Extending Mobile Security Robots to Force Protection Missions

Daniel Carroll, H. R. Everett, Gary Gilbreath, Katherine Mullens
Space and Naval Warfare Systems Center, San Diego (SSC San Diego)
Code 2371, 53406 Woodward Road, San Diego, CA 92152-7383
619-553-7636, FAX: 619-553-6188, carroll@spawar.navy.mil, http://www.spawar.navy.mil/robots/

ABSTRACT

The Mobile Detection Assessment Response System (MDARS) is a joint Army-Navy development effort to field mobile robots at Department of Defense (DoD) sites for physical security and automated inventory missions. MDARS was initiated in 1989 to improve the effectiveness of a shrinking guard force, but was quickly expanded to address the intensive manpower requirements associated with accounting for high-dollar and critical DoD assets. Two types of autonomous platforms patrol inside warehouses (Interior) and outside of storage facilities (Exterior), carrying payloads for intruder detection, inventory assessment, and barrier assessment. The MDARS console for command and control is based upon the Multiple Resource Host Architecture (MRHA), which allows a single human guard to oversee and monitor up to 255 platforms and/or unmanned sensors.

Recent improvements to satisfy mission requirements for physical security have expanded the system capabilities to enable force-protection missions in tactical situations. Rapid-prototyping approaches have facilitated investigations into aiming and firing less-than-lethal weapons on an unmanned platform, deployment of a marsupial capability to carry smaller robots, and seamless all-digital communication between unmanned sensors and unmanned ground and air vehicles. This paper provides an overview of the MDARS evolutionary development approach (using mobile robots and fixed sensors) for both physical security and force protection missions. Special treatment is provided on feedback from developmental tests at Aberdeen Proving Grounds, MD, and operational tests at Defense Distribution Depot Susquehanna PA.

1. Background

The goal of MDARS is to field interior and exterior autonomous platforms for security and inventory assessment functions at DoD warehouses and storage sites. The program is managed by the Office of the Product Manager, Physical Security Equipment, (PM-PSE) at Ft. Belvoir, VA, with the Space and Naval Warfare Systems Center, San Diego (SSC San Diego) providing technical direction and systems integration functions. Separate development efforts target warehouse interiors and outdoor storage areas: MDARS-Interior program and MDARS-Exterior program respectively.

In 1998, the MDARS-Interior (MDARS-I) Engineering Manufacturing Development (EMD) contract was awarded to General Dynamics Robotics Systems (GDRS) of Westminster, MD. The EMD platform is a Cybermotion *K3A Cyberguard* mobility base equipped with additional collision avoidance, intruder assessment, and product inventory subsystems by GDRS. From May to July of 2001, the system underwent a successful Limited User Test (LUT) at the Defense Distribution Depot Susquehanna PA (DDSP). The system is expected to be approved for Low Rate Initial Production in FY02 followed by the first installation at Rock Island Arsenal in FY03.

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Figure 1. MDARS-I Platform and MDARS-E Platform

Robotic Systems Technology (RST, now GDRS) was awarded an MDARS-E BAA contract in 1993 for the development of the outdoor mobility platforms. The mobility base is a rugged four-wheel hydrostatic-drive diesel-powered vehicle equipped with active-laser, ultrasonic-sonar, millimeter-wave-radar, and stereovision sensors for collision avoidance, and differential global positioning system (DGPS) for autonomous navigation. MDARS-E passed a Technical Feasibility Test (TFT) in May 2000, and a System Development and Demonstration (SDD) contract was awarded to GDRS in January 2002. An Initial Operational Test and Evaluation (IOT&E), involving both the MDARS-I and MDARS-E systems, is scheduled for FY06 at Anniston Army Depot, AL. Figure 1 depicts the MDARS-I Platform and the MDARS-E Platform.

The MDARS-I and MDARS-E programs share a common design for the human-machine interface for the command and control console. The MDARS console is based upon the SSC San Diego MRHA, a distributed processing system that allows coordinated control of multiple autonomous resources, including up to 255 interior and exterior robotic vehicles, remote fixed sensors, and/or unmanned sensor pods. Figure 2 shows the MDARS console in the Robotic Operations Command Center (ROCC) at SSC San Diego.

2. Physical Security Payloads

The MDARS payloads pertaining to physical security currently consist of an intrusion detection sensor (IDS) suite, a radio frequency identification (RFID) tag and reader system to perform product assessment (inventory), and a barrier assessment system to check the status of high-security locks on bunkers. The IDS systems currently use motion detection techniques with a variety of sensor modalities to decrease the frequency of false alarms while maintaining a high probability of detection. The tag reader on the mobile platform reads active RFID tags affixed to high-dollar items while on normal patrol duty, updating the locations of the items in addition to verifying their presence. The barrier assessment system also operates while the system is performing its patrol duties, using a separate wireless modem to query the status of locks on bunkers. Most of the payload components are based on commercial off-the-shelf (COTS) equipment.

Figure 2. MDARS console

2.1 Intrusion Detection Assessment System

While patrolling, the robotic platforms detect intruders at randomly-spaced stops along their routes. The current technology for the Intrusion Detection Assessment System (IDAS) requires the platforms to halt in order for the IDAS payload to use multiple sensors to detect movement and a video camera system for a human operator to assess the target. All sensors are fused together to form a composite "threat score" on potential targets. Intruder alarms are reported to the user on the MDARS console. On the MRHA Operator Station, the intruder's range and bearing are displayed on a map window and a digital stream from the camera on the IDAS payload is shown in a video window. Figure 3 shows the Intrusion Detection and Assessment from the MRHA Operator Station.

The MDARS-I IDAS sensor suite consists of Passive Infrared (PIR) and microwave Doppler motion detection sensors on a rotor that spins at 60 RPM, as well as a scanning laser and various sonar sensors that operate in a "presence detection" mode. The scanning sensors provide 360° horizontal coverage over a vertical swath from -35° to +15° in the vertical plane out to a range of 10 meters. The laser scanner and sonars cover the area immediately around the robot out to a range of 2 meters. In general, an alarm is only raised when two or more sensors looking at the same area detect motion, though the PIRs can cause an alarm by themselves if the sensor reading is high enough.

The MDARS-E IDAS suite includes both a millimeter-wave high-resolution scanning radar and a thermal imager mounted on a panning turret assembly. The scanning radar is a *Perimeter Surveillance Radar System (PSRS)* built by Sensor Technologies & Systems, Inc. The output from the thermal imager (Texas Instruments *NightSight*) is processed by a Sarnoff Corporation *VFE-200* vision CPU for image stabilization and moving-target detection. The MDARS-E IDAS is designed to work in the presence of smoke, fog, dust, and precipitation.

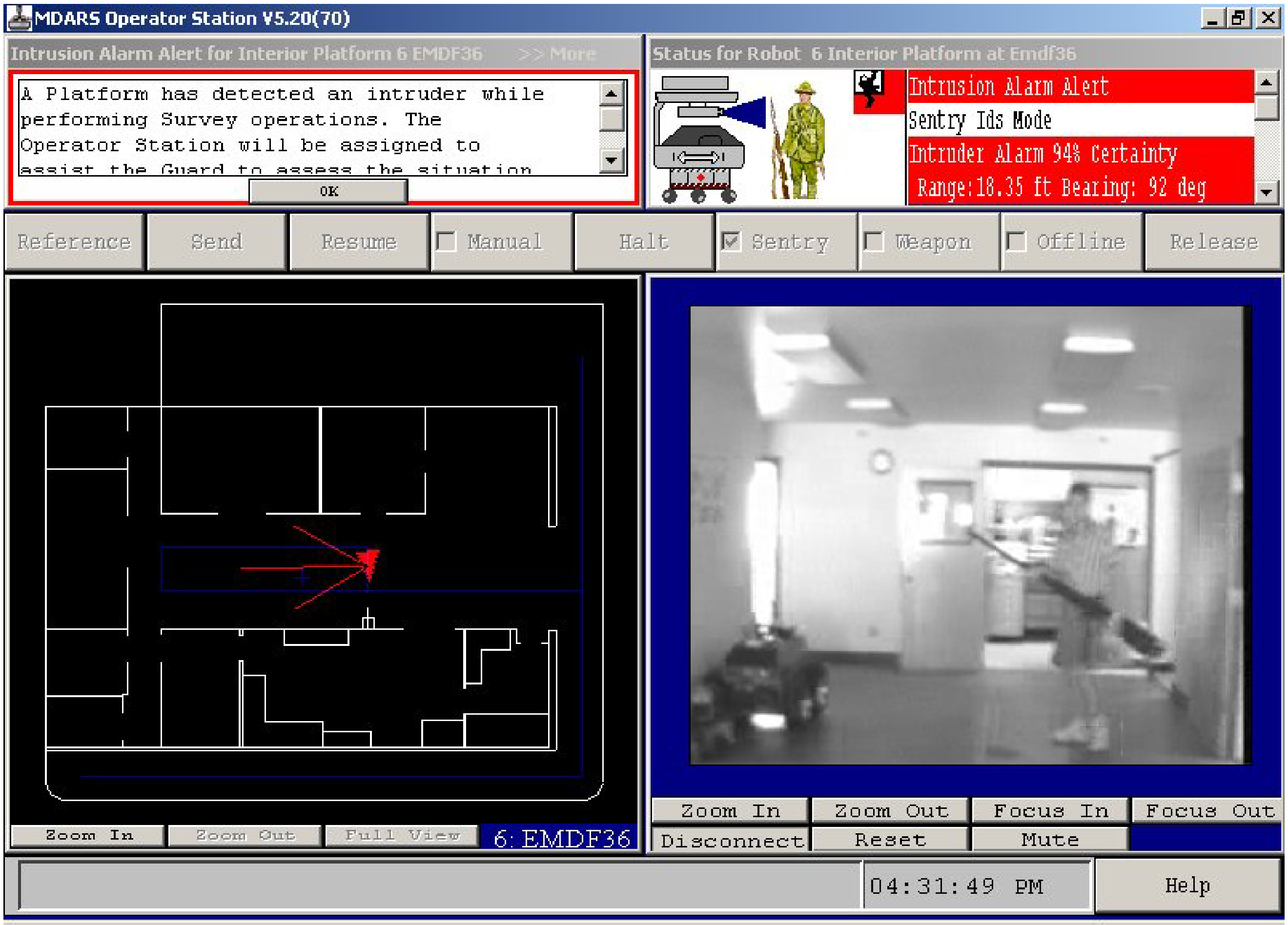

Figure 3. Intrusion Detection and Assessment from the MRHA Operator Station

2.2 Product Assessment System

Inventory tracking is performed by the Product Assessment System (PAS). In order to monitor the locations of high-value, controlled, or special-interest assets in the inventory, RFID tags are attached to the products. Each tag broadcasts a unique identifier at a constant rate, called a "chirp." The PAS payload uses an RFID tag reader connected to two antennae to listen to tag "chirps" when the platform stops along the patrol routes. The platform uploads the location at which it stops at and a list of tags read at that location to the MRHA on the MDARS console. The MRHA PAS computers automatically transfer the data from the MDARS console and triangulate an approximate location based upon multiple tag reads. The MRHA PAS maintains an inventory database and produces reports to inform warehouse personnel of any problems such as missing or moved inventory. MDARS-I and MDARS-E PAS payloads use *Spider III* RFID tags and tag readers manufactured by RF Code. Figure 4 shows the components of the Product Assessment System payload.

Figure 4. *Spider III* RFID tag and tag reader for Product Assessment System payload

2.3 Barrier Assessment System

The Barrier Assessment System (BAS) performs automatic sensing of the state of instrumented locks on bunker doors within a patrol area, thus providing a way for security personnel to determine if controlled areas are secured without having to manually check every lock in the patrol area. An Internal Locking Device (ILD) attached to each door, magnetically instrumented to detect whether the lock is open or closed. When the ILD is closed, current flows through the sensor and powers one of two RFID tags. The “closed” tag broadcasts its tag identifier while the other tag (“opened”) is powered off and silent. When the ILD is opened, the RFID tags to switch roles (i.e. “opened” tag broadcasts and “closed” tag is silent). The BAS payload on the MDARS-E platform reads these RFID tags attached to the lock sensor on the ILD and downloads the state (“opened” or “closed”) to the MDARS console. The user is notified by an alarm if a lock is detected to be opened. The MDARS console displays icons depicting the most recent status of controlled areas. Figure 5 shows the components of the Barrier Assessment System payload.

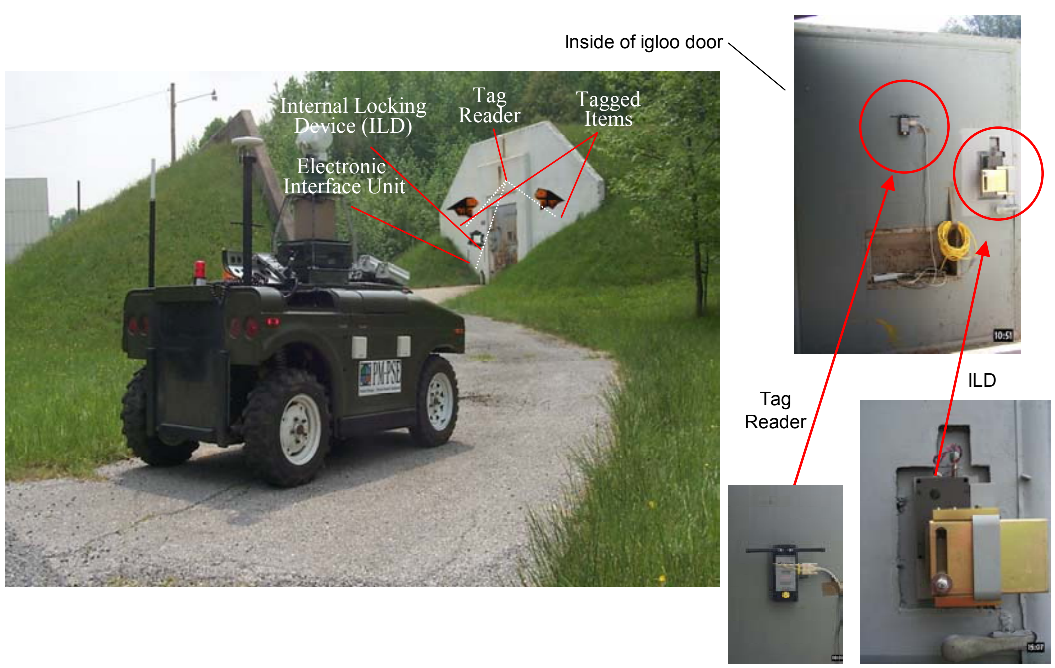

Figure 5. Components of Barrier Assessment System payload

3. Command and Control

The MRHA is a distributed processing system that controls and coordinates the operation of multiple autonomous interior and exterior remote platforms. The system is designed to run automatically with minimal user oversight until an exceptional condition is encountered. This requirement implies the MRHA must be able to respond to exceptional events from several robots simultaneously. Distributed processing allows the problem to be split among multiple resources and facilitates later expansion through connection of additional processors. The individual processors are connected via an Ethernet LAN that supports a peer-to-peer communications protocol. This distribution of function enables human supervision and interaction at several levels, while the hierarchical design facilitates delegation and assignment of limited human resources to prioritized needs as they arise. The Supervisor process sits at the top of the hierarchy and is responsible for overall system management and coordination. The user interface provides a "big picture" representation of secured areas and system resources. User intervention is required only when a platform encounters an exceptional condition, such as an environmental hazard or a security breach. Exceptional conditions are prioritized and an Operator Station display is automatically invoked, whereupon the user is informed of the situation and of response options. This interface allows a user to directly influence the actions of an individual platform, with hands-on control of destination, mode of operation, and camera functions. Figure 6 shows the components of the MRHA.

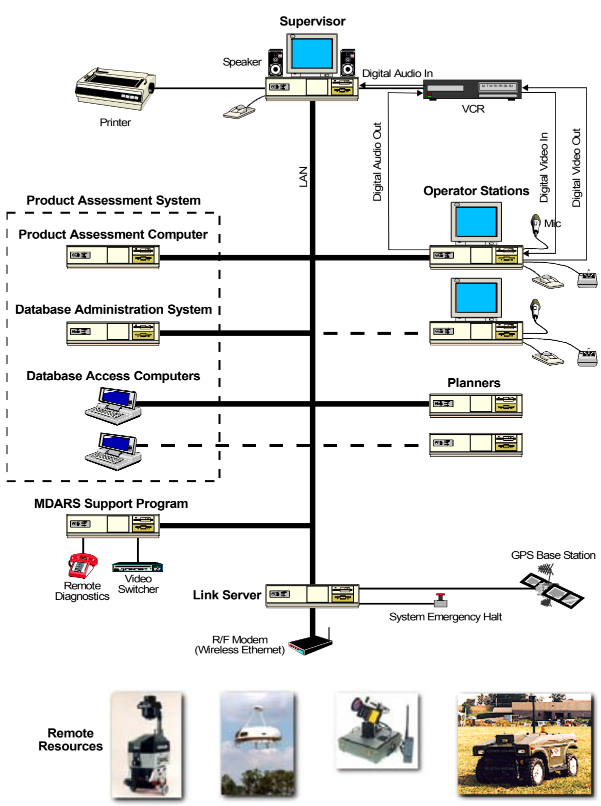

Figure 6. Multiple Resource Host Architecture

4. Evolutionary Development

The MDARS program employs evolutionary development using iterative "design-build-test" cycles. The goal of each cycle is to improve and to optimize the existing system. Cycles are typically linked to a major milestone in the acquisition model and have intermediate cycles to "lock-in" functionality. The "design" phase typically begins with rapid-prototyping for concept demonstration; the "build" phase involves refining the design and carrying out changes to the baseline system; the "test" phase requires systems integration testing. The recent "design-build-test" cycles for the MDARS programs have concentrated on improvements made during the MDARS-I EMD phase and the MDARS-E SDD phase (EMD is analogous to SDD) in order to meet or exceed the user requirements. The cycles concluded with the testing conducted for MDARS-E TFT before entering SDD phase and MDARS-I LUT at the end of EMD phase.

4.1 Recent Improvements

Both the platforms and the MRHA were modified to support the system development for MDARS-E TFT and MDARS-I LUT. On the platforms, components and algorithms on the navigation, obstacle avoidance, communications, and payloads subsystems were upgraded and optimized. For the entire system, an MRHA Interface Design Document (IDD) was implemented to facilitate communications; multiple analog audio and video links were replaced by a seamless digital link; and a Network-Enabled Resource Device (NERD) was designed to interface remote devices to the MRHA.

The MRHA IDD defines the communications between the MDARS command and control console and remote resources, such as MDARS-I platforms, MDARS-E platforms, unmanned sensors, etc. The IDD defines common protocols and messages for wireless communications for all resources. Prior to implementation of the IDD, each platform had its own vendor-specific protocol and controller. Implementation of the IDD allowed the platforms not only to be controlled from a single console, but also to reuse legacy software developed for mobility and for payloads. For example, MDARS-I and MDARS-E use the same PAS payload devices and interfaces; the MDARS console uses the same set of MRHA IDD messages to download PAS data from the platforms.

MDARS uses all-digital communications links between the MHRA and the resources. Previously, low-bandwidth serial modems were used for command and control data and a separate modem was used to send analog video signals from the platforms to the console. The current configuration uses a wireless LAN based upon IEEE 802.11. The analog video components have been replaced with digital video and bi-directional audio support based on the Indigo Active Vision Systems *CODEC* and *Video Bridge Development Kit* for hardware and software compression. By using wireless digital communications for integrated data, video, and audio, the system's complexity has been reduced and the performance simultaneously increased (communication has been upgraded from 900 MHz with 1 Mbps throughput to 2.4 GHz with 11 Mbps throughput).

In addition to providing physical security functions, MDARS needs to interact with the operational environment with minimum involvement from the human guards. The system needs to be able to remotely start the platforms and to open/close access gates as the platforms patrols from one area to another. The NERD converts any electro-magnetic device to an IP address, allowing any auxiliary resource to be integrated into the system over a wireless/wired LAN. For software, the NERD supports control by the MRHA console and/or MDARS robots and the NERD send/receives MRHA IDD messages. It allows interchangeable hardware and software between applications and locations. Figure 7 shows the hardware components of the NERD.

Figure 7. Network-Enabled Resource Device

4.2 Integration Testing

The MDARS-E TFT was conducted in May 2000 by the U.S. Army Aberdeen Test Center (ATC) in the Edgewood Area of Aberdeen Proving Ground (APG), MD. TFT was conducted to characterize the performance of the MDARS-E system for safety, navigation, obstacle avoidance, command and control, communications, and payloads. For the IDAS payload, the platform was stationed at a fixed location and placed in a sentry mode to detect intruders; the “intruders” would approach the platform at various angles, speeds, and profiles (i.e. crawling, walking, or running). For the PAS payload, the system was tested to measure the reading distance for tags attached to a variety of materials at various orientations. Another test was performed for the BAS to monitor the lock on an ammunition igloo and also for the PAS to record the inventory inside the igloo.

The MDARS-I LUT was conducted at DDSP during the period from May to July 2001, under the direction of the U.S. Army Operational Test Command (OTC) of Fort Hood, TX. The purpose of the test was to verify that all components of the system (hardware, software, site preparation, operator training, logistics support, etc.) were ready for fielding at the first operational site. The contractor (GDRS) installed the system at DDSP, trained the operators (both military and civilian), and provided logistic support for failures encountered during the test. OTC provided a test plan and directed each phase of the evolution, including various operator tests (e.g., ability to send a platform to a particular location, teleoperate the vehicle, direct military police to the location of a possible intruder), intrusion detection tests, and inventory tracking. The operators were never made aware of what tests were going to be performed in order to make the scenario as realistic as possible. The IDAS tests at DDSP focused on the ability of the system to detect an intruder and how the operator subsequently responds. The PAS tests evaluated tracking inventory in a day-to-day operational environment.

Overall the systems performed well at both the TFT and LUT. At TFT, the IDAS achieved a probability of detection of 84.5% vs. 90% for desired. During 24 trials, the BAS reported the correct state of the lock and all internally stored inventory was reported. At the LUT, the system detected 97% of the intruders that were within its operational parameters and there were three false alarms and zero nuisance alarms. The inventory system also performed at a high level, detecting 99.8% tags within range and locating them to within 5 meters of their actual location.

4.3 Recommended Enhancements

Based upon feedback from the operational users and testers, below is a partial list of enhancements for the MDARS payloads for physical security:

Multiple Video Displays: The MDARS console currently displays the video from one platform at a time. The user has requested the ability to display video from up to 4 platforms simultaneously. This would allow them to keep track of both the intruder and the response team using multiple cameras.

Multiple Intruders: Though the IDS sensor suites have the ability to track multiple intruders, but only the highest threat intruder is currently displayed on the console. All threats will be displayed in a future version of the MRHA.

Detection on the Move: The ability to detect intruders while the platform itself is moving will greatly increase the probability of detecting an intruder as well as increase the effective range of the vehicle (since it will no longer have to stop to look for intruders). Current schemes being examined include both visual and radar sensors.

Tag Attachment: Further research needs to be done by industry to develop a standard method to attach RFID tags to a variety of products and surfaces. The tags should be tamper resistant and the RFID system should report if a tag has been physically separated from a product.

Not-Inventoried vs. Missing Items: During operational testing, tags were reported missing in the inventory database because the platforms had not performed recently a tag read near their locations. To prevent false alarms, the system needs to record which areas have been inventoried to distinguish between a tag that has not been read vs. a tag that was not close enough to a platform to be read.

Lock Tags: The BAS should support an integrated lock reporting system (versus two separate RFID tags for "opened"/"closed.") If the lock is found opened, inventory stored in the igloo needs to be read remotely on-demand by the guard from the MDARS console and also on-site from a hand-held tag reader to determine if any item is missing.

5. Force Protection Payloads

MDARS was originally designed for physical security missions, operating in a known environment under friendly control to prevent vandalism and pilferage by trespassers and disgruntled employees. By leveraging off recent improvements made for tactical missions, MDARS has evolved to better support force protection missions. Both MDARS-I and MDARS-E have a requirement to provide a non-lethal response capability (such as a pepper-ball gun or a net deployment system). The MDARS-E vehicle can transport a smaller vehicle (such as an air vehicle or a ground robot suitable for more discreet reconnaissance missions) in a marsupial fashion, giving the smaller vehicle greater effective range. In addition, the MRHA will have the ability to collect and display data from legacy fixed sensors at a site and combine that data with the MDARS system so that the systems can be used simultaneously in a non-interfering manner.

5.1 Non-Lethal Weapon

Taking just three weeks from concept formulation to initial testing, an *Angel 2001* paintball gun was integrated with the MDARS-E platform and the MRHA to evaluate command and control concepts for a Non-Lethal Weapon. A video camera is mounted to the barrel of the gun to allow the operator to accurately view the target. The operator uses a joystick at the MDARS console to pan and tilt the camera, and to fire the weapon. The MRHA Operator Station issues standard payload movement commands as well as payload arm and fire commands to a NERD, which controls the gun pod. Future work includes: automatic target detection/tracking; coordinated/cooperative targeting between multiple autonomous weapons pods; hardware size reduction; and use of alternative rounds (e.g., pepper balls used by Border Patrol). Figure 8 shows the Non-Lethal Weapon on MDARS-E.

Figure 8. Non-Lethal Weapon on MDARS-E

5.2 Marsupial Robots

To expand its force-protection and force-multiplication capabilities, SSC San Diego developed the Integrated Marsupial Delivery System concept for MDARS-E to serve as a marsupial carrier for smaller deployable assets. Designed to transport an Unmanned Ground Vehicle (UGV) and/or Unmanned Air Vehicle (UAV), the carrier enhances the MDARS-E capability to provide a flexible tactical response. This synergistic integration takes advantage of the inherent strengths of the individual platforms. MDARS-E is a rugged four-wheel hydrostatic-drive diesel-powered vehicle that can travel over long distances, transporting the UGV/UAV closer to its destination to perform surveillance and reconnaissance. Figure 9 shows the Integrated Marsupial Delivery System concept.

Figure 9. Integrated Marsupial Delivery System concept

The MDARS-E platform can carry the SSC San Diego Urban Robot (URBOT), a low-profile tracked robot that is controlled by an operator via an RF link. Fully invertible, watertight, and employs four video cameras, its small size (can fit through a 24-inch manhole) and excellent maneuverability make it ideal for tunnel and sewer reconnaissance in the below-ground scenario associated with urban warfare. The onboard nickel-metal-hydride rechargeable batteries provide average mission durations of 4 to 5 hours. The MDARS-E platform also acts as a repeater, allowing the remote operator to communicate with the URBOT over the longer-range MDARS RF network, which uses the same integrated format for all-digital transmission of video, audio, and control data.

In March 2002, engineers from SSC San Diego and Allied Aerospace (formerly Micro Craft, Inc.) conducted the first known launch of an autonomous Vertical Take Off and Landing (VTOL) UAV from an autonomous UGV, at the Holtville regional airport just east of El Centro, CA. The launch involved Allied Aerospace's 29-inch Lift Augmented Ducted Fan (LADF) *iSTAR* UAV and the MDARS-E delivery platform. The MDARS-E platform was outfitted with the addition of a prototype fiberglass launch fixture developed by SSC San Diego, designed to accommodate the same bolt pattern used to secure the IDS and the Non-Lethal Weapon payload modules. Strong winds gusting to 20 knots at the Holtville airstrip necessitated the use of a safety tether system for this preliminary test, but subsequent fully autonomous free-flight launches from the MDARS-E platform are planned at SSC San Diego using a modified launch fixture and procedures that should effectively eliminate crosswind constraints.

5.3 Integration with Fixed and Mobile Sensors

Sites that deploy MDARS will usually have a set of fixed sensors in place for intrusion detection, the current DoD standard being the Integrated Commercial Intrusion Detection System (ICIDS). ICIDS typically wires a number of volumetric motion sensors and balanced magnetic switches to a device called a Remote Area Data Collector (RADC). The output of each RADC is routed back to a monitor console at the guard shack. In order for MDARS to co-exist with ICIDS the MRHA must interface to ICIDS in such a way that the moving robots do not cause the ICIDS sensors to sound an alarm. This will be accomplished by temporarily disabling or ignoring alarms from sensors that have an MDARS platform within their field of view. The MRHA console will intercept the output from ICIDS to perform this filtering function. In addition, the MRHA will also act as the sole display console for both MDARS and ICIDS, effectively unifying the two systems. ICIDS alarm leads to an automatic dispatch of MDARS. SSC San Diego is building an integration test bed and development environment using NERDs to interface to ICIDS RADCs.

6. Conclusion

MDARS is a fully automated physical security and force protection system using unmanned vehicles, weapons, and sensors. It uses a combination of payloads for intruder detection, electronic lock monitoring, RFID inventory of high-value assets, and non-lethal response. The MRHA command and control console allows the human user to coordinate multiple resources including interior and exterior autonomous robots. The MRHA defines communications protocol and messages, integrates data, video, and audio on a wireless digital link, and employs Network-Enabled Resource Devices to assign any electro-magnetic auxiliary device support an IP address facilitating integrated autonomous control. Recent system enhancements include an Integrated Marsupial Delivery System concept and integration with fixed sensors.

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