Robotics for Humanitarian Demining

By John Wetzel

A Nemesis to Deadly Landmines

Picture two young brothers playing together in a village. The older brother is hauling his younger sibling around in a wagon. Now picture the wagon more closely – in place of its wheels are large circular anti-tank landmine casings. You're not sure if these wheels are filled with explosives and live fuses or not, but you hope the children never get to find out. As strange as it sounds, this is the type of world many people live in. They must deal with the real threat of landmines on a daily basis, whether it's improvised toys such as the wagon, or a decision whether to travel through a previously mined area to get to market.

For the past few years Applied Research Associates (ARA) has been working with the US Army RDECOM, CERDEC, Night Vision and Electronic Sensors Directorate (NVESD), Ft Belvoir, VA, to develop a robot to detect and neutralize landmines. NVESD is the lead U.S. government organization in the development and application of Humanitarian Demining (HD) technologies.

Initially called the Force Protection Demining System, the Nemesis project goal is to develop an advanced demining system to facilitate the clearance of landmines in the field. The system may be used for HD detection and area reduction in civilian demining operations as well as be fielded for use by military forces.

Despite improvements in both military and civilian mine detection equipment, HD remains a slow, hazardous, and labor-intensive task. The methods currently employed are very similar to those used near the end of World War II. The inherent dangers of mine removal coupled with the growing number of mines emplaced each year have created an urgent requisite for equipment capable of reducing the number of personnel involved in clearance missions. The application of robotics by the Nemesis program is intended to reduce the need for manual mine detection by providing a means for the reliable detection of landmines from a remotely operated vehicle.

Robotic Platform

Figure 1. Nemesis Robotic Platform

For HD employment, the Nemesis project utilizes a light, utility-tracked vehicle as the base platform. This platform, model RC-60 manufactured by All-Season Vehicle (ASV), provides significant ground clearance and reinforced rubber tracks distribute low average ground pressure. A Modular Robotic Control System (MRCS) was developed and integrated with this base platform. The MRCS is compliant with the latest Joint Architecture for Unmanned Systems (JAUS) standards, and consists of three main elements: 1) a man-portable Operator Control Station (OCS); 2) platform control components; and 3) a wireless data and video link. The Nemesis robotic platform with integrated MRCS components is shown in **Figure 1**.

The OCS, shown in **Figure 2**, is a man-portable unit that supports all command, control, and communications to the target platform. The OCS weighs approximately 20 kg (45 lbs) and can be powered by either a 12-volt DC or a 110-volt AC source. External features of the OCS include:

- Two joysticks (one pistol-grip) to control platform or payload functions, and to control camera selection and pan/tilt/zoom functions
- 15-inch video screen in the lid of the unit
- 12-inch touch-screen
- Keyboard
- Emergency Stop (E-stop) button
- On/Off switch and connection ports

Operation of the robotic platform is performed through control of the joysticks and functions on the touch-screen. Joysticks provide control of mobility and the loader arms as well as camera control functions (camera select and pan/tilt/zoom). The touch-screen monitor is also used to view feedback data from the system, such as platform status (e.g., fuel level, hydraulic oil temp), target discrimination data from landmine detectors, and navigation and positioning graphical maps from a Global Positioning System (GPS). The video screen displays feedback from cameras on the platform. Views can be set up to display a single camera view, a combined

Figure 2. Nemesis man-portable Operator Control Station (OCS)

quad-view from four cameras, or a picture-in-picture view of selected cameras through a multiplexed signal.

Components onboard the platform provide remote control functionality through modular enclosures designed to facilitate installation and maintenance, while maintaining manual control capabilities for the vehicle. The primary MRCS enclosures are mounted in a roof-rack on the Nemesis platform and include: Vehicle Control Unit (VCU), Vehicle Radio Unit (VRU), Camera Multiplexer Unit (CMU), and Power Distribution Unit (PDU). Four cameras are implemented as part of the Nemesis robotic platform. Fixed wide-angle cameras are mounted on the front and rear of the platform for forward and reverse driving. Two additional cameras (visible zoom and infrared) are mounted on a pan/tilt unit. Feedback from the cameras is provided at the OCS video display, with options to display a single camera view or a split-screen with multiple views.

Some operational environments dictate specific methods of RF (radio frequency) transmission; therefore, the MRCS is designed to facilitate change-out of radios as needed. The radios are external to the OCS and other platform components so they can be easily exchanged. The current Nemesis wireless RF system consists of two radios: a frequency-hopping spread-spectrum FreeWave data transceiver for command and control; and a DTC digital video radio for video feedback. Operational range of the platform is limited by the video radio. The DTC digital video radios have a range of several miles with power settings at less than 1 Watt.

Humanitarian demining missions require very slow operational speeds, nearing the physical limitation of the platform's ability. To meet this operational requirement, closed-loop speed control was designed to provide near constant slow speeds (< 0.5 km/hr) unaffected by varying terrain or engine throttle setting. This control loop was developed using position feedback from track sensors to maintain constant platform speed in either the forward or reverse direction. Control algorithms were developed and implemented on-board the platform. Two types of sensors were tested on the tracks to provide the position feedback: a high-resolution optical encoder mounted to the rear track wheels; and a low-resolution Hall effect sensor integrated with the track motors. Detailed evaluations proved either sensor provided the necessary feedback to exceed the slow speed requirement, obtaining constant speeds of less than 0.3 km/hr.

Landmine Detection

Detailed investigations were conducted to determine which mature sensor technologies would be best suited for application on the Nemesis landmine detection system. A central finding of this sensor study was a single technology could not meet the detection requirements of the program. Therefore, ARA's approach was to use multiple, complementary sensors. Based on data from previous testing of these mature technologies and the results of detailed evaluation, the PSI Ground Penetrating Synthetic Aperture Radar (GPSAR) and Minelab Electromagnetic Inductance (EMI) arrays were selected as the primary detection sensors for the Nemesis program. Navigation and positioning is provided from the robotic platform to aid in correlation of data from the two sensors.

The radar and EMI sensors were selected for their ability to detect both antipersonnel (AP) and antitank (AT) landmines in a 1.8-meter wide array configuration that leads to improved ground coverage and performance. These arrays are capable of high spatial resolution (3 cm or less) and overlapping detections, thus increasing both the precision and accuracy of the overall system. During a scan, the system collects data from each of the sensing elements, effectively imaging a portion of the subsurface. The Nemesis design accounts for the effects of operating multiple sensor systems simultaneously, configuring the sensors to minimize interference without any loss in sensitivity or performance. A picture of the integrated Nemesis System with the detection sensors attached to the robotic platform is shown in **Figure 3**.

Figure 3. Nemesis robotic platform and detection sensor arrays

A primary focus of the Nemesis project is on processing the detection sensor array data and developing algorithms for signal post-processing, automatic target cueing, and discrimination and classification. The goal is to fuse source sensor data and extracted sensor information to provide an increased level of mine detection while minimizing false alarms. The detection software system will also exploit spatial registration and multi-sensor data fusion algorithms to provide real-time automatic target recognition information to the user. A set of data collected with the Nemesis radar and EMI sensors is shown in **Figure 4**, highlighting the response to three landmine targets.

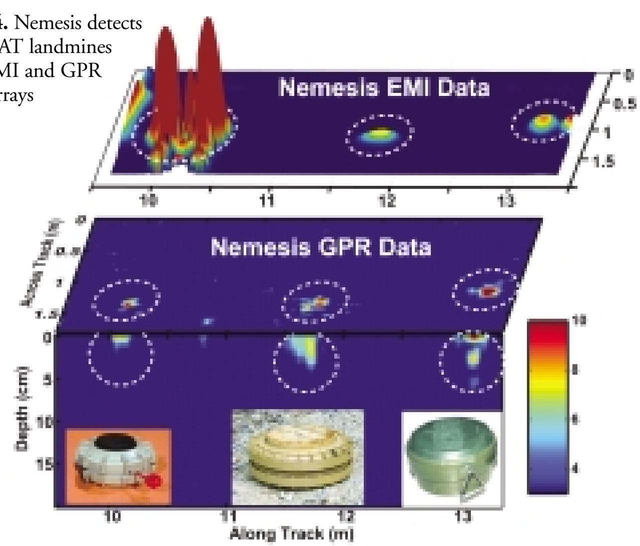

Figure 4. Nemesis detects AP and AT landmines using EMI and GPR sensor arrays

Landmine Neutralization

The objective of Nemesis landmine neutralization subsystem is to destroy landmines without explosive detonation. Explosive methods can create both metallic debris and explosive residue that may inhibit follow-on detection and Quality Assurance (QA) efforts, by creating false alarms for metal detectors and false indications from Mine Detection Dogs (MDD).

The Propellant Torch (PT) being developed by ARA provides the required non-detonative neutralization. Consisting of a heat-resistant paper case filled with a novel pyrotechnic formulation contained by a ceramic nozzle and end-cap, the PT is an improvement over previous devices. When ignited, the PT propellant is rapidly consumed and a super-hot jet of combustion products (~3000 K) exits the nozzle. Jet impingement on a landmine results in quick penetration of the mine case followed by initiation of burning of the explosive inside. After neutralization of the mine, only the mine and torch cases are left behind. As pictured in **Figure 5**, the PT is placed next to a landmine (e.g., VS-50 antipersonnel mine) and ignited to burn out the landmine for neutralization.

Figure 5. Propellant Torch set to neutralize AP landmine

A robotic manipulator arm is used to remove soil overburden if necessary and to place the PT neutralizers in close proximately to the mine. The manipulator arm is attached to a mount, as shown in **Figure 6** with a VS-1.6 antitank landmine. The soil overburden can be removed using tools like a supersonic air ablation system to blow the soil away or a brush to remove excess soil. The gripping feature of the manipulator provides additional capability to remove objects such as rocks, debris or possibly UXO.

Figure 6. Manipulator arm with AT landmine

Nemesis Application

While robotic operations serve to protect the human operators by removing them from harms way, damage tolerance for the Nemesis demining system is also being addressed for potential landmine detonations. Shielding will be provided to minimize blast damage to components and the base vehicle. Armor protection will be integrated to protect critical electronic and mechanical elements, and detection sensors and neutralization tools will be designed to minimize damage and facilitate repairs.

Nemesis development was initiated in 2003 and current project efforts are focused on initial field application by 2008. The robotic platform is already a success story, with the U.S. Marine Corps procuring units for force protection, in which they will implement a water cannon to defeat Improvised Explosive Device (IED) threats. With the vehicle's versatile tool attachment mechanism, the U.S. Army is also planning to use the robotic platform for vegetation clearance. Testing of the neutralizer torches is nearing completion, with the PT ready for operational use by the end of this year. Detection efforts focus on the development of target recognition algorithms using test data acquired from the combined radar and EMI sensor suite.

ARA is an employee-owned engineering firm founded in 1979 and headquartered in Albuquerque, NM. ARA has grown to a staff of over 1,000, with specialties including robotics, computer blast modeling, specialized equipment manufacturing, and pavement technologies for a mix of defense and civilian customers. For more information about ARA see ***http://ara.com/***

John Wetzel is the Nemesis program manager and a principle engineer at ARA's New England Division. To learn more about the program, contact the author at jwetzel@ara.com.

On Deadly Ground

Landmines pose a significant problem worldwide. Many regions are devastated by the aftermath of regional power struggles, which leave behind the scars of war in the form of landmines. According to a 2003 RAND report entitled Alternatives for Landmine Detection, it is estimated there are 45 to 50 million landmines worldwide. These landmines claim an estimated 15,000 to 20,000 victims per year in some 90 countries. In Afghanistan during 2000, mines claimed 150 to 300 victims per month, half of them children. Additionally, these landmines devastate local agrarian-based economies. Fertile land previously used for agriculture is left barren and is overtaken by vegetation, which exacerbates landmine clearance. Local farmers are faced with the choice of whether or not to risk their lives in the mine-infested fields to put food on the table for their families. The United States currently invests about $100M annually in HD mine clearance. At the current rate of mine clearance, it could take 450 to 500 years to complete the clearance of existing landmines.