1992 to 1996, the UGVTEE program took the form of a DARPA program, which has been referred to as the UGV / Demo II program. However, it was actually composed of two separate DARPA programs:

- The UGV / Demo II program was charged with developing autonomous mobility technology. This effort also included development of planning capabilities supported by a separate DARPA planning initiative.
- The UGV / RSTA program, part of the DARPA Image Understanding program, was charged with developing RSTA technology.

The UGV / Demo II program carefully balanced the development and the demonstration of new technology in select areas, transitioning from a strong technology push in early years to a user application focus in the final years. While DARPA and OSD saw the need for technology development via the UGV / Demo II program, their ultimate intent has been to move towards development of fieldability, maintainability, reliability, trainability, etc. -- issues which will be addressed by other UGV/S JPO programs such as TUV and VTC.

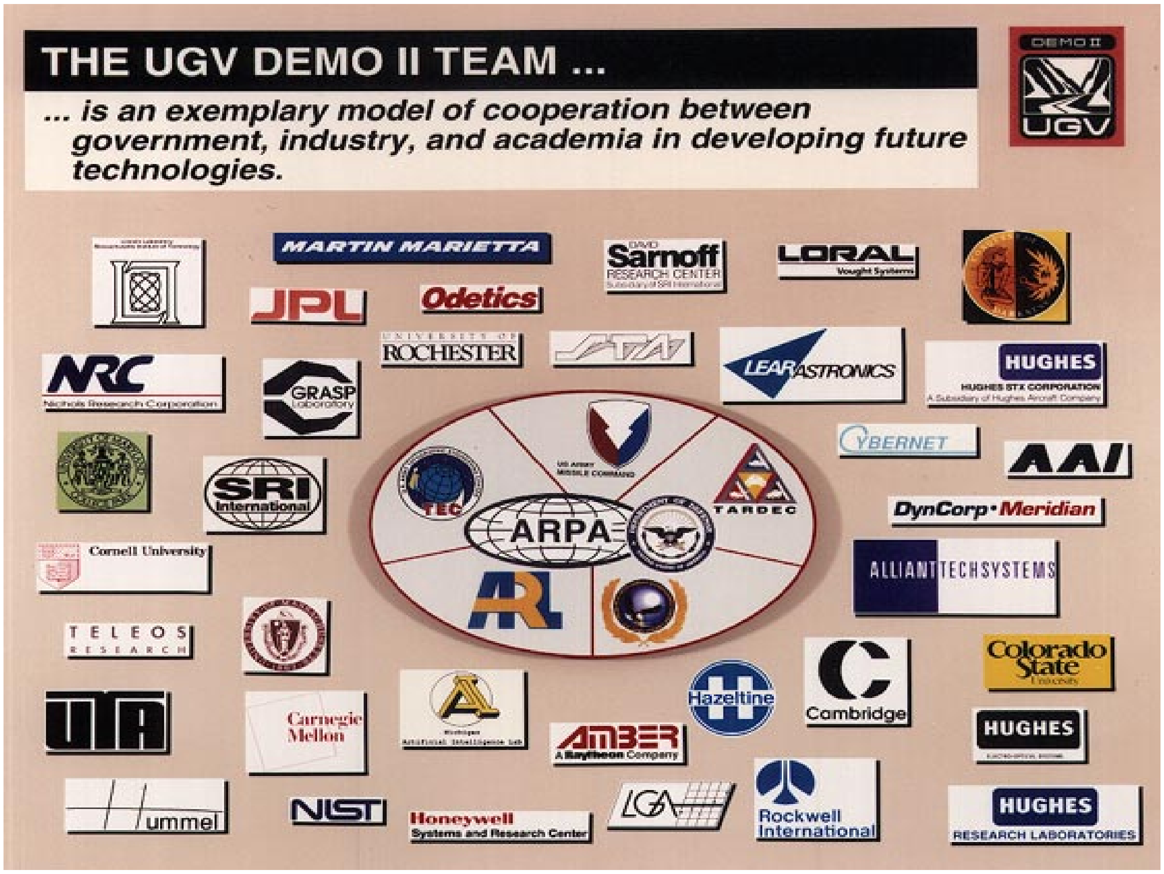


Figure 3. Organization of the UGV / Demo II program.

## 2.2. Technology Developers

The community of co-contractors was responsible for pushing the state-of-the-art and developing key component technology for UGVs. There were three major areas of participation:

- Mobility. The major mobility emphasis of the program was to robustly drive on arbitrary roads, plan and execute a safe path through a variety of off-road terrains, and perceive and avoid obstacles (both on- and off-road).
- Mission Planning / User Interface. This area developed technologies for military mission planning, robotic mission planning, execution control, user interfaces, and cooperative planning and control.
- Reconnaissance, Surveillance, and Target Acquisition (RSTA). The major RSTA emphasis of the program was to provide a sensing and processing system that detects, tracks, identifies, and reports on military targets in the field of regard of the vehicle.

The SSV system also provides teleoperation support for mobility and RSTA. For mobility, waypoint navigation is used. For RSTA, sensor controls and imagery for visual inspection is provided including intelligent target search capabilities that utilize terrain and doctrinal knowledge.

### 2.2.1. Mobility and Mission Planning / User Interface Efforts

Contractors who participated in the areas of Mobility and Mission Planning / User Interface are summarized below along with some of their contributions to the UGV / Demo II program. This list is not all-inclusive and all contractors did not contribute equally to the program. Further details on community results each year are provided in the last paper of this chapter, which describes the annual demonstrations in detail.

**Advanced Decision Systems (ADS).** ADS developed the Platoon Vehicle Planning System (PVPS), software that gave an SSV the ability to develop and execute detailed mission plans, provided a user interface structure (map visualization) and tool set to support mission planning and execution (annotated maps), and ADS assisted with mission planning integration for Demo A. Elements of these plans would be communicated to the IPPS developed by HRL.

**Carnegie Mellon University (CMU).** The Robotics Institute at CMU developed a core set of mobility modules used in all the demos and including: road following, obstacle avoidance, teleoperation, and route planning, along with architectural tools for their integration. These tools include: mission monitoring and execution, inter-module communication, and command arbitration between mobility modules.

**Cybernet.** Cybernet implemented two generations of operator control units to demonstrate system operations and intelligence fusion in a man-portable system. These operator stations were developed as a result of extensive human factors and usability testing.

**Georgia Tech.** Georgia Tech researchers provided multi-agent coordination capabilities including: formation control methods for teams of HMMWVs; Missionlab, a multi-agent mission specification tool set; and teleautonomous control for easily managing teams of autonomous robots.

**Hazeltine.** Hazeltine supplied the AN/PRC-118 Low-cost Packet Radio (LPR), the communications link for the SSV system, which was later upgraded to the higher bandwidth Secure Packet Radio (SPR).

**Hughes Research Laboratories (HRL).** HRL developed and implemented a simulation environment, called the Integrated Planning and Perception System (IPPS), for the integration and testing of unmanned ground vehicle software modules, and HRL performed a detailed assessment and analysis of the operational concepts for which unmanned ground vehicles could be effectively deployed. The integrated software system included Mode Manager and GUI vehicle status displays used for Demo A.

**Hughes STX.** Hughes STX, a subsidiary of Hughes Aircraft, developed the operator workstation (OWS) used within the SSV system at Demo B and onward. The OWS includes technology for multi-resolution map management and terrain reasoning; mission specification and robotic plan editing; and plan execution control and monitoring.

**Jet Propulsion Laboratory (JPL).** JPL developed the obstacle detection system for the SSV system, building on a prior system JPL developed for Demo I. The heart of this work is a real-time stereo vision system that produces range images with 256x64 pixels at a rate of three times per second. JPL also developed and demonstrated capabilities for real-time terrain classification for discriminating rocks from bushes and collaborated in demonstrating real-time stereo vision at night with FLIR cameras.

**Lear Astronics Corporation.** Lear Astronics provided the Modular Integrated Avionics Group (MIAG), which performs integrated GPS / Inertial Navigation for the UGV vehicles.

**National Institute for Standards and Technology.** NIST developed mobility functions for Demo I, Demo II and Project Mustang, including teleoperation, retrotraverse, vision-based road following, LADAR based obstacle avoidance, low level mobility control for the HMMWV, and position sensing combining both inertial sensors (MAPS) and differential GPS.

**Odetics.** Odetics developed the Navigation Imaging LADAR, a device is considered to be key to the SSV's ability to navigate and particularly to recognize obstacles in its path.

**SRI International.** SRI developed stereo sensing and obstacle detection techniques, and then applied these techniques to infrared imagery, which provides a passive ranging capability to support autonomous navigation for military operations 24-hours-a-day.

**Teleos Research, Inc.** Teleos developed software algorithms and a high-speed hardware implementation for generating sparse range images based on stereo imaging.

**University of Massachusetts (UMass).** UMass developed a suite of algorithms for vehicle navigation, including stereo obstacle detection and reflexive avoidance, behavior based control algorithms, terrain visibility analysis, stealth path planning, and vehicle visual servoing on terrain features, and showed the feasibility of landmark-based navigation in the absence of GPS. UMass was also involved in the CSU RSTA effort (see Section 2.2.2).

**University of Michigan (UMich).** UMich contributed innovative software for automatically elaborating an operator's military objectives into robotic mission plans for multiple vehicles, and for coordinated multi-vehicle plan execution, monitoring, and replanning using messaging and plan recognition.

### 2.2.2. RSTA Efforts

In early 1992, the DARPA sponsor asked Lockheed Martin, the system integrator, to submit a "wish list" of RSTA related technologies that were beyond the scope of the system integrator's small internal RSTA effort. Lockheed Martin provided an informational pamphlet to DARPA that:

- Outlined the system integrator's RSTA approach as detailed in the SSV integration contract.
- Gave a detailed description of five technology areas in which a research program might extend the state-of-the-art and contribute technology to the UGV / Demo II program for demonstration.
- Provided a detailed description of then-current SSV system designs in order to help potential RSTA BAA respondents to understand system integration issues.
- Provided a detailed technology description and bibliography of previous work that might constitute a technology base for the BAA efforts.
- Included a suggested collaboration and integration plan that described how the system integrator and a potential new RSTA community should pursue technology integration into the UGV / Demo II program's demos.

The following technology areas were nominated:

- Natural Outdoor Scene Understanding -- The UGV / Demo II effort would largely use maps and teleoperator-designated areas to determine where to search for hostile enemy targets. This technology would use images or sequences of images gathered from a stationary or moving vehicle to determine where to search for hostile targets. It would also allow the recovery of the gross shape of and characteristics of terrain (occlusion ridges, gullies, tree-lines) at long ranges from two-dimensional imagery.
- Model-based Object Recognition in LADAR Imagery (occluded targets, noisy imagery) -- This technology would provide an end-to-end model-based LADAR object recognition system. This area was nominated to help extend the technology to partially occluded targets and to recognition in low-resolution, noisy imagery.
- Motion Compensation and Digital Image Stabilization -- One goal for the UGV / Demo II effort at large was the detection of threats from a moving host platform. Because the vehicles would navigate off road on rough terrain, some form of image stabilization would be necessary. Mechanical stabilization of the current sensors was judged too costly and heavy, so this research area was nominated.
- Adaptable FLIR Target Detection -- The UGV / Demo II effort planned to modify and integrate existing FLIR target detection approaches. To date, most algorithms had no mechanism to adjust their detection parameters in the face of changing thermal conditions that affect FLIR image characteristics. This research area was nominated to extend this technology and bring it into the UGV / Demo II effort.
- Multiple Sensor Fusion for Target Identification -- The UGV / Demo II program would develop an approach that uses FLIR images for target detection and LADAR data for target identification. The fusion research area was nominated to include approaches that use both FLIR and LADAR data to perform target recognition/identification.

In fall of 1993, DARPA completed contract awards for technology developments within the new RSTA program. DARPA later added awards in the area of algorithm evaluation and object oriented mission analyses technology. The resulting RSTA community focused on the following technology areas:

- Motion stabilization (RSTA on the move)
- Adaptive FLIR target detection
- Advanced sensors (polarization)
- Multi-sensor fusion (FLIR, LADAR, video)
- Advanced sensor planning

The contractors in the RSTA program and some of their contributions are summarized below. The reader is directed to the last paper in this chapter describing the annual demonstrations for details on RSTA contractor results each year.

**Amber - A Raytheon Co.** Amber supplied the Radiance 1 infrared cameras used within the UGV / Demo II program.

**Cambridge Parallel Processing (CPP).** The SSV system utilized CPP's DAP 510C SIMD parallel processor computer for real-time RSTA and ATR processing.

**Colorado State University (CSU) / University of Massachusetts / Alliant Techsystems.** The group led by CSU developed: optimization algorithms that match 3-D target models to range and electro-optical imagery, improving target localization; a multi-spectral target detection algorithm (integrated into the SSV system) that finds camouflaged vehicles against natural terrain; and an interactive 3-D visualization environment that illuminates target to multi-sensor data matches.

**David Sarnoff Research Center.** Sarnoff contributed a system for real-time image stabilization and mosaicing of EO/IR imagery acquired while a vehicle is in motion, and detection of moving targets in the stabilized imagery.

**Honeywell Systems and Research Center / University of Rochester.** The team led by Honeywell developed a self-adaptive ATR system that performed context-based configuration and control to improve the accuracy, robustness, and ease of use of FLIR ATR over a broad range of scenarios. The University of Rochester contributed methods and algorithms using decision theory and Bayesian networks for selective use of ATR algorithms that had been learned (by the Honeywell technology) to be appropriate in specific circumstances.

**Hughes Electro-Optical Systems / Cornell University.** The team led by Hughes developed a method of matching models to data (based on the Hausdorff metric) that is robust to real-world imaging conditions and scenarios, and developed a mathematical analysis of the false alarm rate and probability of detection of this system. The formal analytical models enable the system to adapt to variable clutter density to optimize the overall false alarm rate.

**Johns Hopkins University (JHU).** JHU developed a new sensory modality based on Polarization Vision. This approach has demonstrated enhanced and augmented capabilities for ATR and battlefield awareness over existing technologies.

**Lynne Gilfallen Associates (LGA).** LGA developed and implemented a methodology for the evaluation of large, complex research and development programs, and applied it to the RSTA program, and helped to coordinate evaluation efforts within the RSTA community.

**MIT Lincoln Laboratory.** MIT Lincoln Laboratory developed an end-to-end, model-based system (functional templates) for identification of occluded target vehicles in LADAR imagery.

**Nichols Research Corporation / Lockheed Martin Vought Systems / Hummel Enterprises.** The team led by Nichols developed a capability for target classification / recognition / identification in FLIR and LADAR imagery based on geometric hashing and hash point extraction. The FLIR variant of this capability was integrated into the SSV system and was available for the Demo II field exercises at Ft. Hood. Other key contributions included theoretical foundations and applications of geometric hashing, application of geometric hashing to LADAR imagery for target recognition / identification, and Laplacian pyramid fusion of LADAR range and intensity imagery.

**Rockwell International.** Rockwell provided a stationary FLIR-based target detection algorithm, developed LADAR-based background suppression software, and developed FLIR / LADAR fusion registration ideas.

**University of Maryland / University of Pennsylvania / University of Rochester / National Institute for Standards and Technology.** This consortium, led by the University of Maryland, focused on the problem of detecting independently moving objects from a moving camera based on the integration of 2D image stabilization and a moving object detection algorithm. The University of Maryland developed a real-time electronic image stabilization system. The University of Rochester developed algorithms for the real-time detection and location of independently-moving objects by a moving observer, and the recognition of complex temporal textures and activities. The University of Pennsylvania built an active camera system for

RSTA-on-the-move, which enables target tracking and keeps the image constant in size by using zoom pan/tilt control. NIST developed a HMMWV-based testbed for use by the consortium.

**University of Texas - Arlington (UTA).** UTA designed and implemented a decision-theoretic framework for multi-agent sensor planning, which computed optimal observation points and camera angles. UTA also provided a scenario-based analysis of the UGV project to identify user requirements and critical areas for technology development.

### 2.2.3. Government and Administrative Efforts

Government organizations who participated in the UGV / Demo II program are summarized below along with some of their roles and contributions. This list is not all-inclusive.

**Dyncorp / Meridian.** Dyncorp/Meridian assisted the DARPA program manager with initial briefings and Memorandum of Agreement to obtain funding to launch the UGV / Demo II program, with the setup of quarterly workshops or demonstrations in coordination with Lockheed Martin, and with internal DARPA program reviews.

**Science & Technology Associates, Inc. (STA).** STA provided technical and programmatic assistance to the DARPA UGV / Demo II program managers.

**Unmanned Ground Vehicles / Systems Joint Program Office (UGV/S JPO).** The UGV/S JPO:

- Assisted in the development of the vignettes for Demo II at Ft. Hood, Texas.
- Provided two tactical unmanned ground vehicles, the GECKO and POINTMAN and all associated support for use in Military Operations in Urban Terrain (MOUT) Vignette at Demo II at Ft. Hood, Texas.
- Provided Demo II with the results of the first detailed and rigorous analysis of the tactical unmanned vehicle using modeling and simulation in an offensive scenario. This study provided the first ever set of tactics, techniques, and procedures for the tactical employment of tactical unmanned vehicles employed by a mechanized infantry scout platoon.

**U.S. Army - ARL.** The Army Research Laboratory (ARL), as an agent for DARPA, provided Government Program Management of the UGV / Demo II program from 1993 through its conclusion in 1996. Additionally, ARL made specific unique contributions by:

- Providing full coordination and liaison with the staff and soldiers at III Corp and Ft. Hood beginning with Project Mustang, which established the initial relationship, and completing with the detailed planning of the UGV / Demo II field exercises.
- Performing as the DOD-wide military user interface for UGV / Demo II technology.
- Providing the moving target detection algorithms and code for integration into the SSV system.
- Furnishing the Modular Integrated Laser Engagement System (MILES) equipment and interface support for integration into the SSV system.
- Acting as the DARPA contracting agent for David Sarnoff Laboratories' advanced image stabilization technology.

**U.S. Army - Battlelabs.** The Mounted Maneuver Battlespace Lab conducted the DARPA Demo II Unmanned Ground Vehicle (UGV) Battle Lab Warfighting Experiment (BLWE) at Ft. Hood, Texas. The experiment was designed to examine the tactical and technical capabilities and potential combat value of utilizing UGVs to augment battalion and scout platoons performing reconnaissance and security missions, and man-machine issues of training development. This experiment also was to provide initial insights for future UGV concept refinement and development of UGV-specific doctrine, tactics, techniques and procedures to include insights into training support packages and issues. Additionally, the Dismounted Battlespace Lab at Ft. Benning, Georgia supported the MOUT Vignette.

**U.S. Army - CECOM / NVESD.** Significant contributions made to UGV / Demo II program by Communications & Electronic Sensors Command (CECOM), Night Vision & Electronic Sensors Directorate (NVESD) include active participation in workshops and planning meetings, evaluation of RSTA algorithms, and providing static display items for Demo B--Off Route Smart Mine Clearance vehicle and Countermine Joint ACTD display. A Mini Eyesafe Laser Infrared Observation Set (MELIOS) was provided for integration into the SSV system.

**U.S. Army - CANG.** The Colorado Army National Guard (CANG) loaned various military vehicles to the UGV / Demo II program, provided maintenance support for research vehicles, and valuable recommendations and consulting regarding vehicle modification, repair and use.

**U.S. Army - Ft. Hood.** 2-7 Cav, 3d Brigade, 1st Cavalry Division supported the unmanned ground vehicle experiments conducted at Ft. Hood, Texas. The activities at Ft. Hood consisted of a setup and training period followed by three separate vignettes to demonstrate the military worth of unmanned scout vehicles. The setup and each vignette required different levels of support from 2-7 Cav. Maintenance and support (including storage of unmanned ground vehicles) was accomplished through the support of the Ft. Hood Directorate of Logistics (DOL).

**U.S. Army - MICOM.** MICOM served as DARPA's contracting officer for the Surrogate Semiautonomous Vehicle (SSV) Integration Program contract at Lockheed Martin Astronautics.

**U.S. Army - TACOM / TARDEC.** Since the inception of the UGV / Demo II program feasibility study in 1990, the TACOM Robotics Office has supported Demo II in the areas of Intelligent Mobility, Perception, and Planning. TACOM competitively selected the research agencies for DARPA to support Lockheed Martin Astronautics, e.g., CMU, JPL, Hughes, the University of Michigan, and Cybernet, who went on to form much of the core Demo II team.

**U.S. Army - TEC.** Topographic Engineering supplied terrain database construction for the Lockheed Martin Denver Site and the Ft. Hood Site, including digital elevation maps, ortho photos and feature data. TEC also supplied simulation of the bounding overwatch scenario plus contract management support for Autonomous Navigation Research.

### 2.3. System Integrator

The Surrogate Semiautonomous Vehicle (SSV) Integration Program at Lockheed Martin Astronautics (LMA) was the integration site for the UGV / Demo II program. We developed four prototype ruggedized unmanned vehicles plus an operator base. LMA was responsible for vehicle command and control operations; the core reconnaissance, surveillance and target acquisition (RSTA) program, and the modification, integration, and validation of co-contractor technologies. LMA produced four annual field demonstrations: Demos A, B, and C at Denver, Colorado; and the Demo II field exercises at Ft. Hood, Texas. LMA hosted 21 UGV community workshops, worked closely with over 40 co-contractors, and created a testbed for critical new technologies and products. With the combined efforts of the UGV community we have built an autonomous vehicle for the twenty-first century.

The objective of the Lockheed Martin Astronautics SSV Integration Program was to coordinate and integrate DARPA research / test bed activities in support of the Joint Tactical Unmanned Ground Vehicles Program. To that end, the SSV Integration Program was, itself, a 'test bed' contract, serving as a mechanism whereby various advanced computer software and hardware technologies could be examined, individually, and in combination with others. Demonstrations of integrated software and hardware technologies that showed progressive technology development were the principle products of this project.

Lockheed Martin's overall goal was to provide a research test bed for advanced, state-of-the-art software and hardware components, that, when integrated, provide insight into technology required to reliably operate and maintain semiautonomous ground vehicles. Since the program's emphasis was developmental research and integration, the customer requested that a minimal level of documentation be provided; documentation should serve, primarily, as an historical basis from which future work might be undertaken.

## 3. Integration and Demonstration Process

The most visible aspects of the system integrator's role in the program were coordination activities focused at regular workshops, and the annual demonstrations. These activities also occupied one of the smallest amounts of effort by the system integrator. System design, build, integration and field experiment work occupied the bulk of the system integrator's time. The community coordination and integration processes are summarized below.

## 3.1. Community Coordination

UGV workshops were held to facilitate SSV design and integration efforts as well as provide a mechanism for community technical inter-change. Workshops were forums for discussion of all aspects of the SSV program: technical and demonstration requirements, design, technical issues and directions, test and integration activities, and demo preparations. Hardware and software design topics were discussed to facilitate common technical community understanding and to ensure design and implementation feasibility and practicality. Co-contractor efforts were also reviewed with particular emphasis on component functional capabilities, interfaces, and delivery schedules. The workshop meetings were not conferences; they were working sessions with a blend of presentations and specially chartered working groups. The UGV / Demo II program established five working groups - mission planning and user interface, mobility, RSTA, communication, and hardware. Key integration and technical issues were discussed within these working groups.

The approximate frequency of UGV workshops was quarterly, and they were scheduled, if possible, to coincide with planned demonstrations and milestone reviews. Typically, workshop attendees consisted of representatives from project software and hardware development, systems integration and engineering, operations, project management, the customer, government technologists and user representatives, and co-contractors. Conduct of workshops followed a published agenda (as much as practical). During workshops, action items were assigned (with associated need dates) and recorded.

The successful establishment of a process for the development for the annual demos was one of the primary results of Demo A. This approach was successfully continued during Demo B, Demo C, and Demo II. The most significant method of disseminating information and coordinating between the organizations became the quarterly workshops. Working group team members presented concepts, designs, and implementation status at each of the workshops. The primary approach at these workshops was to build consensus among the affiliates. Workshop agendas were deliberately kept flexible and frequently changed during a workshop, depending on the issues at hand. In addition, side sessions frequently addressed and resolved technical issues relevant to different subgroups. Documentation developed at the workshops was disseminated in hardcopy by mail after the workshops were completed. These workshops were extremely effective in that they provided an opportunity for all parties to congregate and converse at once.

Between the workshops, information was exchanged by several methods. E-mail and telephone conversations were the most common form of exchanging ideas, analysis, designs, and code between the associates. Lockheed Martin also established a common ftp area, where files containing FrameMaker documents, CADRE TeamWork databases, software written in C and C++, supporting libraries, “Make” files, and data files could be delivered and accessed via the Internet.

## 3.2. Evolutionary Development Approach to Integrated Demonstrations

In order of increasing technology integration level, there were three general types of demonstrations: Laboratory, Technology, and Integrated. Laboratory demos took place as stand-alone systems without any SSV vehicle integration. An example would be a target detection algorithm implemented in code on a workstation and reading input imagery from files. Technology demos took place as systems integrated onto an SSV just enough to have the capability function on its own. An example would be an image stabilization algorithm implemented on specialized processors which connected to the SSV through mechanical, power, data, and video interfaces, but which did not provide results to the primary target detection subsystem. Integrated demos exercised a completely interconnected set of subsystems over a military mission-derived scenario. An example would be mission planning, vehicle mobility, and target detection applied to reconn an area and perform fire control on identified targets.

SSV software development and integration followed an iterative spiral process methodology that provided the mechanism to allow SSV hardware and software to proceed through a series of increasingly more capable demonstrations. As previously indicated, a significant portion of the software for each demonstration is not developed by Lockheed Martin Astronautics, but rather was provided by co-contractors and subcontractors. As a result, a proportionately larger amount of effort was expended in integration rather than on formal analysis and design. In such a situation, early definition of interfaces is critical to the ease with which the various components are integrated into an operational whole. As one might imagine, development efforts for each succeeding demonstration built upon the previous demonstration. For example, Demo A provided the reuse baseline for Demo B, with Demo B adding new capabilities to existing functionality. To accomplish final integration, minor changes to software were made during demonstration dry runs leading up to the formal demonstration.

When co-contractor or subcontrator code was first delivered, it was initially evaluated by a designated Lockheed Martin software engineer, serving as the technical point of contact for the co- or subcontractor, to determine whether the code meets all program expectations, with particular attention being given to interfaces. The evaluation process typically involved loading and compiling the software on a resident host, and then testing all interfaces to assure interface compatibility. The output of this process was a software component that was then placed under configuration management. In many cases the software would then be required to undergo some modification to make it compatible with the current program processing architecture. After such modifications were made, the code was then integrated with Lockheed Martin Astronautics-developed code and tested. After a demonstration baseline was established, modified code was made available to co- and subcontractors through an ftp server. It was not always the case that modifications to co- and subcontractor code made by Lockheed Martin were incorporated by the co- or subcontractor into future releases. Indeed, frequently, the co-contractor was working on future versions of the software at the same time modifications were being made by Lockheed Martin.

Frequent design and code discussions were held with each of the contributing co-contractors and subcontractors, particularly to identify potential problems concerning interfaces with Lockheed Martin Astronautics and other co- or subcontractor-developed code. It was often the case that co- or subcontractor personnel were on-site and helped with code and development and integration. In such cases, discussions were held on an almost daily basis.

As explained earlier, the SSV Integration Program's primary objective was to provide a mechanism whereby advanced computational hardware and software technologies could be integrated and tested in a controlled, yet 'real' operational environment. The suite of four major program demonstrations provided a development and integration environment that facilitated insertion of increasingly more capable technology. To mitigate program risk inherent with the integration of several state-of-the-art hardware and software technologies, each demonstration's capabilities were largely based upon functionality provided in earlier years. For each demonstration, SSV software quality assurance ensured software baseline integrity was maintained so that the current demonstration baseline could be used as the prototype for later demonstrations.

To mitigate potential vehicle risks resulting from unplanned hardware actuation, all software was rigorously tested prior to in-field vehicle operation. Software was first "bench-tested" to ensure that simulated actuators move as predicted. After simulation testing, software was loaded on the vehicle and executed while the vehicle was on test-stands. Only after successful completion of these tests were in-field vehicle operations conducted. Various safety procedures were implemented and safety devices installed on the vehicle to ensure personnel safety. All safety issues related to both hardware and software were thoroughly reviewed by the program's external Safety Board, with safety procedures established and implemented in coordination with the program's Safety Engineer.

## 4. Demonstration Summaries

Since the program's inception in 1992, four major annual UGV / Demo II demonstrations were completed. Three interim demonstrations (Demo A, Demo B, and Demo C) were performed at Lockheed Martin's Waterton, Colorado facility to confirm incremental progress leading up to Demo II, which took place at Ft. Hood, Texas during 1996. These demonstrations are summarized here and described in detail in the last paper of this chapter.

### 4.1. Demo A

Demonstration A (Demo A) was held in July of 1993 (Figure 4). The goal was to show basic systems operation and precision navigation of a single vehicle. Demo A employed the SSV-A vehicle and a laboratory-based operator workstation. A robotic plan which specified the path and mode changes of the vehicle was developed and overlaid on a digital terrain map. The vehicle was remotely driven onto a paved road using low-bandwidth teleoperation. Once on the paved road, SSV-A switched to on-board autonomous road-following. As the vehicle followed the road, it pulled off at a preplanned point and performed a teleoperated RSTA demonstration, transmitting images of the adjacent countryside back to the operator workstation. The SSV then continued along the road for approximately 1000 meters through a hairpin turn until intersecting a dirt road. SSV-A was teleoperated onto the dirt road, and road following resumed. Upon reaching a hilltop, the vehicle was maneuvered into an observation point via teleoperation. Teleoperated RSTA was again performed. A target was located and a simulated call for fire was performed. The vehicle then drove to a recovery point using teleoperation and road following.

Additional laboratory demonstrations were performed by the UGV community, addressing topics such as obstacle detection and avoidance, tactical communications, and unmanned aerial vehicles.

### 4.2. Demo B

Demonstration B (Demo B) was held in June of 1994 (Figure 5). The goal was to show mission planning, robust semi-autonomous mobility, and target detection and tracking. Demo B employed the SSV-B vehicle and a HMMWV-based operator workstation. A mission plan was generated at the operator workstation and downloaded to SSV-B. Upon plan initiation, the vehicle moved cross-country following a preplanned path that intersected a dirt road. SSV-B then transitioned automatically, without stopping, from cross-country to road-following mode and proceeded down the road for approximately 500 meters until reaching another transition back to cross-country. Upon reaching the RSTA observation point, a video panorama and landmark orientation correction were performed. Next, a hillside road located about 400 meters away was searched for enemy activity. A moving target vehicle was detected using video and tracked using the FLIR. Next, SSV-B searched for stationary targets at a location approximately 1100 meters distant using the FLIR. Location data and images were provided to the operator for target confirmation and a simulated artillery call-for-fire. SSV-B continued its reconnaissance mission by following a dirt road to a sharp fork where the operator used waypoint teleoperation. The vehicle then climbed the hill using the road to the top where it exited the road and moved cross-country. Obstacle avoidance detected and maneuvered around large rocks encountered on the planned path. An additional RSTA observation point and cross-country mobility concluded the mission.

Figure 4. Demo A, June 1993.

Additional laboratory demonstrations were performed by the UGV community, addressing topics such as UAVs, processing architectures, obstacle detection, automated target detection using video, FLIR, and LADAR, operator control units, satellite communications, mission planning, mobility actuators, navigation LADARs, and mine detection. Image stabilization was demonstrated in the field using SSV-A.

### 4.3. Demo C

Demonstration C (Demo C) was held in July of 1995 (Figure 6). The goal was to show two cooperating vehicles performing a scout mission, with an emphasis on individual technology demos rather than the integrated demo. The integrated portion of Demo C employed the SSV-B and SSV-C vehicles and a HMMWV-based operator workstation. A dual-vehicle offensive movement-to-contact mission plan which coordinated mobility and RSTA actions was generated at the operator workstation and downloaded to the vehicles. Each of the vehicles traveled simultaneously from the start point to their respective initial reconnaissance positions. From these positions, they sent images of the terrain along potential enemy corridors of advance to the operator for review. Both vehicles then moved simultaneously towards their primary target search positions. Movement by each vehicle was cross-country at approximately 5 miles per hour. A terrain-feature phase line was used to hold the lead vehicle (SSV-B) until SSV-C caught up, demonstrating cooperation between the vehicles with a true representation of how the military coordinates battlefield movements. Arriving at their positions independently, the vehicles began their target search activities with an initial panoramic view of the target areas and an orientation correction. Next, each vehicle began detailed target searches of their assigned areas. SSV-B detected enemy targets (represented by a Bradley Fighting Vehicle, an M60 tank, and an M113 APC). These target detections were sent to SSV-C for verification, demonstrating cooperative dual-vehicle RSTA. Following receipt of

Figure 5. Demo B, June 1994.

confirming detections from SSV-C, SSV-B then sent prioritized target reports back to the operator. Upon initiation of the defensive portion of the integration demonstration, the operator issued a new plan to the vehicles, canceling the ongoing offensive mission. Both vehicles moved simultaneously towards their assigned defensive positions, where they monitored assigned enemy corridors of advance for targets. Moving target detection occurred on SSV-B, followed by target tracking. Once detection was confirmed by the operator, a call-for-fire was performed with a simulated missile firing from an Apache helicopter against the laser designated target.

Reflecting the emphasis on individual technology capabilities, Demo C featured a large number of technology demonstrations, the majority of which were at least partially integrated into the SSV system.

Mission Planning and User Interface tech demos included: (1) Premission Planning Tools (military plan decomposition, contingency planning, robotic plan editor, observation point planning, formation planning, terrain visualization, route planning, mission lab); (2) Plan Execution and Monitoring (multi-vehicle plan execution control and monitoring, contingency monitoring, cooperative teleoperation); and (3) Formation Driving / Zone Security (formation control off-road, RSTA zone security, cooperative plan execution monitoring).

Mobility tech demos included: (1) Obstacle Detection Sensors (stereo video, FLIR stereo at night, LADAR, radar); (2) Stereo Obstacle Avoidance (positive obstacle avoidance, negative obstacle avoidance); (3) Obstacle Map Generation and Sharing (dynamic route replanning, obstacle map sharing, map updating); (4) Military Hill Cresting; and (5) Multispectral Terrain Classification.

RSTA tech demos included: (1) Mobility and RSTA Capabilities of the ARL Mustang Vehicle (moving target detection with stabilized video, retrotraverse, teleoperation, satellite communications, operator control unit); (2) Moving Target Detection (with stabilized image and panning sensor); (3) Stationary Target Detection, Recognition and Identification (color target detection, FLIR target recognition, FLIR target search / recognition / identification, LADAR target search / recognition / identification, FLIR clutter suppression); (4) Adaptive RSTA System Using Reconfiguration / Retraining; (5) FLIR Mine Detection; and (6) Lab Demos (sensor fusion of FLIR and LADAR, RSTA on-the-move, target detection with polarization sensor, RSTA at

Figure 6. Demo C, July 1995.

night, RSTA target recognition on Paragon architecture).

### 4.4. Demo II

Demonstration II (Demo II) was held in May and June of 1996 at Ft. Hood. The goal was to perform both offensive and defensive missions using three cooperating vehicles in a military environment. Demo II employed the SSV-B, SSV-C, and SSV-D vehicles and a HMMWV-based operator workstation. Following Demo C, a panel of military user organizations selected three vignettes as the focus for Demo II: (1) Forward Observer; (2) Military Operations In Urban Terrain (MOUT); and (3) Recon / Counter-recon. The mission of the Forward Observer Vignette was to deploy behind enemy lines and seek out high-value targets for engagement with indirect fires. The objectives were to demonstrate RSTA capabilities, the ability to formulate and transmit calls-for-fire, and the ability to adjust fire. The mission of the MOUT Vignette was to clear an enemy occupied village / buildings. The objective was to examine the interplay between manned units and UGVs in a village clearing operation. There were two missions for the Recon / Counter-recon Vignette. Mission 1 was move to contact using UGVs to provide reconnaissance forward of manned units. Mission 2 was take defensive positions and detect probing enemy scout forces. The objectives of these missions were to examine UGV-driven variations of tactics, techniques, and procedures, demonstrate mission planning / replanning, mobility, and RSTA capabilities, and demonstrate force multiplication. All three vignettes were performed by soldiers of the 2-7 Cavalry, who generated the mission plans and


Figure 7. Demo II, Forward Observer Vignette, May/June 1996.

operated the SSV vehicles from the HMMWV-based workstation.

The Forward Observer Vignette (Figure 7) employed the SSV-C vehicle. From start point to the observation point, SSV-C traveled approximately 2000 meters unmanned, encountering muddy terrain and target hulks. After arrival at the observation point, SSV-C began the RSTA phase of the mission, scanning the preplanned area of interest using the color camera and FLIR. A target was detected at 1400 meters range using FLIR imagery. The operator then used the Melios laser range finder to determine active range to the target, checking it with passive ranging. A fire control sequence was initiated with the supporting mortar section, and live fire used to engage the target. The first ranging shot was well within manual standards, and only two more adjustment shots were required before going to fire for effect. All target adjustments were performed using the vehicle. SSV-C then moved approximately 1000 meters to a second observation point, completing the mission.

The MOUT Vignette (Figure 8) employed all three vehicles. Each was moved independently, about 500 meters, to observation points overlooking different sectors of the MOUT training village. Next, each SSV reconned the village using its color camera and FLIR. Enemy activity detected in the imagery from each vehicle was relayed to the commander of the manned forces occupying the village. Personnel movement from building to building, sniper activity on the roofs, and personnel in building windows were all observed, during both daytime and nighttime operations. Two smaller teleoperated vehicles were used within the town itself. Unplanned SSV vehicle movements were executed to obtain new observation points. The mission ended with the completion of the force-on-force occupation of the town.

The Recon / Counter-recon Vignette (Figure 9) also employed all three vehicles. This vignette was controlled by the Mounted Maneuver Battlespace Laboratory (MMBL) as a warfighting experiment. The SSV vehicles were attached to a scout platoon and deployed in a variety of manners, alone and in conjunction with manned

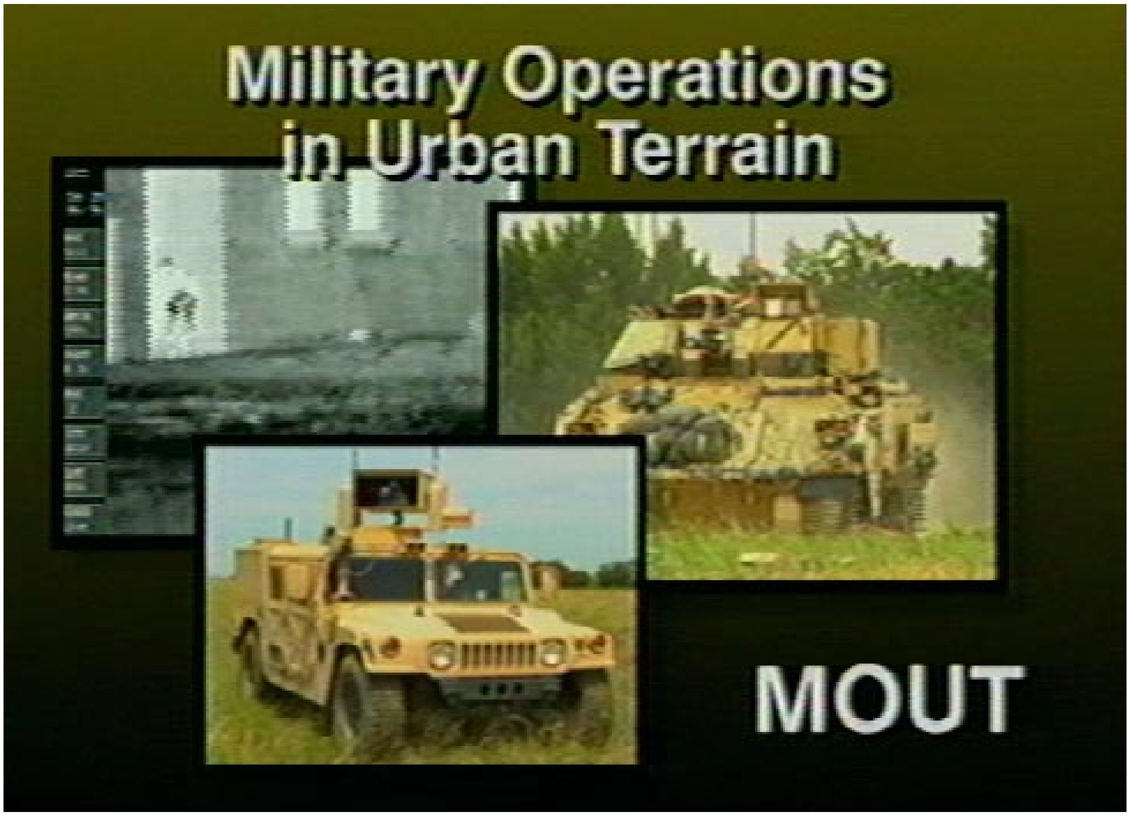


Figure 8. Demo II, Military Operations In Urban Terrain (MOUT) Vignette, May/June 1996.

vehicles. The scouts operating the SSV vehicles worked within the time constraints of the overall mission. Automated RSTA performance for the Recon / Counter-recon missions was good for ranges up to 1500m. Beyond that, manual target detection within the imagery was required. During the experiment, the operators became more proficient in utilizing the vehicles, which survived longer in subsequent engagements. Overall, a very high operations tempo was maintained relative to the single demonstrations of previous years.

Additional laboratory demonstrations were performed by the UGV community, addressing several RSTA topics, as well as mission mobility, tactical communications, and vehicle controls.

## 5. Conclusions

The UGV / Demo II has been highly successful, as supported by external evaluations such as the following.

"The UGV / Demo II program has made significant progress in advancing the state of the art for performing UGV functions autonomously, stimulating user awareness and interest, and understanding the soldier-machine interface. The technology capabilities demonstrated are impressive. A set of sophisticated components of an autonomous vehicle has been developed and integrated on demonstration systems, Feedback from the user community has helped to focus technology efforts toward a program that will provide the enhancements required to produce a more robust, more capable UGV to meet multiple military needs." [UGV MP, 1996, page 35]

The UGV Battle Lab Warfighting Experiment (BLWE), part of the Demo II activities at Ft. Hood, Texas, "found significant potential value added to the warfighter in increased situational awareness, reducing risk to manned platforms, increasing the tempo of operations, and protecting the force. There is a significant potential for this technology to provide a technical solution to the Force XXI doctrinal requirement to expand the battlespace. It also has potential for significant contributions to conducting decisive operations, rapid force projection, and sustain the force. This technology could have wide application across the entire force structure, providing a technical solution to requirements across the mounted


Figure 9. Demo II, Recon / Counter-recon Vignette, May/June 1996.

maneuver battlespace. Based on the results and findings of this experiment, it is recommended that further experimentation be conducted with this technology to refine warfighter requirements, and that TRADOC support further material development of the semi-autonomous technology." [UGV BLEFR, 1996, page iv]

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