Autonomous Combat Asset Deployment and Retrieval

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16 October 1995
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Abstract

The exposure of personnel to varying levels of threat during combat support missions can be reduced through the use of unmanned systems. A large class of these missions involves deployment and/or retrieval of combat assets. Using a standard platform such as a HMMWV, a taskable deployment / retrieval system can be implemented based on UGV / Demo II technologies. This system could perform such missions as deployment and/or retrieval of mine fields, decoys, obstacles, remote sensor systems, supplies, etc. Asset deployment requirements include both pre-mission specification of coordinates and autonomous sensor-guided placement. System requirements include full terrain traversal ability, ruggedization / miniaturization of sensing and processing to maximize payload area, and complete autonomy or operation over a tactical data link. The system must also be fully human-operable to support low risk scenarios.

1. Introduction

Today's soldier must have the ability to perform a myriad of tasks including self camouflaging, maneuvering, maintaining equipment, understanding electronics and sensors, communicating, firing weapons, and working cooperatively. 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 intelligence gathering, establishing obstacles, breaching obstacles, channeling an enemy attack, deception, counter reconnaissance, NBC surveillance and monitoring, and ambushes. A large class of these missions involves the deployment and/or retrieval of combat assets:

- Remote sensors (seismic, acoustic, EO, FLIR, RF, magnetic, weather sensors, etc.).
- NBC detectors.
- Mines of many types.
- Munitions for demolition.
- Smart mines, directed remote weapons, mini-hunter vehicles.
- Decoys.
- Supplies, containerized material.
- Obstacles: cratering, concertina wire, etc.
- Radar transmitters.
- Communication relays.
- Micro UAVs.

An autonomous Combat Asset Deployment and Retrieval system (UGV / CADR) based on UGV / Demo II technology would place a collection of assets onto the battlefield quickly and reliably while using fewer people (who are also exposed to less risk). More specifically, some advantages of an autonomous UGV / CADR system are:

- UGV / CADR reduces manpower. While soldiers accomplish the deployment and retrieval of the above combat assets very well, many man-hours are required. By assigning these man-hour intensive, repetitive tasks to UGVs, the soldiers performing the deployment and retrieval of combat assets could be released for other combat duties. Other variables effecting man-power include: assets that involve multiple units, assets that require a long time for individual emplacement, long distances and thus travel time to the deployment / retrieval area, and long distances between individual emplacement positions within that area.

- UGV / CADR reduces risk to the soldier and enables a larger number of high-risk mission options.

- UGV / CADR can emplace assets in positions and orientations, based on complex rules, more consistently and precisely than humans.

- UGV / CADR enables ownership of a dynamic asset system by a warfighting unit. “The sergeant wants total control over the system that his unit relies on.” UGV / CADR ultimately will place a sophisticated, powerful capability into a simple package that serves the moment to moment needs of the unit, including deployment, redeployment, and use the asset system on short notice -- all without involving outside parties. The modular UGV / CADR system can grow to deploy emerging asset capabilities providing distributed battlefield awareness, direct fire weapons, indirect fire targeting, and deception.

The UGV / Demo II Program has developed and demonstrated core technology capabilities necessary to perform autonomous, unmanned ground vehicle missions. The next step is to further develop the UGV technologies, make them more robust, and apply the technologies to military applications where lives and money can be saved. This paper proposes a new, tactical, outgrowth and continuation application of UGV / Demo II technologies for deploying and retrieving combat assets.

This paper outlines the need for an autonomous Combat Asset Deployment and Retrieval (UGV / CADR) system and describes how this system might be built based on UGV / Demo II technology. Section 2 lists many missions identified via specific performance objectives. These missions involve deployment and retrieval of combat assets which could potentially be handled by the UGV / CADR system. Section 3 presents the UGV / CADR system concept. More detailed “vignette” descriptions of several missions are presented in Section 4. The key technology capabilities needed beyond UGV / Demo II technology are also summarized. Section 5 discusses the design of the UGV CADR system in more detail. The paper ends with a summary and a mission / capability roadmap in Section 6.

2. Need

Following are some performance objectives and specific needs that a UGV / CADR system could meet:

• Battlefield awareness

- -- Deploy a distributed sensor system that would detect, track, and identify every ground vehicle and helicopter in a 10 km by 20 km area that contains, for example, an area of interest.
- -- Deploy a similar system to cover a 100 km border, deployed within one day, on one day's notice.
- -- Deploy a similar system to cover a 20 km beach, deployed within two hours, on one day's notice.
- -- Deploy a single remote surveillance unit to monitor a key area of interest or facility that is 40 km behind the front line.

• Ground defense security for small unit operations

- -- Establish hastily by one man, an automated ground defense security zone around a drop zone, landing zone, or forward arming and refueling point. The distributed sensors in the ground defense security system would detect, track, and identify every ground vehicle and moving human in a 4 km by 4 km area, and helicopters out to 10 km. The security system would provide more coverage and vigilance than a small unit could provide, thus augmenting the watching ability of the soldiers.

• Mine, munitions, or smart weapon deployment

- -- Deploy 12 boxes of (MOPMS - modular pack mine system) remote scatter mines distributed in a 4 km by 4 km area that is 20 km distant, within one hour, on one hour notice. Autonomously drive a scatterable mines system (FASCAM - family of scatterable mines) along a designated path located 20 km away.
- -- Lay a field of surface mines, while mapping the location of every mine. ("Roving" mine fields can be implemented by having the UGV / CADR system pick up and move the entire minefield every few days.)
- -- Deliver and place heavy munitions onto a bridge or inside a tunnel, which are subsequently triggered to destroy the structure.
- -- Deploy directed remote weapons for ambushes in 20 specific positions. Deploy 20 mini-hunter vehicles in a 10 km by 40 km area. (The mini-hunter vehicle is another possible outgrowth of the UGV Demo II program -- these are small UGV vehicles performing a deep attack, target designator mission.)

• Decoy deployment

-- Deploy decoys (e.g., thermal, acoustic, and RF generators) simulating six operating tank platoons in six specified fake staging areas in a 10 km by 20 km area, including three tree line areas and three open areas behind intervisibility lines.

• Transport supplies

-- Establish a forward cache, 50 km distant.
-- Deliver emergency supplies to a supply area, up to 20 km distant.

• Deploy obstacles

-- Lay 1 km of single-strand concertina wire along a designated path 20 km distant.
-- Cut a tree every 50 feet inside a lightly wooded area, 2 km by 2 km, in 2 days.
-- Hastily establish crater obstacles in a 2 km by 4 km area, across every road and throughout the primary trafficable areas, using four HMMWV loads of M180 demolition cratering kits.

• Radar transmitter

-- Deploy a trailer towed radar transmitter to a location 40 km distant. Return to the radar transmitter a week later and redeploy it to a new location 40 km distant from the original location.

• Perimeter security for a large moving force

-- Deploy a perimeter containing a mix of remote sensors, mines, and decoys along the flanks of a large moving force and its logistics trail. A "rolling" distribution can be implemented by picking up distant trailing segments of the deployed assets and appending them to the continually advancing front segments.

3. UGV / CADR System Concept

Using a standard platform such as a HMMWV, a taskable deployment and retrieval system can be implemented based on UGV / Demo II and other government-developed technologies. A concept of what such a system might look like is shown in Figure 1.

Usage of the interior volume of the HMMWV platform for the UGV / CADR system is critical. A new, self-contained UGV hardware unit will put all the UGV components into a 3-foot square rack. The smaller space required by the UGV components will permit a set of assets and a deployment mechanism to fill the space vacated in the HMMWV truck bed.

The technology required to create the UGV / CADR system consists primarily of Demo II technology, in addition to two new types of capabilities transferred from previous technology development programs:

- The UGV / Demo II technologies that would be required include pre-mission planning, mission execution monitoring, road following, cross-country follow path, obstacle detection and avoidance during vehicle maneuvering, and low bandwidth communication links.

- The first new type of capability is sensor-guided placement of assets. Asset deployment requirements include both pre-mission specification of coordinates and autonomous sensor-guided placement. The later includes selection of specific asset placement positions based on sensed local terrain, placement relative to structures such as tree lines or laying concertina wire, and manipulation involved in installing and activating the asset at each placement site. A sensor-guided placement capability already exists using Demo II technology, mainly stereo-based terrain reconstruction. Additional base technology is available from the ARPA RSTA and IU programs.

- The second new type of capability is asset manipulation. Primary manipulation functions are unloading the asset onto the ground, limited deployment of asset appendages, repositioning and possibly burying the asset. The base system will use a simple and reliable built-in gantry crane for unloading assets, with varying levels of end-effector sophistication being possible. More sophisticated manipulation capabilities could optionally be provided by the addition of a second higher-degree-of-freedom manipulator. Which missions could be performed depends on many factors such as choice / design of the asset package, crane and/or manipulator, and end-effectors. Several asset deployment missions have rather simple technological requirements.

Control of asset deployment functions would be performed in the same way as the vehicle would be controlled -- limited operator involvement. High level control would normally be used but teleoperation capability would be included for contingency operations.

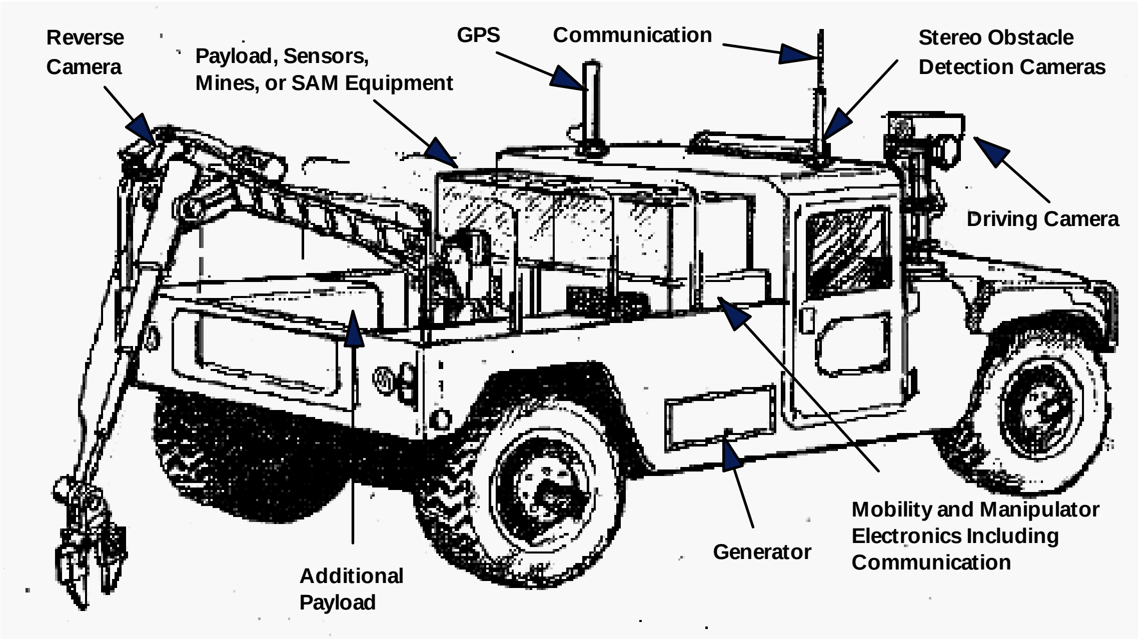

Figure 1. UGV Unloading and Emplacing an Asset. Major Components of the UGV / CADR System are Labeled. Loading and unloading would be performed by a gantry crane (not shown in this figure) and, when needed, an additional manipulator arm can be added into the modular system.

Most of the technologies required to autonomously deploy and retrieve a set of assets currently exist individually. For example, basic mobility functions have been provided by the UGV / Demo II Program. Manipulator control capabilities have been provided by NASA funded Space Station and Satellite Servicing efforts. DOE programs have provided mobility, manipulator, small robot packaging, and sensing capabilities. Mission sensing base technology for asset deployment have been developed by the ARPA IU and RSTA programs, and others. Mission planning, real-time planning, and control capabilities can be transferred from additional ARPA programs.

The UGV / CADR system would typically deploy not a single unit asset, but a large number of assets during one mission, as illustrated in Figure 2. Often a mix of assets would be deployed, for example a mix of sentry sensor assets and mine assets. A platoon of multiple cooperating UGV / CADR vehicles (HMMWVs or future 5-ton truck variants), operating over night, could deploy (or retrieve, or reposition) an enormous number of assets, each one precisely placed.

Other than infiltration and extraction from the mission area, the general sequence of tasks during a deployment mission is as follows:

1) Move to general area for deployment of asset #n (e.g., map coordinate).
2) Select specific area (e.g., based on accessibility to area once details are in view).

3) Select specific site (e.g., next to a bush).
4) Off-load asset.
5) Deploy and activate asset.
6) Return to step 1.

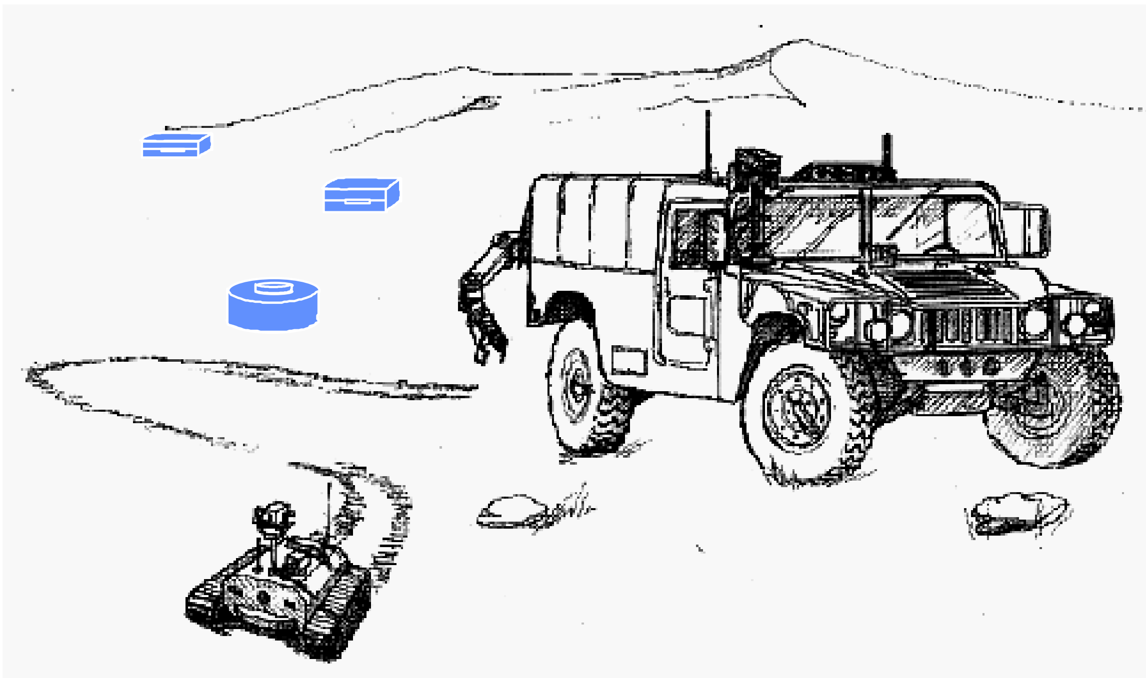

Figure 2. UGV Deploying a Mixed Set of Assets Over a Large Deployment Area.

4. Vignette Descriptions

This section discusses a few specific missions and their associated issues in more detail as examples. Several missions were listed in Section 2 and described according to performance goals. Table 1 lists the types of missions discussed in Section 2 and summarizes the key new capabilities (beyond Demo II capabilities) that are needed to provide the asset deployment and retrieval capability. Next we discuss a few specific missions from that table.

MOPMS. A current, very viable mission that could be performed by the UGV / CADR system would be the deployment and in some cases retrieval of a mine deployment system called MOPMS (module pack mine system). MOPMS is a containerized portable mine system that can be carried by two men. The container holds 17 antitank mines and 4 antipersonnel mines. It weighs about 150 pounds. All MOPMS mines have short duration, self-destruct times. By placing several MOPMS containers on the proposed system, a mine laying or rapid reaction mine laying capability is obtained. The container is emplaced and the mines are explosively scattered upon command. Command activation is done by radio. When the container is activated, the mines are scattered in a fan-shaped pattern extending about 35 meters from the container. If the mines are not needed, they are not scattered and the container is simply picked up and moved away. Since MOPMS scattered mines self destruct, like all modern mines, retrieval is not required. The best features of combining the MOPMS with a UGV would be its mobility and logistical savings, and activation only when required. The UGV could be moved forward into the face of an enemy attack with no concern for loss of life. Enemy attacks that occur on unexpected avenues could be stalled or delayed with this rapid reaction, economy of force, mine laying system.

Table 1. Combat Asset Deployment and Retrieval Mission Needs Beyond Demo II Technology.

Mission	**Required Capabilities**	
	Site Determination (Pre-mission Planning, Local Flatness, and ...)	Manipulation (Unload and ...)
Deploy Remote Sensors - SAM, High Autonomy - Microphones, Low Autonomy - Seismic	- Local Intervisibility Sensing - Feedback from Sensor Operator	- Heading Placement - Reposition Based On Feedback - Push Sensor Spike Into Ground
Deploy Mines - Remote Scatter (MOPMS) - Individual Ground Placed - Scatter-On-The-Move - Directed Remote Weapon - Remote Munitions (Bunker Buster)	- Traversable Area Sensing (Road, Obstacles) - Local Placement Planner (Coverage, Route)	- Scatter Heading Placement - Bury Individual Mines - Activate Mines - Reposition Directed Remote Weapon - Emplace Munitions
Deploy Decoys - Thermal - Visual - Acoustic - RF	- Semi-Hidden (Treeline) - Local Terrain / Treeline Sensing for Thermal/Visual	- Open / Spread Decoys - Heading Placement - Activate Decoy
Transport Supplies - Logistics Train - Forward Cache	- Operator Hand-Off To Receiver	- Cover with Camouflage Nets - Stacking Boxes
Deploy Obstacles - Concertina Wire	- Parallel Existing Wire	- Anchor Wire

- Cut Trees, Poles	- Position Near Tree, Pole	- Hold Spools - Apply Power Saw
Retrieve Assets - Remote Sensors - Mine Modules - Decoys - Containerized Material	- Object Location (Passive / Active) - Cargo Bed Usage	- Grasp Handle - Load In Cargo Bed - Deactivate
Deploy / Retrieve Towed Equipment - Radar	- Locate Trailer / Hitch - Trailer Docking	- Activate Hitch
Deploy Communication - Lay Landline Wire - Deploy Radio Repeater		- Hold Spool - Heading Placement - Activate Equipment

Remote Sensors. Another type of mission is the placement and retrieval of unattended ground sensors. When combined with a UGV, the system could provide monitoring of a specific site / area on short notice. Multiple sensors would be stealthily deployed to a site / area, with limited ground truth, and monitor all activity continuously. The sensors would monitor for important and unusual activity, both human and vehicular. Low autonomy ground sensor systems have simple deployment requirements, such as setting or dropping each unit on the ground, or driving a spike into the ground. Typically these systems rely on seismic or acoustic sensors, though limited use of imaging sensors is gradually being introduced. High autonomy ground sensor systems generally include imaging sensors, more sophisticated analysis of all sensor data, target detection and classification, activity analysis, battlefield visualization, and integration with rapid response targeting systems.

Surveillance and Monitoring (SAM), for example, is an emerging ARPA Image Understanding program oriented towards high autonomy remote sensor systems. It has the goal of producing the technology capability to build a backpackable, modular, reconfigurable unit to perform a variety of surveillance and monitoring functions for tactical ground-based missions. While focusing on new image-based capabilities, the SAM units would also incorporate emerging acoustic sensing capabilities. SAM units could be installed on UGVs (providing advanced UGV / RSTA capability), manned vehicles (augmenting RSTA capabilities of humans on board), carried for deployment on a soldier’s back, or distributed in large numbers on the battlefield by the UGV / CADR system. SAM units could be provided with short-range mobility to obtain optimum dynamic observation and stealth while emplaced. The SAM program is likely to tackle a series of performance goals using a distributed sensor system, with annual demonstrations, that will focus on battlefield awareness on the open battlefield. Section 1 listed some representative mid-term performance goals. The SAM program also is likely to partially address surveillance and monitoring of individual facilities and within an urban environment.

Decoys. Decoys are employed to deceive or surprise the enemy. With today's advancements in enemy monitoring capabilities, the deployment / retrieval of phony assets would mislead the enemy as to the pattern and extent of the friendly attack or defensive plans. Phony minefields are areas of ground used to simulate live minefields and deceive the enemy. They are used when lack of time, personnel, or material prevents employment of actual mines. Phony minefields can supplement or extend live minefields, and may be used as gaps in live minefields. To be effective, a phony minefield must look like a live minefield by either burying metallic objects or making the ground look as though objects are buried. The UGV / CADR system could be used to "dig" phony positions or deploy metallic obstacles representing actual mines. A different decoy mission might involve the deployment / retrieval of acoustic and/or thermal devices. These devices could be deployed to represent friendly tanks preparing for an attack. If deployed in multiple locations, the enemy would not know where the main attack was staging from until the attack was started. Once the attack started, the devices could be picked up and reused.

Supplies. While actual resupply functions would require larger load carrying capabilities than provided by the current HMMWV-based UGV, the required UGV functions could be transferred to a 5-ton truck or other logistic vehicles. This would allow supplies (i.e., ammunition, fuel, food and water) to be moved forward while under fire or within a contaminated area with no risk to human life.

Obstacles. Mines were previously discussed as a potential asset to be deployed / retrieved. Other obstacles could be supported by the UGV / CADR system. A hasty on- or off-road crater could be supported when time is limited and enemy threat is high. The M180 demolition cratering kit is specifically designed to produce craters in all types of soil. The kit is self-contained and consists of a shaped charge, a firing device, and a 40-pound cratering charge. The UGV / CADR system could deploy the M180 kits in various configurations dependent upon the width of the desired crater. Another obstacle example is wire. Wire obstacles such as a triple standard concertina fence could be laid to prevent surprise assaults from points close to the defensive area. An anchor picket would be positioned, the concertina installed one line at a time, and anchored with staggered joints. The UGV / CADR system would be required to drive parallel to the first line for the second and third lines, position the current wire line in proper relationship to the other lines, and drive the anchor joints into the ground.

5. System Design and Technology Capabilities

The major components of a UGV / CADR system are:

- A UGV vehicle platform (e.g., HMMWV) that has space to hold assets.
- Autonomous mobility capabilities produced by the UGV / Demo II program.
- Operator console functionality produced by the UGV / Demo II program.
- New site determination capabilities for sensor guided emplacement of each asset.

- A built-in gantry crane with interchangeable end-effectors and associated manipulation capabilities (and optionally a general purpose manipulator for some tasks).

This section discusses these elements for a nominal system. A simpler concept demonstration system could be constructed initially, and many future growth paths exist, as outlined in Section 6.

5.1. Vehicle Platform and UGV Hardware Components

The hardware architecture of the SSV (SSV core architecture) can be reduced to fit in a meter square box shown in Figures 3 and 4. This architecture maintains the same SSV capabilities and current state of the Demo II technologies but reduces the size of the packaging. This leaves the back end of a HMMWV virtually empty to support payload requirements.

Figure 1 depicts all the hardware elements of a UGV. Other than the SSV core architecture unit, this includes components distributed over exterior and unused small spaces of the vehicle: a generator (APU), actuators, sensors, and antennas.

The SSV core architecture unit can be installed in many types of military vehicles. The HMMWV platform would be the preferred choice, particularly for development purposes, due to experiences in the Demo II program. UGV / CADR system requirements include full terrain traversal ability, maximizing payload area, and ruggedization / miniaturization of sensing and processing. In the longer term, 5-ton trucks and combat engineering vehicles can be fitted with SSV core architecture units and would be particularly well suited for asset deployment and retrieval due to their large payload capacities and ruggedness.

In the shorter term, an existing Demo II vehicle could be used for UGV / CADR concept development: Its software / hardware architecture is directly compatible with the proposed SSV core architecture. It can immediately support development of site determination capabilities. Space for holding a small manipulator and one asset could be created by removing the DAP and VCRs, though additional power may be needed. Asset unloading and manipulation capabilities can be developed initially in a high-bay type area using building power, and moved to a fully functional field vehicle once one is available.

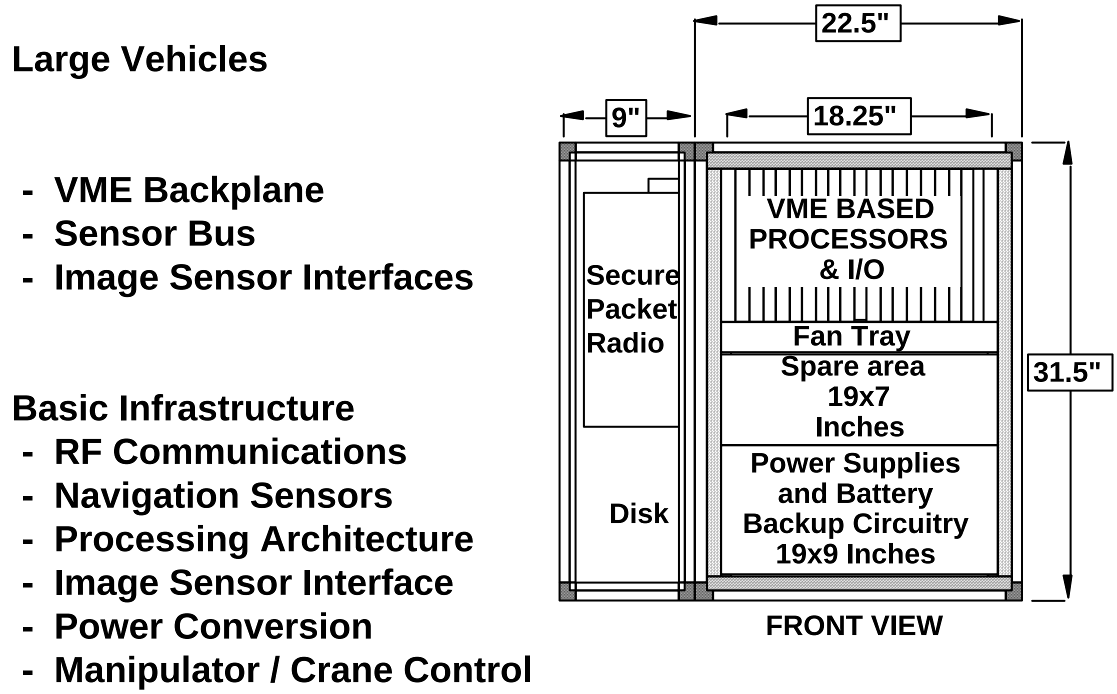

Figure 3. SSV Core Architecture Packaging Holds Centralized UGV Components in a Meter Square Box.

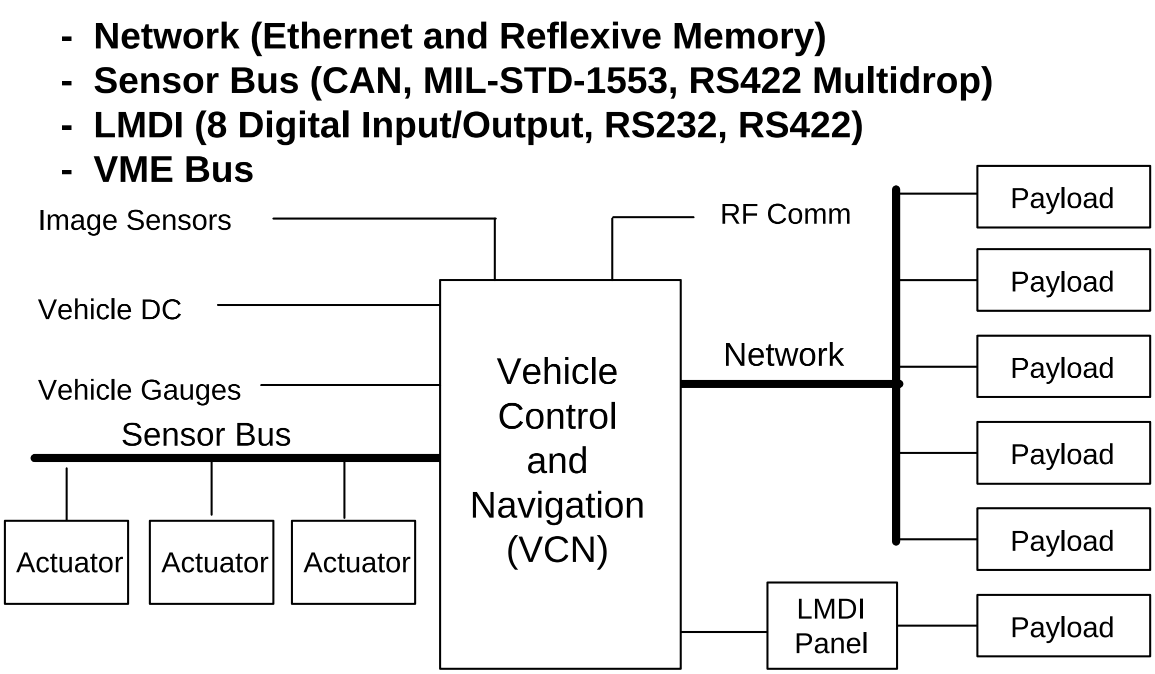

Figure 4. SSV Core Architecture and Interfaces.

5.2. Existing UGV / Demo II Technology --- Operator Console Functions

All of the operator console functionality from the UGV / Demo II system would be used in the UGV / CADR system, including: pre-mission planning, execution monitoring, teleoperation (for moving the UGV), RSTA interfaces, the core operator interface built around the map manager, and the Base vehicle housing all the operator console related equipment.

The Demo II functionality in the SSV Base vehicle, plus the following additions, form the nominal operator console system for the UGV / CADR system. The core operator interface must be extended to support (manipulate, display, database) asset objects. The operator must be able to enter the asset payload that was loaded onto the UGV prior to executing the mission -- so the mission planner knows the proper payload is loaded for the specified mission, and so the system can plan how to unload mixed asset payloads. The operator must be able to specify deployment areas on a map display, specific locations for deployment in some cases, and specific paths for deployment (e.g., wires, minefields). When the system automatically selects deployment positions, deployment paths, and paths of ingress / egress, the operator must be able to modify or fine tune them. Finally, a new interface is needed to support teleoperated unloading and asset manipulation.

The continued advancement of UGV technology and applications will drive further development of the operator console's form factor. The current Demo II form factor is a HMMWV shelter, which can be driven to a military tactical operation center (TOC). The existing components inside the shelter are few in number, are all self-contained COTS items -- though none are selected specifically to be of small size -- and could easily be installed into some other form factor, for example a tall rack and a workstation. The necessary operator console functionality is now well understood, and this same functionality could be incorporated into a fully self-contained, ruggedized, suitcase-sized unit, built with available smaller-sized components and fairly small amount of engineering effort. A conceptual suitcase unit, which is not self-contained and requires various external components, has been constructed within the Demo II program. Key factors in generating a militarized suitcase unit are: intimate design knowledge of the controlled UGV system present and future and the ability to produce a fully self-contained, ruggedized unit. Design of future operator consoles, such as the suitcase, must also consider integration with existing battlefield database systems (e.g., post mission plans, log positions of deployed mines) including logistics systems (e.g., log supplied delivered) and future asset monitoring systems (e.g., post enemy vehicle positions, activities, etc.).

An example of how the UGV combat asset deployment and retrieval system might eventually be demonstrated follows: Four soldiers drive the HMMWV-based system and a return transport HMMWV within 10 km of the deployment area. One soldier pulls out his laptop computer, selects and marks the deployment spots or simply a deployment area on a map displayed on the laptop screen. The laptop displays the driving path automatically selected for executing the deployment, plus an estimated completion time.

The soldier fine tunes the path as he sees fit. The soldiers exit the deployment HMMWV and give it a final checkout, keeping the laptop with them, and click on the "go" icon. The HMMWV drives off and deploys the assets in the specified locations. For example, the mission may be to deploy a distributed SAM sensor system at specified locations while scattering MOPMS throughout the same area. Any deviations in exact deployment positions are reported back to the laptop, as are any other situations or problems encountered during the deployment. The soldier with the laptop can monitor deployment progress or simply wait for and review the mission complete notice. The laptop could also used to monitor the deployed SAM units: every vehicle in the 40 km x 10 km (for example) deployment zone would be detected, tracked, identified, and reported on the map display of the soldier's laptop.

5.3. Existing UGV / Demo II Technology --- Autonomous Mobility

Autonomous mobility is a fundamental requirement of the UGV / CADR system, as it is in the current UGV / Demo II program. All Demo II mobility technology is needed, including road following, cross-country waypoint navigation, and obstacle detection / avoidance. Future UGV programs are certain to continue broad development efforts for these capabilities. Driving through difficult terrain with dense obstacles is the key technical challenge.

Fortunately, the advanced techniques for terrain extraction, analysis, and obstacle recognition needed for driving are also central to the site determination capabilities required for deployment and detailed positioning of assets.

5.4. Site Determination Capabilities

Site determination refers to sensor-guided selection of exact emplacement positions (or paths) and subsequent sensor-guided manipulation of each asset, as necessary, at those positions. Different levels of site determination capabilities are required for different missions. Fortunately, the base technology already existing from the Demo II program is adequate for several asset deployment applications. The key technology is construction of local terrain maps using stereo vision. Other sensor approaches have also been used. Additional base technology is provided by other ARPA programs -- image understanding, pre-mission and real-time planning. Site determination capabilities can be divided into four categories, which logically would be developed in the following rough order.

Pre-mission placement: The placement position of each asset is determined at pre-mission time. The operator would select each placement point on a map or he could specify an area and the system would automatically select placement points. The UGV would drive as close as possible to each placement position and drop off the asset without any on-site, sensor-guided placement capability. During execution the UGV mobility system may not be able to achieve some placement positions so deployment may be aborted for those positions.

Local data placement: The UGV senses simple local terrain data when it arrives at each placement position and performs analysis of that local data for placement decisions. Local terrain maps will initially be constructed using stereo vision (as used for mobility obstacle avoidance). Subsequently high-resolution stereo with field of regard control would provide fine resolution details for select areas. A ground cover classification capability would be subsequently added. Almost all deployment missions require that the asset be set on flat ground. Analysis for local flatness of the data sensed at the exact unloading site is a fundamental need. Other simple analysis tasks include: intervisibility analysis for selecting a hiding spot or a position where certain areas are visible by a remote sentry asset; traversable areas sensing (e.g., road, obstacles) for selecting optimal mine placement positions; simple positioning of remote munitions (e.g., on top of a buried bunker, inside a tunnel, on the road in the middle of a bridge); and path planning for the laying of communication wires.

On-site placement planner: Some assets need only be placed on flat ground anywhere near the specified placement position and others require some simple analysis of the local terrain data. But other missions, including some of the above ones, require more sophisticated planning for selection of one or a series of placement positions based on locally sensed data. Positioning of each additional unit in a high-autonomy distributed remote sensor system with imaging sensors can depend on the exact positions and associated fields of view achieved for all already placed units. Positioning multiple mines obviously requires careful and detailed position and path planning based on traversability, obstacles, coverage, routes, doctrine, etc. Dynamic replanning of routes will be essential when laying or scattering mines.

Placement around structures: Other assets are placed next to or on specific structures, such as treelines, along laid concertina wire, on road surface areas of some bridges, inside tunnels, etc. Such placement requires that the system first locate and recognize certain structures. While general purpose recognition of structures is well beyond the state of the art, recognition of certain specific structures is possible. Trees and treelines in relatively open terrain could be recognized in the terrain and depth maps produced by stereo vision sensors -- enabling the deployment of decoys in front of treelines or the downing of trees. Long spiral structures of concertina wire could possibly be detected and tracked -- enabling the deployment of additional strands of wire or associated mine fields. Structural elements on the top of a bridge when driving down the roadway could be recognized -- enabling better placement of munitions other than in the middle of the road. And finally, new ARPA IU programs are expected that will address vision-based sensing for surveillance and monitoring in urban environments -- this base technology will allow some limited asset placement in lightly structured locations.

5.5. Manipulation Capabilities

This concept paper considers a broad range of combat asset deployment or retrieval tasks which require varying levels of manipulation capability. For example, placement and repositioning of an asset on the ground can be accomplished easily for many asset form factors. Burying a mine is a challenging but doable task. Manipulating asset control mechanisms or deploying asset appendages can be very challenging tasks. Robot arm and manipulation capabilities for asset deployment must be selected with great care. This technology has slowly and steadily progressed over the years, but only the most basic technology is ready for military robotic applications.

Fortunately the variety of asset deployment missions contain many deployment tasks that involve low technical risk. The UGV / CADR system concept provides a simple, reliable, core capability for unloading and loading assets and for solving the low-technical-risk deployment tasks. The identification of these tasks and the design of the manipulation system providing this core deployment capability is the basis for a creating a successful UGV / CADR demonstration system. Growth paths to additional capabilities and missions will be discussed below. Certain assets are more amenable to manipulation by a robot than others, and certain assets are more amenable to sensor-guided location and manipulation than others. These are characteristics of existing asset systems. But asset systems can also be designed to make manipulation and sensor-guided operations easier, either by adding simple fixtures to existing asset packages, or by the development of new military asset packaging guidelines making future assets more compatible for transport and manipulation by robotic systems. An example of an asset that is easy to work with would have a plain box with a large top-mounted hook for grasping, self-deploying appendages, and large markings to aid locating the box for retrieval. Less robot friendly assets generally can be handled, but require more sophisticated robotic mechanisms and capabilities. Minimal asset modification is traded against the complexity of the manipulation capability required. Of course, assets that are less robot friendly can always be overpacked into containers that are robot friendly -- a family of such standard containers is readily designed.

The core capability to unload and load assets in our current UGV / CADR concept would be provided by a gantry crane that is mounted over the truck bed and carries interchangeable end-effectors. The gantry crane system provides access to the entire truck bed for asset storage, a full reach from anywhere in the truck bed to beyond the back of the vehicle, and an asset lift capacity up to 150 pounds. Just as important, the gantry crane is simple, reliable, easily maintained and resistant to dust and grit. While computer control of the crane will be the norm, manual controls would also be provided at the truck bed. Only three degrees-of-freedom (crane/manipulator joints) are required to pick and place an asset if the heading need not be controlled or adjusted. Four degrees-of-freedom are required to deploy an asset with heading alignment.

Concepts for crane and/or manipulator implementation need to be refined based on the reference missions selected to be performed by the UGV / CADR. The entire crane or manipulator would have a standardized electrical/mechanical interface to the vehicle allowing it to be removed for some missions or replaced with a higher performance manipulator.

Growth paths for additional manipulation capabilities are provided by more sophisticated end effectors, both on the gantry crane and on a second higher-degree-of-freedom arm optionally added for complex asset manipulation operations. Note that some complex manipulation tasks can be off-loaded from the robot: Some assets that require mechanical activation can be activated by a human as the truck bed is loaded for the mission. Others can be activated (and otherwise commanded or queried) by remote control on the UGV or a distant human (e.g., at the UGV operator console). Some emerging autonomous assets would self-deploy any necessary appendages, such as extendible antennas or mine trip wires.

Control architectural considerations must address the ability of the operator to assume control of the system, perform a portion of the task, and then allow the system to resume its mission. The manipulator would have end effector changeability and force-torque sensing for use in the control loop (i.e., impedance control).

5.6. Retrieval Capabilities

The technologies needed to perform deployment and retrieval tasks have many similar characteristics. Some of these include pre-mission decisions built into a robotic plan, maneuverability throughout the battlefield, knowledge of emplacement techniques, and knowledge of emplacement positions. The same capabilities would be used to retrieve assets. If the system must retrieve assets deployed by soldiers, then the system would need additional capabilities to search for and identify the individual assets. Initial demonstration efforts should separate deployment from retrieval. Even when assets were placed by the UGV, retrieval is harder than deployment. The asset must first be located, the retriever must position itself precisely next to the asset, and the asset must be grasped.

6. Summary

Deployment and retrieval of combat assets are common, fundamental activities performed on the battlefield. UGV / Demo II technology provides the foundation for automating many combat asset deployment missions. This is a rich and highly relevant application of UGV technology and an excellent driver for continued development of UGV technologies. Figure 5 outlines the number of missions that we think could be demonstrated in 3 to 4 years. Supporting technology capabilities are also summarized.

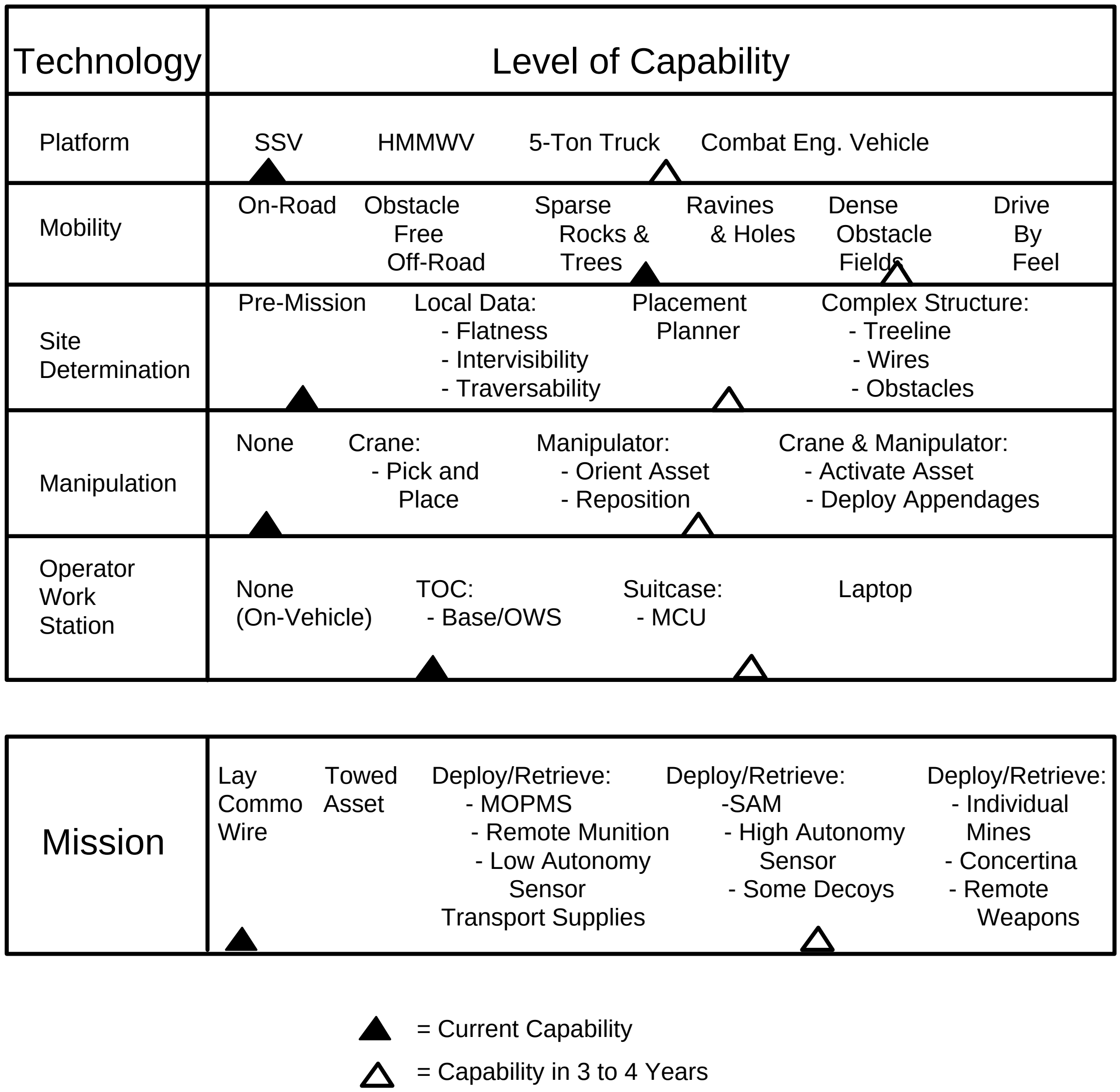

Figure 5. Technology Roadmap Showing Asset Deployment and Retrieval Missions Solved and Associated Technical Capabilities Required.