Description of the UGV / Demo II System

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Abstract

A description of the UGV / Demo II system is provided in this paper to familiarize the reader with the vehicle and related subsystems. The basic vehicle hardware is first described and then the subsystems for autonomous mobility, mission planning / user interface, and RSTA are summarized. Finally, the integration process is discussed.

1. Introduction

The UGV / Demo II system is designed to perform mounted scout missions, i.e., missions in which autonomous vehicles explore a region looking for enemy activity and report back to a command post. The autonomous vehicles in the system, referred to as Surrogate Semiautonomous Vehicles (SSVs), are all based on the High Mobility, Multipurpose, Wheeled Vehicle (HMMWV) platform, which provides extra payload space for this research and development program. The SSVs are equipped with sensors, actuators, and computers for autonomous operation. The RSTA sensors are mounted on a high-speed pan/tilt platform on top of the vehicle. An SSV was built for each of the yearly demonstrations (a total of four), and one base-station vehicle was constructed.

Figure 1 shows all of the vehicles, named SSV-A, BASE, SSV-D, SSV-C, SSV-B, from left to right in the figure. Three of these are low-profile vehicles with the full suite of mobility and RSTA capabilities described below. Figure 2 shows two of these vehicles. SSV-A, shown in Figure 3, is a prototype with a higher profile and a subset of the mobility and RSTA capabilities, and was the first SSV built. The SSVs are commanded and monitored from an operator workstation in the BASE vehicle, shown in Figure 4.

2. Hardware

Vehicle Platform. The basic vehicle is a M1097 HMMWV. The vehicle was modified to the minimum extent practical to maintain depot serviceability. In particular, no elements of the engine, drivetrain, or suspension were modified.

Figure 1. SSV family in desert tan: SSV-A, BASE, SSV-D, SSV-C, SSV-B.

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Figure 2. Low profile SSV vehicles (SSV-B, SSV-C).

Figure 3. Testbed SSV vehicle (SSV-A).

Equipment is organized into logical groups inside the vehicle, as illustrated in Figure 5.

Figure 4. BASE vehicle, which contains the multi-vehicle operator workstation.

Power Generation and Conversion. Two 7 kW generators provide electrical power for all on-board systems. They are housed in fireproof insulated boxes, one in each rear footwell, located at the bottom of the vehicle just behind the driver and passenger seats (see Figures 6 and 7). Power is distributed as both 240 and 120 VAC. Computer, sensor and communications systems are protected by an AC uninterruptable power supply that can power these systems for 15 minutes.

Environmental Control. Two independent 12 kBtu air conditioning units are centrally mounted adjacent to a shared air intake. Hot exhaust air is vented through the rear wheel wells. Flexible ducting feeds cooled air from the combining plenum to all the electronics racks and enclosures. The air flow is primarily forced by the air conditioner fans, with additional fans for circulation within and between enclosures.

Processing Architecture. On the driver's side, the controls rack contains the vehicle controller system (VCS) VME-card cage and two amplifier boxes. On the passenger side, the processing rack contains two VME-card cages: one for general processing and the other for RSTA processing. Each of these two card cages contains a server processor, which can also access a total of 8 Gbytes of disk space. For in-field development work, one processor has a keyboard and monitor mounted at the passenger seat. Each card cage also contains several commercial image processing boards. The controls rack and the passenger-side processor rack are accessible by opening the side vehicle doors. The rear of the vehicle contains space for specialized processing equipment, accessible through the tailgate. The RSTA system's SIMD parallel processor and a VCR are located there.

The mobility card cage contains three Sparc 5CE, two Sparc 2CE, and one 68040 processors, along with a MV200 / MV20 Datacube configuration. The RSTA card cage contains one Sparc 5CE, one Sparc 2CE, and one 68040 processors, along with a MV20 / Digicolor Datacube configuration. The DAP parallel processor, dedicated to RSTA funct-ions, is connected to the RSTA card cage via two interfaces: a SCSI interface to a Sparc board and a parallel interface to an image processing board.

Vehicle Control System. The vehicle control system performs the real-time control of all actuators. Its VME-card cage contains a Sparc 5CE processor, two servo control boards, and analog and digital interface boards. Two chassis contain eight power amplifiers each, both pulse-width modulated servo channels and stepper channels, for the mobility actuators and the pan/tilts.

Mobility Actuators. There are six actuators that control all the mobility functions of the vehicle: 1) steering; 2) throttle; 3) service brake; 4) transmission; 5) parking brake; and 6) transfer case. The steering actuator is located in the cab and mounts around the steering column. The throttle actuator is mounted under the hood with a short linkage to the throttle mechanism. The remaining actuators are all housed in a single box under the vehicle body.

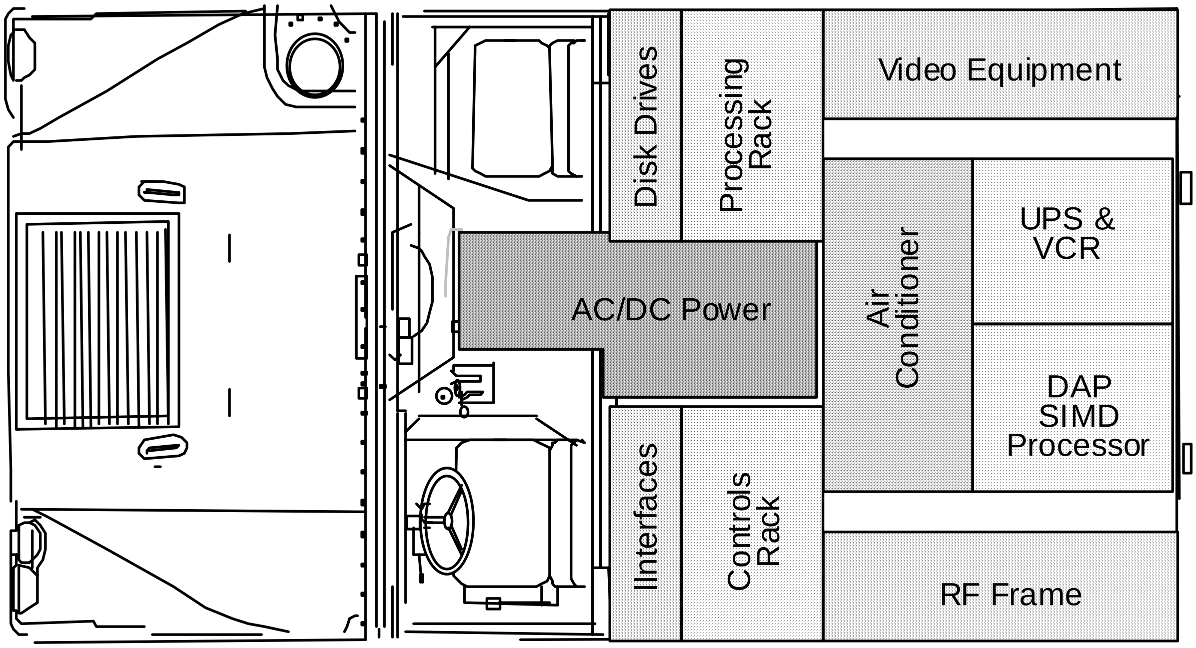

Figure 5. Configuration of equipment areas inside SSV-B, C and D.

Mobility Sensors and Sensor Pointing. Figure 8 shows the placement of mobility and RSTA sensors on the SSV. The obstacle detection sensors are two pairs of stereo black and white charge-coupled device (CCD) cameras: a wide field-of-view (FOV) pair to cover as much of the vehicle's turning radius as possible; and a medium field-of-view pair for better resolution at longer distances. These sensors are located on a fixed mount on the roof over the windshield for maximum forward visibility while not interfering with the RSTA sensors. The medium FOV pair may also be located on the RSTA pan/tilt platform. The mobility pan/tilt, mounted in front of the windshield on the right side, carries the color CCD video camera used for road following. The pan/tilt is elevated above the hood so that the camera is located at the roofline for maximum visibility without interfering with the RSTA or obstacle detection sensors on the roof. A backup camera, with a wide FOV lens, provides the operator with a rear view for use during reverse teleoperation.

RSTA Sensors and Sensor Pointing. The RSTA pan/tilt provides ±270 degrees of side-to-side motion and ±30 degrees of up-down motion, and fine tracking control. The RSTA pan/tilt payload includes: a 3-5 micron indium-antimonide FLIR sensor with a dual field-of-view lens (roughly 3 and 11 degrees), a color CCD camera with an auto-iris zoom lens (4.5-45 degrees), a multiple integrated laser engagement simulator (MILES) designator, and a laser range finder.

Navigation Sensors. The modular integrated avionics group (MIAG) from Lear Astronics Corporation was used to provide navigation data on each SSV vehicle. It is an integrated differential GPS and inertial navigation system that has state-of-the-art 3-axis fiber-optic gyros and 3-axis accelerometers providing accurate position and orientation data, a 3-axis magnetometer, and odometer input. Differential corrections are computed at a base station, inside the BASE vehicle, located at a stationary surveyed point, and are continuously relayed to the SSV vehicles so that the MIAG can adjust for any GPS range errors.

Safety Systems. A fail-safe emergency stop system assures personnel and equipment safety in conjunction with operating procedures. There are two detection chains, one for emergency stopping (E-stop) and one for computer controlled stopping (soft-stop). The E-stop chain, when triggered, forces all mobility actuator amplifiers to preset values, disables computer control, pneumatically activates the service brake via an independent actuator, and kills the drive engine. Trigger sources include in-cab push buttons on both driver and passenger sides, a watchdog timer monitoring control system heartbeat, and a radio pendant with dual receivers. The soft-stop chain incorporates two hardware triggers, in-cab push buttons and the safety radio, and several software triggers, such as communication loss and driving behavior failure. The vehicles also have an audible backup alert and external strobe lights to indicate when the E-stop system is armed and when the MILES laser is energized. A special soft-stop capability is included for temporary loss of GPS differential corrections (transmitted from the BASE vehicle over the packet radio ethernet). When lost, the SSV comes to a stop in a suspended mode waiting for a resume from the operator workstation interface.

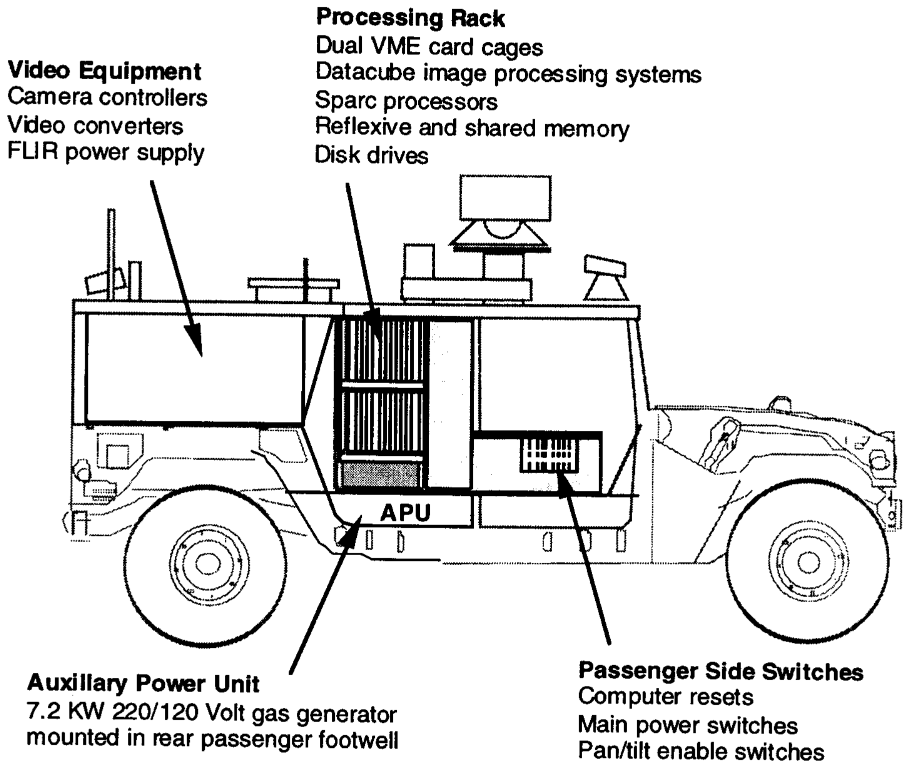

Figure 6. Passenger's side view of SSV equipment.

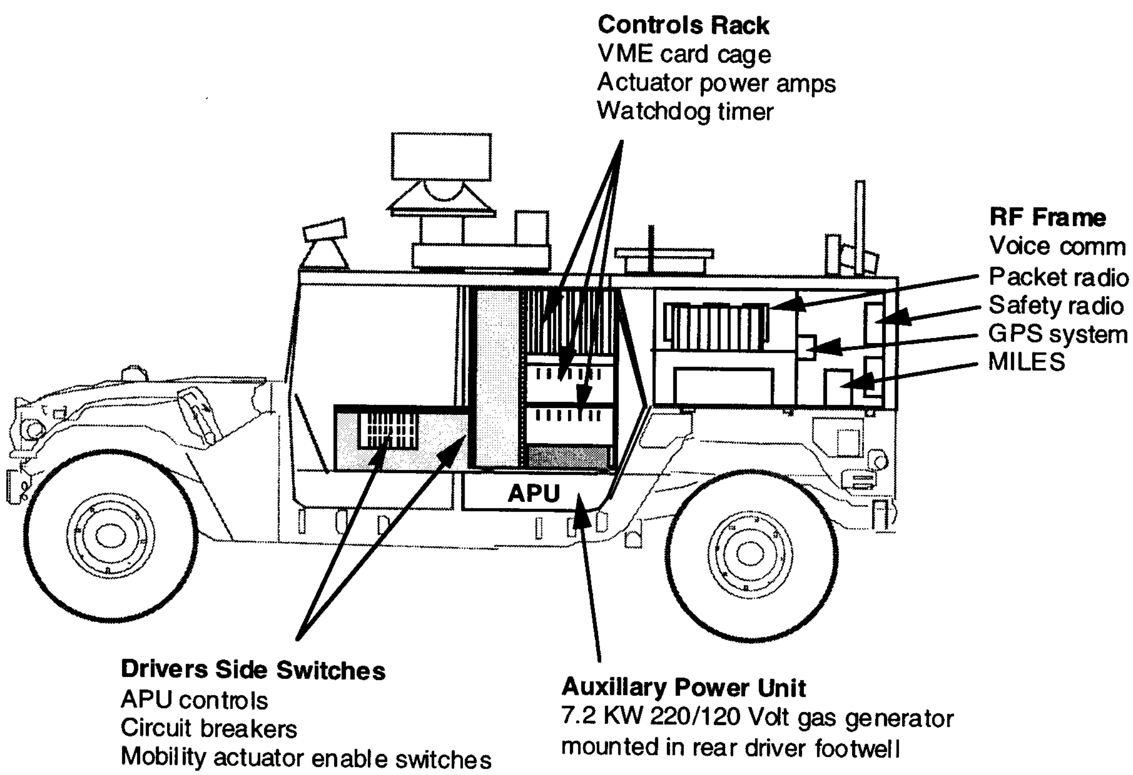

Figure 7. Driver's side view of SSV equipment.

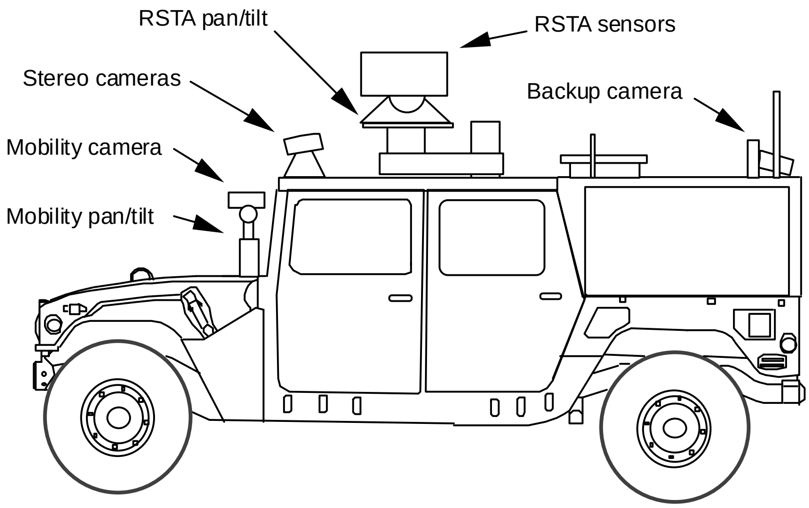

Figure 8. Placement of mobility and RSTA sensors on the SSV.

Communication. The tactical packet radio is the command and control data link among the vehicles. On each vehicle, the radio connects via a network interface unit to the local area network connecting all the on-board processors. A time-division multiple access protocol is used by the radios. The maximum network throughput is 150 kilobits per second. An inter-process communications protocol defines data structures and connections between processes on the various processors, both on- and off-vehicle. Messages are routed using the standard TCP/IP transport, with connections arranged by communication servers on each vehicle. A video transmission system is available for developmental test and demonstration purposes.

The BASE Vehicle. The BASE vehicle is a HMMWV-mounted control station for the SSV system. The equipment is contained inside a command shelter, and powered from an external generator. The BASE hardware consists of three subsystems: a two-display operator console, a differential GPS receiver/transmitter subsystem, and the packet radio communications subsystem. The two-display operator console is comprised of two Sparc-based single board computers with 128 and 64 Mbytes respectively and running the UNIX operating system, two 19-inch color monitors, a 4 Gbyte hard disk, two keyboards and two mice. The differential GPS receiver/transmitter subsystem consists of a Sparc-based single board computer running the VxWorks operating system, a serial port interface board, and a GPS receiver. The packet radio communications subsystem consists of a 486-based desktop computer, a 15-inch color monitor, an HDLC-protocol interface card, an ethernet interface card, and a packet radio.

3. Autonomous Mobility

Vehicle Controls. Active axes of individual, real-time control are: 1) steering; 2) service brake; 3) throttle; 4) parking brake; 5) transmission; 6) transfer case; 7) mobility pan; 8) mobility tilt; 9) RSTA pan; and 10) RSTA tilt. The control modes include fixed gaze pointing, inertial point tracking, and steering control modes. Automated speed (throttle and brake) and transmission control are used for all movement of the vehicle. Specialized subsystem controls include the MILES laser designator, the laser range finder, and the FLIR sensor and lens.

Cross-country Waypoints. The cross country behavior tracks a series of map waypoints defined by the robotic plan. It utilizes pure pursuit navigation and has two primary modes of operation: path following, which ensures precision route following, and goal seeking, which allows more maneuver room between map waypoints.

Road Following. The road follower uses a neural network, trained on a specific road type, to steer the vehicle based on the image of the road. Speed is set by confidence in the match between image and network. Neural network type and parameters are selected by the robotic plan executor.

Low-bandwidth Teleoperation. The waypoint teleoperation capability uses low communications bandwidth by only requiring snapshot images. It provides for camera selection, dynamic camera models, sensor pointing, and remote communication of images and pick points between the vehicle and the operator workstation. The pick points define a short motion trajectory. Pre-defined trajectories (e.g., half-back left) are also available. Both forward and backward vehicle motion can be teleoperated.

Obstacle Detection and Avoidance. The obstacle detection system uses stereo video images to create a range image, which is passed to the obstacle avoidance behavior. This behavior searches for discrete obstacles. Vehicle steering and speed are controlled to avoid these obstacles.

Formation Control. Operating in conjunction with another driving behavior, the formation control behavior maintains a specified group formation by adjusting speed and steering on all the vehicles. The vehicles communicate position and heading information among themselves at a low rate, and maintain relative positions within a specified tolerance.

Hill Cresting. The hill cresting capability provides the ability to halt the vehicle's motion when a designated target area comes into view of the RSTA sensor package, while the main body of the vehicle is occluded from view from the target area. The specified target point is tracked by the RSTA pan/tilt as the vehicle ascends the hill until it comes into view over the crest of the hill.

4. Mission Planning / User Interface

Graphical User Interface. The SSV system operator is presented with a map-based application that displays an aerial image or paper map with graphical overlays layered on top for annotating map features, map analysis results, robotic vehicle plan, and mission specification symbology. The core of the planning architecture resides within the main operator interface system, and is comprised of military mission specification, robotic plan editing, and plan management and generation modules. Mission monitor display/control capabilities include graphical indication of vehicle location and the robotic plan execution capabilities.

Plan Execution and Monitoring. The plan execution and control system is a network of distributed modules, which cause a team of vehicles to achieve a specific objective. The input to the system is a robotic plan, which takes the form of a sequence of instructions for each vehicle. The robotic plan represents an annotated map. Typically the plan includes road-following and cross-country routes with pre-specified stop locations for executing RSTA activities. Multiple vehicles' motion are explicitly coordinated, including sequentially interleaved, concurrent coupled, and concurrent independent modes.

Pre-mission Planning Tools. The pre-mission planning tools consist of several "planning expert" tools, which assist the operator during the creation of a mission plan. These tools are: 1) The route planner, which uses traversability and observability cost maps to propose mobility routes; 2) The observation point planner, which partitions RSTA search areas among multiple vehicles and maximizes viewing area; 3) The formation planner, which proposes vehicle formation based on planned path and mission context; and 4) Mission specification, which decomposes a military mission specified using graphical control measures and doctrinal symbology into a robotic plan.

Robotic Plan Editor. The robotic plan editor provides a graphical tool for manual creation and editing of single- and multiple-vehicle robotic plans. Capabilities include: 1) Layout and editing of mobility routes and stop points; 2) Templates for all link types with default parameters; 3) Link annotation entry and editing; 4) RSTA search area entry and modification; and 5) Automatic entry of coordination actions between multiple vehicles upon plan creation.

Target Verification and Fire Control. The target verification and fire control capability provides operator control and monitoring of remote RSTA processing tasks, interactive feedback, and manual-control of vehicle RSTA assets.

"Unconfirmed" targets detected by the SSV vehicles appear as icons on the map-based display. The target response capability displays video and FLIR images containing annotated suspected targets for user verification and to prune false alarms. The fire control capability supports the MILES laser designation and TacFire.

5. Reconnaissance, Surveillance, and Target Acquisition

Stationary Target Search and Detection. The stationary target detection system uses FLIR imagery to detect candidate targets. A two-stage detector employs two algorithms: double window contrast pre-screening, followed by boundary probing. The system also has the capability to detect stationary targets based on color, specifically by using an RGB-color lookup table implemented as a multi-variate decision tree trained on data collection images. Results from the FLIR- and color-based detection algorithms can be combined to help improve detection performance. Detections can also be verified by a second SSV vehicle, improving the overall probability of detection and reducing false alarms. The laser range finder is used to determine range-to-target for improved detection performance and for exchange of target coordinates with the operator and other vehicles. The range is measured during a second sensor look, with the original detection centered in the image and thus bore-sighted with the laser rangefinder.

Moving Target Search, Detection and Tracking. The moving target detection system detects and tracks consistently moving blobs extracted from a binary difference image obtained from a stationary FLIR or color camera. After detection of a moving target, the RSTA system's executive performs target hand-over to a FLIR-based correlation tracker module, which controls pan/tilt movements to keep the centroid of the moving target in the center of the image. The target can then be "hit" with the SSV's laser designator.

Target Recognition. A target recognition system operates on FLIR image chips after the initial detection of a target. A detected target is segmented and compared with pre-stored target models using a geometric hashing algorithm. The outputs from this algorithm include target type and target pose.

Manual Control. Manual controls include the ability to move the pan/tilt, set certain camera/lens parameters, and the ability to acquire and display a panoramic overview image. The fire control panel displays imagery of detected/recognized potential targets for verification by the operator and subsequent calls for fire. It can also be initiated manually and used for manual target search operations.

6. Size of the SSV System Software

Table 1 shows the approximate size of the source code for all parts of the SSV system. All parts of the system are included here, though some of them are lumped together. The table lists the number of lines in the source code files, including comments and blank lines. On average within the SSV system, 30-40% of the total number of lines of source code are comments and blank lines.

7. The Integration Process

Types of Demonstrations. The yearly demonstrations that were central to the UGV / Demo II program dictated a year-long integration cycle. Co-contractors had the choice of four different types of demonstrations: lab demo, stand-alone technology demo, integrated technology demo, integrated mainline demo. Each type of demo requires progressively more work and lead time. Ideally, a co-contractor would progress from one type of demo to the next during each yearly demo cycle. The different types of demos are described in more detail below.

Lab Demo

- Description: A lab demo is a self-contained demo provided entirely by the co-contractor, which runs on equipment in a lab area. Typically the demo involves only a workstation. Some RSTA lab demos used sensors and other hardware that the co-contractor brought as a self-contained unit.
- Co-contractor effort required (during the year before the demo): Minor effort. The co-contractor does everything.
- System integrator effort required: No effort, except to provide the lab space.
- Audience impact: A lab demo is good for presenting technical results to a technical audience, but is of little interest to an end-user audience.

Table 1. Approximate amounts of code contained in the SSV system.

Lines	Subsystem or module
72,134	Road following: ALVINN
99,140	Road following: RBNN
1,632	Cross-country waypoints (FOLLOW_PATH)
118,221	Obstacle detection (stereo)
58,657	Obstacle avoidance (SMARTY)
5,764	Formation control
8,877	Drive by feel (DRIBLE)
10,728	Semi-automated turn teleop (SATURN)
17,524	Low-bandwidth teleoperation (STRIPE)
17,364	Command arbitration (DAMN and display)
201,633	Vehicle controls: (GNS, VCS, vcs_display, watch_vehicle)
16,414	Additional Datacube code (mobility_SPP)
28,900	CMU utilities (CMU_Utl)
656,988	**Subtotal for Mobility**
218,652	Graphical user interface: STXmcu
21,221	Graphical user interface: STRIPE_OWS
61,201	Graphical user interface: RSTA_OWS
2,030	Graphical user interface: ows_image_server
8,400	Observation planning tool (OP)
102,923	Route planning tool (D*)
86,896	Plan execution control and monitoring (SAUSAGES)
501,323	**Subtotal for Mission Planning / Operator Interface**
246,189	**Subtotal for RSTA (See Chapter 3 for detailed RSTA breakdown)**
1,872	Automated vehicle startup: vehicle_startup
19,078	Automated vehicle startup: commandow
20,471	Inter-process communications (IPT)
18,837	LM utilities (Utl)
4,102	IPT utility (prtcx)
64,360	**Subtotal for Infrastructure**
1,468,860	**Grand Total for Entire SSV System**

Stand-alone Tech Demo

- Description: A tech demo runs on an SSV vehicle, and typically has interfaces only to the low-level SSV components, such as the ability to move the RSTA pan/tilt and grab an image. There is minimal interfacing with the SSV or RSTA system software or operator interface.
- Co-contractor effort required (during the year before the demo): Small effort (e.g., 2 person-weeks of software implementation in addition to their regular work, 1-2 visits to the integrator site for 2 days each). Typically the code that runs for the demo is the exact same code that the co-contractor uses at their home location, with simple low-level function calls added to access SSV vehicle components, and with some modifications to provide a self-contained graphical display.
- System integrator effort required: Medium effort (e.g., 3 person-weeks of total effort). Provide

the low-level function calls. Support the co-contractor.
- Audience impact: A stand-alone tech demo will maintain the attention of an end-user audience, but with a low level of interest.

Integrated Tech Demo
- Description: A integrated tech demo runs on an SSV vehicle and is partially integrated with the SSV system software, including on-vehicle executive functions and the SSV operator interface.
- Co-contractor effort required (during the year before the demo): Large effort (e.g., 2 person-months of software implementation in addition to their other work, 2-3 visits to the integrator site for 2 or more days each). The co-contractor delivers code that conforms to an agreed upon function call interface.
- System integrator effort required: Large effort (e.g., 4-6 person-months of total effort). Roughly half this effort is related to field work to debug, test, and exercise the code, and work towards a dry run of the demo.
- Audience impact: An integrated tech demo generates strong interest from an end-user audience.

Integrated "Mainline" Demo
- Description: The integrated "mainline" demo uses all the SSV vehicles to execute an unmanned end-to-end mission scenario. It is the showpiece for each year's demonstration activities. Such a demo may require 30-60 minutes to execute, all autonomously. The co-contractor provides capabilities integral to the execution of the mission scenario.
- Co-contractor effort required (during the year before the demo): Very large effort (e.g., 6 person-months devoted solely to the demonstration activities).
- System integrator effort required: Large effort (e.g., 4-6 person-months of total effort). Roughly two thirds of this effort is related to field work, and often overlaps with other demo efforts.
- Audience impact: The mainline demo is a convincing illustrative field exercise of the technology capability to an end-user audience.

Planning Yearly Demo Activities. Planning activities for each yearly demo are focused at the community workshops (typically 2-3) during the year leading up to each demo. Planning begins at the community workshop immediately following the last year's demo. In preparation for this workshop, the integrating contractor works with the sponsor to create an outline of the next demonstration. For example, this might include selection of the site for the demo, an initial mission plan including the path that the SSVs would drive through and the locations of enemy vehicles and their actions during the mission scenario. The integrating contractor would present this plan at the workshop to provide a framework for discussion. Typically the attendees would break out into specified groups (navigation, mission planning and operator interface, RSTA, communications) to discuss technical status, how their work will advance over the coming year and capabilities that could potentially be incorporated into the demo. Summaries of these breakout group discussions would later be presented to the group at large. A second workshop, and sometimes a third, would follow the same introduction/breakout/summary format and serve to refine the plans for the demo. All the presentation materials at each workshop would be bound and distributed to attendees.

A single person within the integrating contractor organization typically is responsible for all aspects of getting an assigned co-contractor's capability integrated into the SSV system (or ready for a tech demo). This person and a counterpart within the co-contractor organization do all the detailed planning, integration, discussion, debugging, field work, rehearsals, etc. needed to make the demo happen.

Software Integration. The software delivered by co-contractors and sub-contractors is integrated into the SSV system by Lockheed Martin Astronautics. The process involves first compiling the code, performing applicable tests and then determining what functionality and interface upgrades are needed. As much as possible, programs are exercised with a lab-based simulator, which runs the same software as in the fielded SSV system. The code is also archived at this point so a history can be kept of the system integrator's modifications. Integration efforts may include adding a message interface, handling events and errors, inspecting the hardware interface for compliance with the robotic vehicle specifications, and handling timing issues.

Upon completion of the software integration a full system integration process is performed to combine software and hardware into an operable system. System integration is normally performed on the vehicles by first running a vehicle simulation to test software and hardware inter-operability. Next a series of field tests are conducted with limited autonomy, focusing on specific design validations. The final test takes the robotic vehicle(s) through a fielded exercise with a full-up system run.

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