Reconnaissance, Surveillance, and Target Acquisition in the UGV/Demo II Program

William E. Severson and Raymond D. Rimey*
Martin Marietta Astronautics Group
POBox 179, M/S H8380
Denver, CO 80201
{severson, rimey}@ssv.den.mmc.com

Abstract

The UGV/Demo II program was established to develop and mature, within 5 years, the navigation and automatic target recognition technologies critical for minimally supervised, semi-autonomous, unmanned ground vehicles for military scout missions. The program, initiated in 1992, focuses on and exploits the artificial intelligence, computer vision, and advanced processor development sponsored under ARPA's science and technology program using militarily relevant scenarios. The vehicles are HMMWV's outfitted with on-board sensors and processing, and conduct reconnaissance, surveillance, and target acquisition (RSTA) operations supervised by a human operator over a low-bandwidth radio link. FLIR, LADAR, and CCD camera sensors are used to detect, track, and identify targets using on-board parallel processing architectures. An operator monitors and initiates RSTA activities using a remote graphical user interface, and verifies detected targets from transmitted image "chips". A highlight of the program is the active collaboration with leading researchers in ATR and image understanding from government, industry, and universities, and the integration technology from these sources. Key RSTA technologies being developed and integrated include: adaptive FLIR-based target detection and identification, model-based recognition using LADAR, sensor fusion, moving target detection and tracking, image stabilization, and multi-agent planning. A series of four demonstrations, held each year from 1993 through 1996, show the evolution and maturity of the technologies. The final demonstration will have four cooperating vehicles conducting offensive and defensive missions. This paper summarizes the UGV/Demo II program, RSTA technological achievements to date, and plans for the future.

*This work is sponsored by the Advanced Research Projects Agency (ARPA) and the Office of the Secretary of Defense (OSD), under the contract Surrogate Semiautonomous Vehicle (SSV), contract number DAAH01-92-C-R1O1, monitored by the U.S. Army Missile Command.

1 UGV/Demo II Program Overview

The objective of the UGV/Demo II program is to develop and mature, within 5 years, those navigation and automatic target recognition technologies critical for the development and demonstration of supervised, autonomous, unmanned ground vehicles capable of performing military scout missions with a minimum of human oversight. The intent is to focus on and exploit the artificial intelligence, computer vision, and advanced processor developments sponsored under ARPA's science and technology program in militarily relevant scenarios. The developed autonomous navigation and automatic target recognition technologies will be transitioned to the principal DoD agencies that are responsible for and support the acquisition of unmanned ground vehicles. A secondary objective is to establish a supporting R&D base among academia and industry.

The U.S. Army Infantry School would like a remotely controlled ground system to operate in the most dangerous areas of the modern battlefield, open terrain that is highly trafficable. This has led to the premise that the system should be unmanned and fast. The project emphasis is on effective robotic technology that has multiservice applications and is unique to unmanned vehicles on the ground. The primary goal of the Unmanned Ground Vehicle (UGV) Demo II program is to demonstrate the utility of advanced UGV systems to conduct tasks that enhance the Department of Defense force structure [Mettala and Firschein, 1993]. This demonstration will combine both an offensive and defensive operation in a militarily relevant situation.

Key technologies that this program focuses on include: systems architecture, passive stereo vision for obstacle detection and avoidence, autonomous navigation, premission planning, mission monitoring and control, RSTA (Reconnaissance, Surveillance, and Target Acquisition) functions, laser radar (LADAR) technology, and non-line-of-sight communications.

The UGV Demo II initiative is a suite of related contracts in which the various contractors are each responsible for the development of key component technologies. Principal components of the UGV Demo II scenario are four vehicles, the multivehicle control unit, and RSTA targets. The major navigation emphasis of the program is to robustly drive on arbitrary roads, plan and execute a safe path through the terrain, and perceive and avoid obstacles (both on- and off-road). The major RSTA emphasis of the program is to detect, track, and identify targets using FLIR, LADAR, and CCD camera sensors, provide tele-operation support (sensor controls, imagery for visual inspection), and development of intelligent target search capabilities using terrain and doctrinal knowledge. Generally, targets will be detected using FLIR and/or color sensors and identified using LADAR (possibly in combination with FLIR and color).

There are three interim demonstrations (Demos A, B, and C) to illustrate incremental progress leading up to the final demo (Demo II). Martin Marietta's Waterton, Colorado facility is used for the interim demonstrations. Demo II will take place at Ft. Hood, Texas.

- Demo A demonstrated basic mobility and teleoperation capabilities for a single vehicle [Chun and Jochem, 1994]. Date: July of 1993.
- Demo B incorporated off-road navigation and stereo obstacle avoidance, core target search functionality, stationary target detection in FLIR imagery, and moving target detection, tracking, and designation capabilities. Date: June of 1994.
- Demo C will involve a cooperative, dual-vehicle mission. Potential cooperative capabilities include the sharing of obstacle and terrain feature information in a common database, cooperative searches, "bounding overwatch" maneuvers, target verification from the second vehicle for passive ranging to the detected target and reduced false alarm rate. Date: June of 1995.
- Demo II will involve two pairs of vehicles controlled by an operator using a portable multi-vehicle control unit. Date: June or July of 1996.

2 RSTA Progress — Demo B

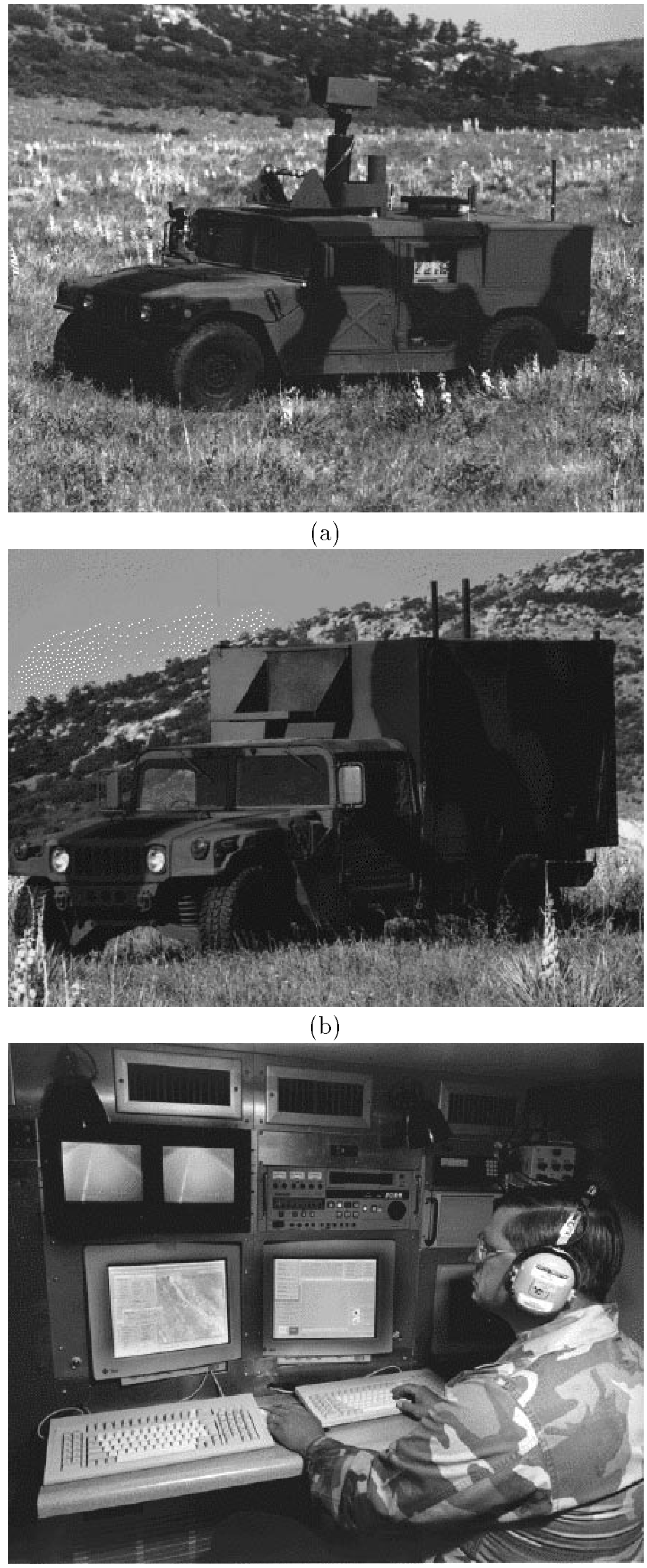
2.1 Vehicles

Figure 1(a)-(b) shows the SSV-B and SSV-Base vehicles. The SSV-B vehicle is a totally new design based on experience with the SSV-A vehicle built for Demo A. The SSV-Base vehicle is new and houses the operator workstation (Figure 1(c)) from which all SSV-B vehicle pre-mission planning and mission control are performed. See [Chun and Jochem, 1994] for details of the SSV vehicle hardware and software architecture.

2.2 Sensors

FLIR and color video cameras (Figures 2 and 3) were used to execute the RSTA mission for Demo B. FLIR was used to search for stationary targets, color was used to detect moving targets, and FLIR was used for target tracking. A Miles laser designator simulation system was integrated into the vehicle, but this capability was not demonstrated during Demo B.

The FLIR camera (from Amber Engineering, Inc.) has a 256x256 indium antimonide (InSb) focal plane array sensitive over the 3-5 micron band. A filter is installed before the focal plane array to further limit this band to approximately 4.5-5 micron. This filter helps reduce reflective clutter present in daylight scenes. The FLIR



(a) (b) (c)

Figure 1: The (a) SSV-B and (b) SSV-Base vehicles, and (c) the operator workstation inside the SSV-Base vehicle.

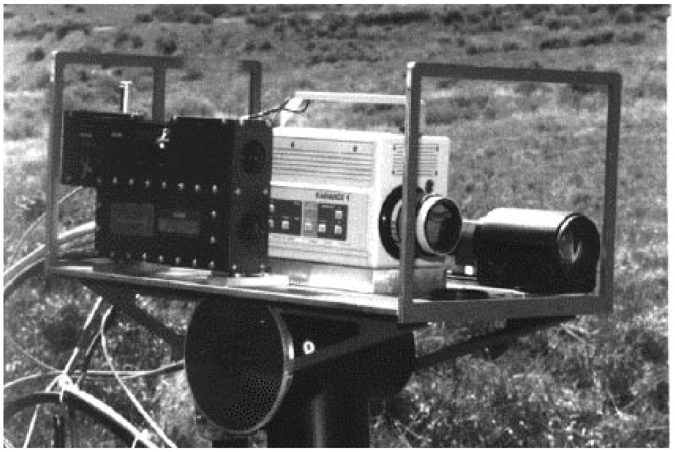


Figure 2: The pan/tilt holding the RSTA sensors on the SSV-B vehicle. Shown from left to right are: the Miles designator system transmitter, the Amber FLIR camera with a fixed lens, and the color CCD camera with the variable zoom lens.

has a dual field of view (FOV) lens, with a 11.11 degree view for wide area search and a 2.79 degree view for detailed target inspection and far range target search. FLIR pixels have 12 bits.

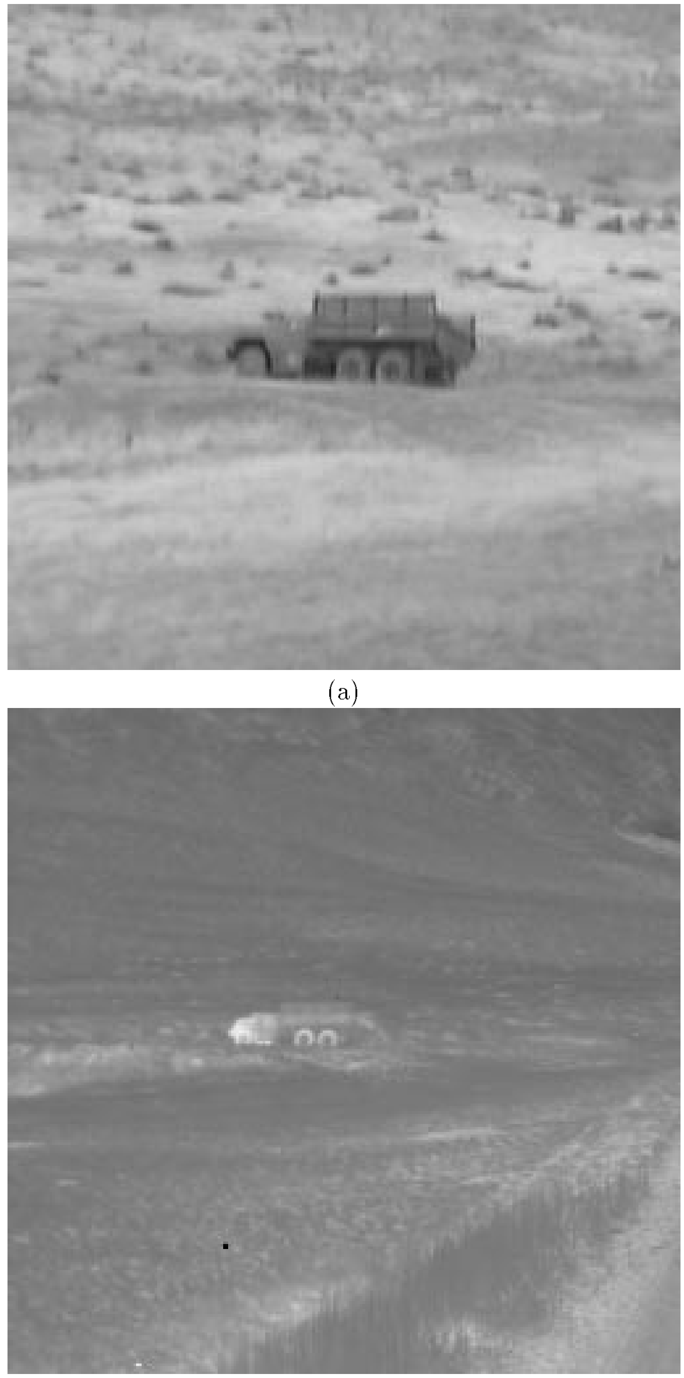
The color video camera is a CCD color camera with a variable zoom lens. The FOV of this camera can vary between 4.5 and 45 degrees.

Raw sensor data is acquired using Datacube mv20 hardware, and transferred through shared memory to Sparc boards and a DAP (SIMD parallel processor) for additional processing. The color and FLIR cameras and the Miles system transmitter are mounted on a pan/tilt unit on the top of the vehicle, approximately 3 meters above the ground. The position and orientation of the SSV-B vehicle are measured by a system containing a differential GPS receiver (the differential transmitter is in the SSV-Base vehicle), flux-gate compass, and tilt meters.

2.3 Software Architecture

The RSTA software system is organized as a set of tasks managed by a task executive on the vehicle (see Figure 4). Commands such as "Search a map region for targets" or "Generate an image panorama for the operator" are received by the task executive. Tasks are constructed for these commands; all tasks have (initialize, execute, pause, resume, terminate) functions that can be called by the task executive. A task's execute function is designed to be non-blocking, so that a task does not tie up the system waiting for the pan/tilt to get into position, for example. The task executive handles contention among tasks regarding hardware resources, such as the pan/tilt or the DAP. It also executes tasks based on task priority.

Many RSTA commands involve a search area, which can be specified as a set of points defining a polygonal region on a map, or as an azimuth range (specified in either vehicle or world coordinates). The specified search



(a)

(b)

Figure 3: Example (a) color and (b) FLIR images of an M35 truck.

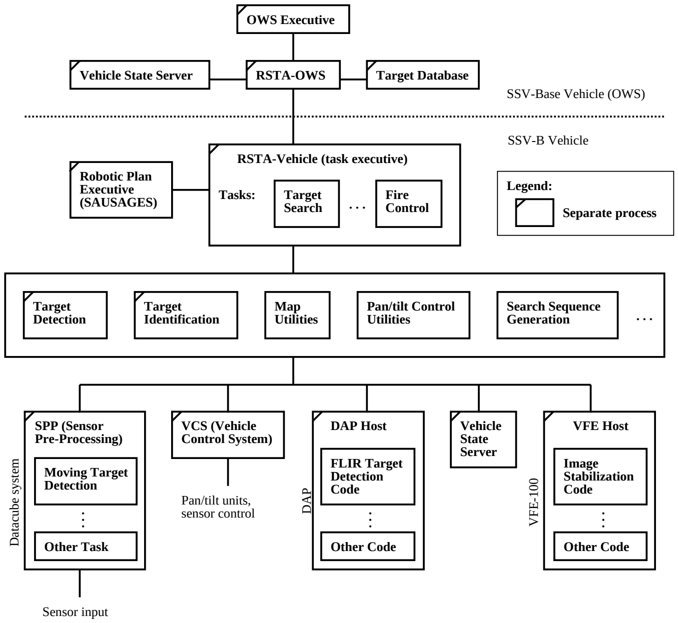


Figure 4: RSTA system software architecture.

area and current vehicle pose are used to calculate a set of views that covers the search area. In Demo B, a search area was covered with a simple raster scan.

The main RSTA commands implemented for Demo B are summarized below. These are issued by the on-vehicle robotic plan executive (using mission pre-planned activities) or issued interactively by the operator over a radio link to the vehicle during a mission.

Stationary Target Search. This command directs the system to search the specified area for stationary targets. For each sensor view in the search, a FLIR – color image pair is acquired. Potential targets are found using a statistical double window filter [Nguyen, 1990] followed by a probing algorithm for finding approximate target-like shapes (*i.e.* rectangular contrast regions). The probing stage is based on work by [Bienenstock *et al.*, 1990, Baras and MacEnany, 1992]. These algorithms are implemented on the DAP. When a potential target is detected, image chips from each image are sent over the radio to the operator for verification.

Moving Target Search. This command directs the system to search the specified area for moving targets. The moving target detection and tracking system is based on an image difference based motion detection system that uses the color camera and that was developed at Army Research Labs (ARL) [David *et al.*, 1990, Balakirsky and others, 1993]. The detection system was extended by Martin Marietta with a "hot spot tracker," which controls the pan/tilt to keep the hottest spot on the detected target centered in the FLIR image. The core of ARL's system is implemented on a DataCube mv20 board. The ARL algorithm requires that the image background be stationary. A color image of a detected, moving target is sent via the radio to the operator for verification. The operator may then initiate continuous (slow, about 6 second interval) display of color images of the object being tracked, and the operator may then trigger the Miles laser designator system. Miles designation was successfully tested by Martin Marietta, but was not included in Demo B due to safety issues and time constraints.

Terrain Reconnaissance. This refers to a variety of activities, such as assessing trafficability, checking out roads and bridges, *etc.* In the Demo B RSTA system, this command directs the system to collect high resolution color images covering a search area. These images are archived on the vehicle for post-mission analysis, or sent over the radio for operator viewing as they are collected.

Generate Panorama. This command directs the system to collect a mosaic of images over a very wide field of view, and to send it over the radio to the operator for viewing. This panorama view is a useful manual method of orienting the operator with the vehicle's surroundings, verifying that a landmark or terrain region is visible, *etc.*

Fire Control Support. This command directs the system to point the color camera in a specified direction, or to point at a specified map coordinate or location of a previously detected target. The operator may initiate a continuous (slow) stream of images that the operator can use to verify that indirect fire is being delivered to the proper location.

Manual Control. Tele-operation control of the RSTA sensors and pan/tilt unit is supported. Images from the FLIR or color camera can be acquired manually.

3 RSTA Plans — Demos C and II

3.1 Demo C

Demo C will feature a dual-vehicle cooperative mission; this is the principal new functionality to be demonstrated in June 1995. A new SSV-C vehicle will be constructed as a copy of the SSV-B vehicle. Detailed planning for Demo C is underway. This section discusses capabilities presently under discussion.

A pair of vehicles could search cooperatively for enemy targets, each covering a portion of the terrain. The vehicles could perform a "bounding overwatch" maneuver, having one vehicle stopped in a partially concealed position, searching for targets, while the other vehicle advances to its next position, assessing trafficability as it moves. The roles would reverse when the other vehicle arrives at its next watch position. Target verification could also be demonstrated, where one vehicle would find a target and get confirmation of the target from the second vehicle.

A number of improvements can be made to a vehicle's method of selecting viewpoints for a search while allowing for (typically) gross errors in knowledge of vehicle orientation. For example, horizon lines can be extracted by segmenting out the (cold) sky in FLIR images. This information can be used to insure that RSTA sensors are directed at areas of interest in a target search. Also, a horizon line found this way can be compared to projections of map elevation data in some cases, to accurately register the vehicle's position and orientation to the map. Given an improved knowledge of vehicle orientation, map elevation data can be used to give range estimates to points within FLIR imagery. Range estimates are very useful for estimating a bound on expected target sizes, which detection algorithms can utilize. A new and improved GPS and orientation measurement system is planned for the vehicles, but the amount of improvement in the field has not yet been verified.

Map data can also be used to improve target search areas. For example, highly trafficable areas can be given priority in a search, and non-trafficable areas (based on slope, for example) can be pruned. Other knowledge and sensed data may provide the basis for more sophisticated prioritized search techniques. The capability to select viewpoints for a search may also be enhanced to include reasoning about terrain occlusions when the vehicle is stationary, and also when it is moving.

Incorporation of a color-based target detection algorithm (from Colorado State University), and incorporation of a FLIR-based target identification system (from Hughes), are being considered for Demo C. This would help to improve both target acquisition performance and the range of acceptable performance. Incorporation of stabilized video (from Sarnoff and Sensar) would enable the vehicles to detect moving targets (from ARL) [David *et al.*, 1990, Balakirsky and others, 1993] while on the move. This would allow the vehicles to continuously search for targets rather than limiting target searches to stop points between vehicle moves.

A combined stationary and moving target search functionality could be implemented to alleviate the operator or pre-mission planning system from having to make assumptions about enemy target state. This is a conceptually simple extension that involves running separate algorithms simultaneously and accounting for differences in field of view for these algorithms in the sensor scan pattern.

Key non-RSTA capabilities that will probably appear in Demo C include: pre-mission planning, plan monitoring and control for cooperating vehicles; a more robust and usable system; and more emphasis on what a real user (*e.g.* an Army scout) needs. The RSTA operator workstation (OWS) may also be enhanced and should be better integrated with the remainder of the OWS.

3.2 Demo II

Demo II will involve four cooperating vehicles conducting navigation and ATR in militarily relevant offensive and defensive missions. It is critical that the vehicles be able to detect and identify targets with minimal operator interaction.

To achieve this ATR performance a targeting LADAR will be added to the RSTA sensor suite; its expected delivery date is May of 1995. As such it will not be incorporated into Demo C, but it will be used extensively in Demo II. FLIR- and color-based target detection processes will find potential targets; LADAR data will be collected at these locations and analyzed to provide a target identification (or indication of false alarm). Fusion approaches to target identification would additionally utilize narrow FOV FLIR and color data collected at these locations.

There is general consensus within the ATR community that the 3D nature of LADAR data is extremely helpful for performing fine target identification. This is especially true with variable lighting and thermal environments.

As an example, Martin Marietta's approach to LADAR-based target identification is a model-based approach, using a hypothesize and test paradigm. An indexing module initially generates a set of (target, pose) hypotheses, which are subsequently refined and pruned in a recognition stage. The indexing stage can vary in its level of sophistication, although simpler algorithms will need to generate more hypotheses to insure that the correct hypothesis is present (putting greater burden on the recognition stage). Candidate approaches to indexing include ground projections of LADAR data for target dimension and pose estimates [Li *et al.*, 1989]. FLIR processing results can also be utilized.

The recognition stage prunes this set of indexed hypotheses to find the correct target hypothesis in the set. For a given hypothesis, a CAD model of the target and sensor characteristics are used to generate predicted features. A 3-dimensional feature matching algorithm compares the predicted features to features extracted from the image. Based on the match, an improved pose for the hypothesis might be found. The extent and quality of match may also dictate that a new prediction be generated. The prediction would account for a refined pose or possibly a subpart articulation.

Key aspects of this approach are hypothesis search space management, the ability to extract a set of features from the LADAR image that are descriptive of the target, and the ability to accurately predict features of a hypothesized target. These feature sets must be in a form that is readily comparable in the matching algorithm.

4 RSTA Integration and Research

The RSTA program has dual goals. One goal is to integrate co-contractor results into the annual demos. The other goal is to produce new research results directed towards the RSTA application area, to provide an experimental research environment and infrastructure, and thus to encourage experimental research.

A recently emerging emphasis in the integration thrust is to work with users (*e.g.* Army scouts) to better understand what a scout needs and desires in a semi-autonomous scout vehicle. This effort will lead to new problems for both research and application development work, and will effect what is contained in future demos. The research thrust is coming from the other direction; researchers produce new research and technology that can be pushed into the annual demos.

4.1 Integration

Martin Marietta is the integrator for the UGV/Demo II program. The principal source of RSTA technology development for the program resides with the set of RSTA co-contractors for the program. These are leading researchers from government, industry, and universities, working under ARPA sponsored programs to advance the state of the art in RSTA technology, and working to develop programs and products that can directly be transferred and integrated into the UGV/Demo II program. The BAA for the RSTA program stressed the production of programs over pure concepts or theory, and encouraged integration onto the SSV vehicles for showing at the annuals demos. The technology transferred for Demo B was ARL's moving target detection system, and the technology transfer currently anticipated for Demo C was noted in Section 3.1.

Each annual demonstration has actually consisted of three kinds of demos called lab and tech demos, and the main demo. These three kinds of demo require progressively more maturity in the algorithms and effort to actually create.

- **Lab demo.** The purpose of a lab demo is to show initial research results, preferably (but not necessarily) on imagery related to SSV demo scenarios. The developer provides (or borrows) all equipment required to run a lab demo, typically only a workstation. A lab demo does not involve an SSV vehicle.
- **Tech demo.** A tech demo uses an SSV vehicle and is a stepping stone to a main demo. It demonstrates that the technology is mature and useful enough to be part of a main demo, without consuming the large effort required for total integration into the SSV vehicle system.
- **Main demo.** The main demo involves the SSV vehicle(s) autonomously performing a complete mission. Work incorporated into a main demo must be delivered to Martin Marietta six months to a year prior to a demo in order to be integrated.

Any reference to a demo in this paper that is not explicitly referred to as a lab or tech demo is in fact a main demo.

4.2 Research

A summary listing of the RSTA co-contractors and their research areas is given in Table 1. The RSTA co-contractors are loosely organized into "subgroups," co-contractors with similar interests (See Table 2). For example, subgroup members have similar needs for CAD models and imagery, and can help each other find such data as already exists.

Some other groups and related work in the SSV program include: stereo and obstacle detection and avoidance (JPL, SRI, Teleos, CMU); autonomous driving (CMU); University of Massachusetts at Amherst (stealthy movement and pre-mission flyover analysis); and pre-mission planning (*e.g.* University of Michigan at Ann Arbor, Hughes Research Labs, Georgia Tech, CMU).

A fundamentally important need of the RSTA co-contractors is representative imagery, which they can use for development and testing of their algorithms.

- One such set of imagery, called the "Ft. Carson data set," was collected during 4 days in November 1994 at Ft. Carson, CO. It includes 35mm color film, Amber FLIR, and Alliant LADAR images, and is currently available to the RSTA co-contractors.

Co-contractors	**Research areas**
Army Research Labs	Moving target detection and tracking. Multivehicle cooperative ATR. Wide-baseline stereo.
Colorado State University, Alliant TechSystems, University of Massachusetts at Amherst	Integrated FLIR, color, LADAR recognition system. Model-to-image matching and pose estimation.
Honeywell, University of Rochester	Learning classifier system for configuring and training ATR suites. Bayes net and decision theory system.
Hughes, Cornell University	Adaptive FLIR ATR system using image complexity measures.
LGA	Evaluation of RSTA algorithms.
Martin Marietta	LADAR ATR algorithms.
University of Maryland, University of Pennsylvania, University of Rochester, NIST	Image stabilization, egomotion, extract vehicle shadows, detect moving objects, integration on NIST vehicle.
MIT Lincoln Labs	LADAR ATR algorithms.
Nichols Research Corp, Loral, NYU	FLIR and LADAR ATR system.
Rockwell	Adaptive background suppression and environmental characterization.
Sarnoff	Stabilized video, and image motion parameter estimation.
University of Texas at Arlington	Scenario analysis. Multivehicle RSTA sensor planning.

Table 1: RSTA co-contractors and their research areas.

Scenario Analyses and Planning, combined with Metrics and Evaluation University of Texas at Arlington - Erik Mettala LGA - Ted Yachik NVL - Rich Peters
Adaptive FLIR ATR Hughes group - Dave Doria Honeywell group - Barry Roberts
Multi-Sensor Fusion and Stereo CMU - Takeo Kanade Colorado State University - Ross Beveridge Nichols Research Corp group - Andy Ackerman Rockwell - Ted Jenks
LADAR Model-based Vision MIT Lincoln Labs - Dan Dudgeon Martin Marietta - Ruey Han
Motion and Active Vision Army Research Labs - Phil David University of Maryland group - Larry Davis Sarnoff - P. Anandan

Table 2: RSTA subgroups.

- The "A. P. Hill data set" resulted from a data collection partially funded by ARPA for the RSTA program. This data set was collected during 4 weeks in April-May 1994 at Ft. A. P. Hill, VA. It includes images from 35mm color film, Mitsubishi FLIR, Amber FLIR, second generation tank sight, and the Raytheon Tri-Service LADAR. This data should become available to the RSTA co-contractors 1Q95.
- Another data set will be collected for the RSTA program during 3-4 weeks starting in September 1994. This data collection will use the same site and types of targets (*i.e.* old generation) as will be used in Demo C. The proposed Demo C site is fairly similar to the area around Ft. Hood, where Demo II will occur. The data will include 35mm color film, CCD color, and Amber FLIR images.

Complementary to obtaining data for the RSTA co-contractors is the need for experimental evaluation of research results. "Experimental evaluation of scientific progress" is a theme that should be encouraged [Firschein *et al.*, 1993, Bolles *et al.*, 1993]. Obviously the researchers themselves are (should be) performing extensive experimental evaluation during the course of their work. In addition, one of the RSTA co-contractors, LGA, is responsible for defining metrics and evaluation procedures for the RSTA program.

4.3 RSTA Research and Technology That is Still Needed

Certain problem areas that are important to Demo C, Demo II, and beyond are covered by RSTA program co-contractors, but others need further research.

The problems areas that currently have good coverage are:

- Improved FLIR target detection via adaptive techniques or fusion with color.
- FLIR target identification.
- Image stabilization.
- Moving target detection and tracking from a moving platform.
- RSTA planning with simple terrain/doctrine reasoning: basic search coverage, bounding movement.
- LADAR MBV target identification.

Problems areas that may need more coverage include:

- **Cooperative RSTA.** Generally, multivehicle cooperative target search, recognition and tracking.
  - How should N vehicles divide up a search task? Or many search tasks?
  - Given that one SSV vehicle has made a potential target detection, how should it be verified? That SSV could attempt to verify the detection from its current position or by selecting a better position to move to. Or verification could be performed by another SSV, either at it current position or after selecting an optimal position for verification. Similar issues exist when identification rather than verification must be performed.
  - How should overwatch positions be selected when a pair of vehicles are performing a bounding overwatch? The positions could be selected during pre-mission planning. Each individual position may need to be locally modified before each bounding movement.
- **Local dynamic planning.** This topic includes: looking at a suspected target from different viewpoints; using different sensors to inspect a suspected target; and selecting which ATR algorithm to use.
- **Smart search.**
  - The basic search problem is to find the best set of sensor viewpoints (or footprints) so that a stationary SSV vehicle searches an area while minimizing the amount of occluded terrain in the search area. "Viewpoint" includes sensor zoom factor as well as sensor pan/tilt angles.
  - The smart search problem is to use other terrain and doctrinal knowledge in order to select and prioritize the viewpoints. Similar knowledge can be used to help interpret results from ATR or vision algorithms. At an extreme, scene analysis techniques could be used to extract terrain and scene features used by the smart search system.
  - Enhancements to basic search will also be required. For example, the SSV vehicle will have to select (and update) viewpoints to cover a search area while the vehicle itself is moving and the occluded parts of the terrain vary over time.
- **Local stealthy movement.** How to use 3D terrain information to hide an SSV vehicle and position it to see something.
- **RSTA and navigation at night.** Scout perform the majority of their work at night.
- **RSTA using acoustics.** Scouts make heavy use of acoustical techniques.
- **Fast RSTA (*i.e.* active vision?).** An scout may want individual RSTA operations to be performed very fast. Operator workstation display of complex time varying RSTA results may become an issue. Fast RSTA would enable the SSV vehicle to maintain situational awareness of its immediate surroundings.
- **Uncooled FLIR technology.** Doing RSTA fast and at night would be facilitated by having several (cheap) FLIR cameras on a single vehicle. Modify existing ATR algorithms to use this sensor. What new things can be done with N FLIR cameras on a single vehicle?
- **Situation assessment.** Recognize enemy formations and tactical situations based on terrain, target detections, and doctrinal knowledge. This detection information may be from a single image or search, but more likely is built up over time from several searches by different SSV vehicles. Detections could

be vehicles as in SSV scenarios, or smaller objects such as artillery, mortars, people, fortifications, *etc.*

- **Context-based vision.** The operator workstation, annotated map data, and other knowledge can be used to select specific ATR or vision algorithms to run in specific places in the scene, and to constrain how the output of the algorithms should be interpreted.

Acknowledgements

Many thanks to Bill Hoff and Steve Hennessy for their valuable contributions to the RSTA program. They were major contributors to both the overall management of the RSTA program and to the Demo A and B RSTA efforts.

References

[Balakirsky and others, 1993] S. Balakirsky et al. Semi-autonomous mobile target engagement system. In *Proceedings of the Association of Unmanned Vehicle Systems (AUVS-93)*, pages 927–946, 1993.

[Baras and MacEnany, 1992] J. S. Baras and D. R. MacEnany. Model based ATR: Algorithms based on reduced target models, learning, and probing. In *Proceedings of the Second Automatic Target Recognizer Systems and Technology Conference*, 1992.

[Bienenstock *et al.*, 1990] E. Bienenstock, D. Geman, S. Geman, and D. E. McClure. Phase II technical report, Development of laser radar ATR algorithms, contract no. DAAL02-89-C-0081. Technical report, CECOM Center for Night Vision and Electro-Optics, October 1990.

[Bolles *et al.*, 1993] R. C. Bolles, H. H. Baker, and M. J. Hannah. The JISCT stereo evaluation. In *Proceedings: DARPA Image Understanding Workshop*, pages 263–274, 1993.

[Chun and Jochem, 1994] W. H. Chun and T. M. Jochem. Unmanned ground vehicle Demo II: Demonstration A. *Unmanned Systems*, 12(1):14–20, 1994.

[David *et al.*, 1990] P. David, S. Balakirsky, and D. Hillis. A real-time automatic target acquisition system. Technical report, Harry Diamond Laboratories, 1990.

[Firschein *et al.*, 1993] O. Firschein, M. A. Fischler, and T. Kanade. Creating benchmarking problems in machine vision: Scientific challenge problems. In *Proceedings: DARPA Image Understanding Workshop*, pages 177–182, 1993.

[Li *et al.*, 1989] R. Y. Li, Y. Y. Li, and J. D. Leonard. Model-based target recognition using laser radar imagery. In *Proceedings of the SPIE Conference on Advances in Image Compression and Automatic Target Recognition*, 1989.

[Mettala and Firschein, 1993] E. G. Mettala and O. Firschein. Reconnaissance, surveillance, and target acquisition research for the unmanned ground vehicle program. In *Proceedings: DARPA Image Understanding Workshop*, pages 275–279, 1993.

[Nguyen, 1990] D. M. Nguyen. An iterative technique for target detection and segmentation in IR imaging systems. Technical report, CECOM Center for Night Vision and Electro-Optics, November 1990.