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Modular Robotic Control System for Landmine Detection

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ABSTRACT

A Modular Robotic Control System (MRCS) has been developed and integrated on a light utility tracked vehicle for landmine detection technology applications. The MRCS architecture consists of three main elements: 1) a man-portable Operator Control Station (OCS); 2) Platform Control Components (PCC); and 3) a wireless data and video link. The OCS provides the remote operator with command, control, and communication with the PCC located on the vehicle platform. The PCC consists of control nodes linked by high speed Ethernet. The wireless data and video link incorporates radios and antennas to transmit video and send commands between the OCS and the platform PCC. The MRCS is designed to be compliant with the Joint Architecture for Unmanned Systems (JAUS). Closed-loop speed control of the vehicle platform was developed to provide the required slow speed operation for the landmine detection subsystem. Current project efforts are focused on navigation and mapping development for MRCS and application of the landmine detection subsystem, consisting of ground penetrating radar and metal detector arrays.

Key words: Robotics, Control, Navigation, JAUS, Humanitarian Demining, Landmine Detection.

I. INTRODUCTION

Proliferation of landmines is a global problem. Many areas of the world have been devastated in the aftermath of wars and regional power struggles, often leaving minefields filled with unexploded ordnance (UXO). In most areas there is no easy way to identify the location of minefields or individual mines, and mines can remain active for many years. Worldwide, it is estimated that there are 45 to 50 million landmines that 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. The United States currently invests about $100M annually in HD mine clearance. At the current rate of mine clearance, it would take 450 to 500 years to complete the clearance of existing landmines (MacDonald, 2003). Therefore, development of more effective and safe means to detect and neutralize landmines is required.

Robotics provides a safe alternative to extremely hazardous operations that are conducted manually, such as current Humanitarian Demining (HD) efforts. 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 Nemesis project application of the MRCS is intended to limit the need for manual mine detection by providing a means for the reliable detection of landmines from a remotely operated vehicle.

II. ROBOTIC CONTROL SYSTEM

The MRCS architecture incorporates a modular design providing remote control of vehicle functions and control of payload tools. Manual operation capability of the platform is maintained, and MRCS is compliant with the latest Joint Architecture for Unmanned Systems standards. Modularity of the MRCS also facilitates application of this control system to various vehicle platforms as required for different specific mission applications.

For the Nemesis project HD employment (Wetzel and Smith, 2003), we utilized a lightweight, utility-tracked vehicle as the base platform. This platform provides significant ground clearance and is controlled through electro-hydraulic valves, which facilitates integration of the MRCS. Reinforced rubber tracks provide a low average ground pressure, and an excellent suspension system provides a stable ride.

MRCS components incorporate three primary elements: 1) a portable Operator Control Station (OCS); 2) Platform Control Components (PCC); and 3) a wireless data and video link. Each of these three major elements is discussed in greater detail in the sections that follow, as well as a brief description of the software architecture and its application for JAUS-compliancy. The Nemesis robotic platform with integrated MRCS components is shown in Figure 1.

Figure 1. Nemesis HD Robotic Platform

A. Operator Control Station

The OCS, shown in Figure 2, is a man-portable unit that supports all command, control, and communications to the target platform. The OCS can be powered by either a 12-volt DC source or a 110-volt AC source. The OCS is 53 cm (21 in) wide, 43 cm (17 in) deep and 19 cm (7.5 in) thick, and weighs approximately 20 kg (45 lbs). External features of the OCS include:

- Two joysticks (one pistol-grip) to control platform or payload functions, and to control the 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

Figure 2. Operator Control Station (OCS)

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 allows the operator to implement different tools for conducting specific mission functions using simple icon buttons on the screen. For example, the joystick control functions could be switched from driving mode to controlling a robotic manipulator arm used to deploy an air ablation tool for removing soil overburden from a landmine. This facile method for re-mapping the joystick provides a versatile tool on the OCS to facilitate incorporation of alternative control functions as they become necessary. The touch-screen is also used to view other 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 quad-view from four cameras, or a picture-in-picture view of selected cameras through a multiplexed signal.

B. Platform Control Components

Architecture of the PCC, located on the robotic platform, is fully modular and highly scalable. Adding a new payload can be accomplished by plugging the payload node into the network on the platform and selecting the payload configuration library at the OCS for control and display. Control for the vehicle platform is accomplished through a single control node on the PCC.

Actuation of platform functions through the PCC is accomplished through a combination of valve, linkage, and electronic controls. The method of controlling through hydraulic pilot valves enhances remote control performance and reduces maintenance requirements of actuator hardware components. On the Nemesis base platform, hydraulic pilot valves are used to control movement of the left & right tracks and the lift & tilt of the loader arms. An electric actuator is used to manipulate the throttle linkage. Other platform functions, such as lights and engine start, are controlled electronically through switches and relays.

Components added to the platform were packaged to facilitate installation and maintenance. Mounting of components does not interfere with manual control of the platform. Using an Ethernet network and working to maintain modularity enabled us to use portable component enclosures of minimum size and weight to facilitate installation and preserve space in the cab. The primary MRCS enclosures are mounted in a roof-rack on the Nemesis platform, as shown in Figure 3, and include: Vehicle Control Unit (VCU), Vehicle Radio Unit (VRU), Camera Multiplexer Unit (CMU), and Power Distribution Unit (PDU).

Figure 3. Platform Control Components (PCC) on Roof-Rack

We implement four cameras 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 as noted in the previous section.

C. *Data and Video Link*

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.

An Alternate Control System (ACS) has also been developed to provide communication and control for the robotic platform from the OCS through fiber optic tether in place of the wireless RF. The ACS is integrated on a spool that automatically feeds the tether out as the platform travels to perform a mission, and automatically re-spools the tether as the platform returns. Applications of the ACS include urban operations and overseas training missions where frequency allocation is a problem.

D. *Software and JAUS-Compliancy*

The MRCS software architecture is based around two primary components: 1) operator control from the OCS and 2) vehicle control at the VCU. The OCS command structure includes control of platform mobility, cameras and any payloads. OCS software also provides feedback and display of platform and payload status (e.g., gauges, mapping location, and detection sensor information). The VCU receives commands from the OCS and executes the desired functions on the platform.

MRCS software is designed to be compliant with the Joint Architecture for Unmanned Systems. JAUS standards provide specifications for command and control messaging, and are focused on application of interoperability for robotic systems. The goal is for any JAUS-compliant OCS to have the ability to control any JAUS-compliant robot and payload.

III. NAVIGATION CONTROL DEVELOPMENT

Recent MRCS efforts have focused on development of navigation technologies to support robotic applications requiring more autonomous capability. Initial efforts for development of closed-loop speed control and vector drive navigation are discussed in the following sections.

A. *Closed-Loop Speed Control*

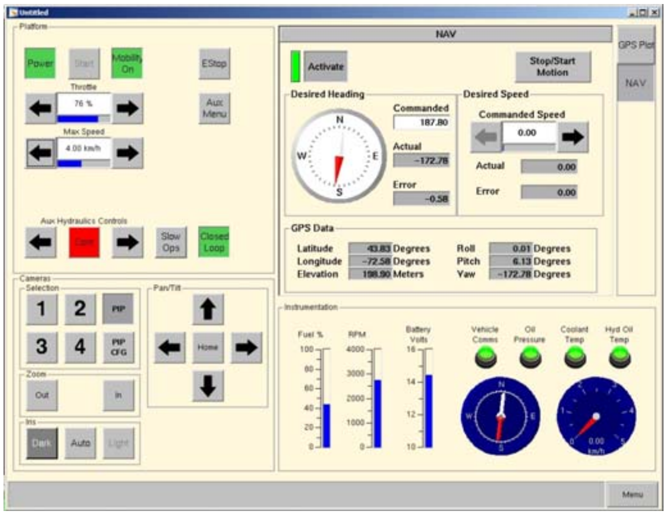
Humanitarian demining missions require very slow operational speeds, nearing the physical limitation of the platform’s ability. To meet this operational requirement, closed-loop speed control was designed to provide the capability to drive very slowly (< 0.5 km/hr) over varying terrain at different engine rpm (revolutions per minute – i.e., throttle setting) levels. Both hardware and software enhancements were needed to accomplish this task.

A control loop was devised that would use position feedback from the tracks to control the platform hydraulic valves to maintain a constant speed. Control algorithms were developed and implemented on-board the platform. The control software was written as a separate module from the rest of the VCU on-board code so it could easily be ported to a different control node enclosure later for separate implementation. 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 that either sensor provided the necessary feedback to exceed the slow speed requirement, obtaining constant speeds of less than 0.3 km/hr.

B. *Navigation and Mapping*

Navigation development efforts began with design and application of a vector drive algorithm for the robotic platform. Vector navigation provides autonomous control of direction (i.e., heading) and speed, and is the core building block for autonomous motion. Heading feedback is provided by a compass sensor. With operator input for a given heading and speed, the vector navigation function provides autonomous hands-free motion in which the platform rotates to the commanded direction and then drives in that direction at the commanded speed.

The OCS provides an interactive Graphical User Interface (GUI) on the touch-screen display. The customized windows and controls provide options for different functionality depending on the application. For vector navigation, the OCS GUI provides a compass heading that displays the current heading and allows the operator to select the desired heading. The commanded speed is also included in the GUI, as shown in Figure 4.



Throttle: 76 %

Max Speed: 4.00 km/h

Desired Heading

Commanded: 187.80

Actual: -172.78

Error: -0.58

Desired Speed

Commanded Speed: 0.00

Actual: 0.00

Error: 0.00

GPS Data

Latitude	43.83	Degrees	Roll	0.01	Degrees
Longitude	-72.58	Degrees	Pitch	6.13	Degrees
Elevation	198.90	Meters	Yaw	-172.78	Degrees

Figure 4. OCS GUI for Vector Navigation

Current work efforts are focused on application of waypoint navigation algorithms using feedback from a GPS/INS (Global Positioning System / Inertial Navigation System) integrated sensor suite to provide autonomous control of position and speed. Using waypoint navigation the platform travels autonomously from its current GPS location to a desired GPS location, while platform motion is regulated to stay within a predefined corridor between the GPS locations. The platform will then proceed to the next waypoint location. Display on the OCS provides a graphic map representation of the vehicle position and path.

IV. LANDMINE DETECTION

Detailed investigations were conducted to determine the leading sensor technologies for application on the Nemesis landmine detection system. A central finding of this sensor study was that a single technology could not meet the detection requirements of the program. Therefore, our approach to detection considers the use of multiple, complementary sensors. Based on successes of field-testing and results of our detailed evaluation, a stepped frequency Ground Penetrating Synthetic Aperture Radar (GPSAR) array and a time domain Electromagnetic Inductance (EMI) array 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 following sections provide descriptions of the sensor array hardware and the data processing and algorithm development.

A. <u>Sensor Arrays</u>

The radar and EMI sensors were selected for their ability to detect both antipersonnel (AP) and antitank (AT) landmines; the array configuration 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. Consequently, a single scan images the response to subsurface targets in three-dimensions. The ability to include depth information is an extremely valuable asset to target classification.

The GPSAR array comprises a 2.0-meter wide antenna array and the associated electronics. Multiple transmit and receive antennas composed of circularly polarized spiral antenna elements embedded in printed circuit boards are used to acquire 46 independent real-aperture focal points across the array. The locations of transmit and receive antenna pairings are designed to optimize across-track image resolution. Opposite circular polarization is used for transmit and receive antennas in order to reduce antenna coupling effects and maximize the return signal. The GPSAR array is a stepped frequency continuous wave (SFCW) radar operating over the 400 MHz to 4 GHz range. An additional advantage of this stepped frequency system over comparable systems is the versatility of designing the frequency spectrum to adjust for soil conditions or clutter.

The EMI detector consists of a 2.0-meter wide array and associated electronics. It uses a multi-period sensing technology to account for variability in soil conductivity, including highly mineralized soils. The system also incorporates bipolar transmission from a single transmitter coil and an array of receiver coils to reduce the effect of mutual coupling from magnetically influenced mines. A major innovation of the EMI array is its ability to compensate for variability in soil properties without loss of sensitivity. Raw data or data images are generated from three output data types. Although the system will respond to all metallic targets, the varying responses from individual channels produce different information for discrimination of suspect targets.

Nemesis design accounts for the effects of operating multiple sensor systems simultaneously. The sensors are configured to minimize interference without any loss in sensitivity or performance. During evaluations, systems were operated with minimal impact on the test site. For example, sensor systems were mounted and operated at “standoff” and did not contact the ground. A picture of the integrated Nemesis System with the detection sensors attached to the robotic platform is shown in Figure 5.

Figure 5. Detection Sensor Arrays Attached to Robotic Platform

B. Data Processing and Algorithm Development

The Data Acquisition System (DAS) provides central management and coordination of data acquired by the various peripheral sensors including the detection sensors and the navigation and positioning module sensors. The DAS logs spatially correlated data files from the detection sensors by utilizing the position feedback provided by the navigation and positioning module. These correlated data, as well as the velocity and position information, can be accessed by various user interfaces. Currently, the MRCS OCS displays the platform velocity and global position and heading data recorded by the DAS.

A primary focus of the Nemesis Program is on processing the detection sensor array test data and developing algorithms for signal post-processing, automatic target cueing, and discrimination and classification (Zachery, Schultz and Collins, 2005). Our goal is to fuse source sensor data and/or extracted sensor information to provide an increased level of mine detection while minimizing false alarms. Extensive preliminary testing has yielded results that define system integration issues and constrain detection performance for each sensor array. An important focus of testing is the characterization of signal-, image-, and physics-based features used in discriminating targets from clutter. Acquisition of single and dual-mode data collected over simulants, landmines, and UXO facilitates the development of a preliminary library of system target responses from which optimal features are determined. 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.

V. SUMMARY

The Nemesis MRCS and detection sensors are being developed to provide a safe, remotely operated system from which to conduct Humanitarian Demining operations. The detection array mounted to the front of the platform will be used to identify potential landmine targets through the integration and data fusion of a multi-sensor array. This integrated system will be operated from a safe distance through the MRCS, controlled through a set of joysticks and displays at the OCS.

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