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ROBOTIC IED DETECTION USING SUPERVISED AUTONOMY TO REDUCE OPERATOR STRESS AND FATIGUE

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ABSTRACT

Autonomous robots can maneuver into dangerous situations without endangering Soldiers. The Soldier tasked with the supervision of a route clearing robot vehicle must be located beyond the physical effect of an exploding IED but close enough to understand the environment in which the robot is operating. Additionally, mission duration requirements discourage the use of low level, fatigue inducing, teleoperation. Techniques are needed to reduce the Soldier's mental stress in this demanding situation, as well as to blend the high level reasoning of a remote human supervisor with the local autonomous capability of a robot to provide effective, long term mission performance.

GDRS has developed an advanced supervised autonomy version of its Robotics Kit (GDRK) under the Robotic Mounted Detection System (RMDS) program that provides a cost effective, high-utility automation solution that overcomes the limitations and burden of a purely teleoperated system. GDRK is a modular robotic appliqué operated by a common controller capable of transforming any tactical platform or payload into an optionally manned system. RMDS is a government program to enable robotic control of a Husky route clearance vehicle with a mine detection sensor payload.

This program provides the user with standard teleoperation control of the vehicle as well as semi-autonomous modes including cruise control, precision waypoint navigation with operator error correction and a visual mode allowing the operator to enter waypoints in the current video feed. The use of autonomy is tailored to give the operator maximum control of the robotic vehicle's path while minimizing the effort required to maintain the desired route. Obstacle avoidance sensors are employed to protect the mine detection sensor. Practical issues and lessons learned during integration and testing are presented.

INTRODUCTION

The goal of the RMDS program is to remove the operator of a Husky route clearance vehicle equipped with a mine detection sensor (Figure 1) from harm's way without compromising the mission and without requiring additional personnel. This requires adding robotic actuators to the Husky and creating a control system that allows the operator to monitor the mine sensor output while maintaining the vehicle path within the route. Important constraints are the precision and accuracy of the vehicle's path, speed, safety of the sensor and vehicle, and operator workload.

The vehicle path control must be at least partially autonomous to allow the operator to monitor the mine detection sensor data during operation; full teleoperation requires too much attention, reducing the operator's effective use of the sensor. It is not currently desirable to rely entirely on automatic recognition of targets, therefore the operator must watch the sensor data closely. Typically Husky vehicles with the mine detection sensor are used at low speeds on dangerous routes that are often repeated, making this mission an excellent application for robotics. Additionally, the requirement for a specialized operator with specific domain expertise to monitor sensor data while maintaining control of the vehicle indicates the need for some level of autonomous behavior to limit the operator's workload.

RMDS is intended to be operational in a relatively short period, requiring a short development and implementation cycle. This short development cycle, combined with the danger of the mission and expertise of the operator, indicate that a semi-autonomous system with an operator constantly involved is the best solution.

Figure 1: Husky with mine detection sensor

SYSTEM OVERVIEW

The system developed to fulfill the RMDS requirements consists of a robotically actuated Husky with Ground Penetrating Radar (GPR) mine detection sensor and a radio link to another route clearance vehicle configured as a control vehicle. The Operator Control Unit (OCU) is installed in the control vehicle where the RMDS operator monitors the mine detection sensor data and watches video relayed from cameras on the Husky to verify that it is travelling on route as expected. The OCU includes controls for the Husky that allow the operator to intervene when necessary, either via teleoperation or by interacting with the vehicle's semi-autonomous controls. It is expected that the RMDS operator and the driver of the control vehicle will work independently, needing only minimal cooperation for vehicle coordination.

The Husky carries multiple video cameras, inertial navigation sensors, GPS sensors and a LADAR sensor, as well as all of the sensors required for the actuation system and the GPR mine detection sensor. The cameras are used as aids for the operator, providing situational awareness for the Husky. The inertial and GPS sensors are used by the navigation system to provide global localization and local position tracking. The LADAR sensor is used to detect hazards and prevent damage to the vehicle and mine detection sensor by stopping the Husky when it is in a semi-autonomous mode. The LADAR is not used for path planning as it is mission critical that the Route Clearance Team follow a specific, pre-determined, route. Vehicle status information is available from the OCU.

Concept of Operations

The RG-31 will follow the Husky within 100-500 meters during a mine clearing operation by combat engineers in a route clearance convoy. The system is expected to operate at slow speeds, up to 5 KPH on unimproved roads and up to 12 KPH on paved roads. The RG-31 driver is provided with a Lane Tracking Indicator (LTI) intended to reduce the RG-31 driver's workload to precisely follow the path of the Husky. The LTI will show the RG-31 driver how closely the command vehicle is tracking to the route cleared by the Husky. A mine marking system on the Husky is controlled from the GPR OCU to mark the location of the mines detected.

Control Modes

Special emphasis was put on the development of appropriate control modes for RMDS. Robotic actuation of a vehicle and sensor is not particularly difficult, but developing a system that allows the operator to effectively carry out a mission with a robotic system is not simple. Human-robot interaction can be very complex and a system that is difficult to use is likely to be abandoned in favor of easier alternatives. Route clearance missions are dangerous and tedious, while demanding significant attention from the operator. The robotic system must assist the operator rather than complicate mission execution. To this end the RMDS program leverages lessons learned from past teleoperation and semi-autonomous development conducted by General Dynamics Robotics Systems.

HUMAN DRIVING

The Husky can be driven by an operator in the cab, particularly if it is to be driven over long distances at high speeds while not performing mine detection. Also, in case of a failure of the robotic system or an event that requires reacting in a way that the OCU does not accommodate, the operator can use the Husky as he would any other. It is also important to note that Husky's are large, potentially dangerous vehicles and it is likely that there will be situations where both operators and bystanders are more comfortable with a human inside the vehicle. Providing the operator with the option to drive from inside the vehicle may increase confidence in the system, which could in turn lead to the system being used in more scenarios. While being used in this mode, the system does not fulfill the requirement to remove the operator; this mode is not intended to be used when scanning for mines.

TELEOPERATION

The operator will have the option to take full control of the robotic Husky at any time. In this mode the vehicle takes no actions that the operator does not command and follows all operator commands blindly. Teleoperation allows the operator the maximum amount of control, but also requires maximum attention. This mode is necessary for the system to be usable in situations that require the operator to have complete control, but it requires too much operator attention to be practical when traveling long distances.

Teleoperation introduces some difficulties over direct driving. One significant problem is the operator’s inability to feel the acceleration of the remote vehicle, which removes important cues that drivers are conditioned to exploit. This physical decoupling from the vehicle causes the driver to compensate for the lack of proprioceptive vehicle motion sensing by focusing on the remaining sensory inputs, usually just video. This requires the operator to ignore conditioning from previous driving experience and can be disorienting. The operator must continually concentrate on the trusted senses while disregarding others and performing the mission. The workload associated with this kind of operation is much greater than when using normal direct control. This effect is accentuated when the operator is in a moving vehicle, since it is intuitive to react to the acceleration that is felt, which is independent of the motion of the vehicle being controlled. It is possible for the operator to experience motion sickness.

Another significant issue is latency. When the operator commands the robotic vehicle to move or change course, latency can cause a delay between the issuing of the command and the vehicle’s reaction and then another delay between the action and the resulting change in sensor data and video. This often results in overcompensation by the operator, which can cause oscillations in the path of the vehicle. When the operator is forced to compensate for the effects of latency, performance degrades and speed is drastically reduced.

Another problem with teleoperation is that the operator has diminished situational awareness compared to a driver in the cab. This requires the operator to give wider clearance to obstacles and makes it unsafe to teleoperate the vehicle in some situations that a driver could handle safely.

These issues render teleoperation impractical for long duration travel and situations that require the operator to devote attention to something other than driving. This indicates the need for operational modes that require less human interaction. There are capabilities, such as cruise control, that can be added to address some of the problems of teleoperation.

Teleoperation is intended to be used by the operator to navigate around obstacles in the route and to deal with unforeseen situations. It is not intended to be used heavily during the mine scanning portion of route clearance missions.

Cruise-Control

This mode simply adds speed control to teleoperation. It is identical to cruise control in a car and similar to the throttle in a boat or airplane. This slightly reduces the operator workload, and also mitigates some latency issues related to maintaining speed. Latency increases the difficulty of estimating the robotic vehicle's speed, particularly when video frame rate appears variable. Halting video creates the illusion of speed fluctuations. With cruise-control, the operator is less concerned with these apparent speed changes. The set speed can also provide clues that can increase the operator's understanding of video affected by latency. This is due to the operator's knowledge of the vehicle's speed and therefore the amount of progress that should be apparent in consecutive video frames. When frames are dropped or delayed, the operator can recognize the disruption. Cruise-control also introduces the possibility of collision without active operator input, so constant operator attention is necessary. This mode is intended to be used when the vehicle must be teleoperated over long distances.

SUPERVISED AUTONOMY

Supervised autonomy allows a vehicle to follow a path defined by waypoints, which in this case can be thought of as GPS coordinates. This type of control requires significant robotic intelligence, as the robot must constantly track its position, heading, speed and path to the next waypoint. The control software must also take into account the dynamics of the vehicle. This type of control is commonly used in unmanned air systems, where it is very effective due to the relative lack of obstacles. It is unreasonable to attempt this type of control without obstacle and terrain sensing capability, which would lead to collisions with obstacles in the path. The RMDS operator acts as one sensor, stopping the Husky when he sees potential obstacles or other danger. The LADAR is the primary obstacle sensor. It is used to stop the vehicle when there is an obstacle directly in the path.

Common obstacle avoidance and path re-planning approaches are not implemented. This is a mission consideration; the primary purpose of the RMDS Husky is to find targets in the route, and to do this it must follow the route. Allowing the robot to autonomously leave the route for any reason would be allowing the robot to autonomously undermine its mission, with potentially catastrophic consequences. The response to obstacles in the route is left entirely up to the operator, who is a route clearance expert and is ultimately responsible for the mission. The system will stop immediately and alert the operator when an obstacle is encountered in the route.

Waypoint based navigation with predetermined paths is the best solution for RMDS, since more complex and capable control methods generally conflict with mission requirements by allowing the robot more freedom than appropriate for route clearance. Finding the shortest path to the final destination and determining the easiest path to traverse are not route clearance objectives. It cannot be assumed that routes have any particular distinguishing factors that the robotic vehicle could discern, so it is not reasonable to rely on the robot to find the desired route. It is also unwise to assume that any given waypoint path is entirely correct or even that a high quality path will be followed perfectly, so RMDS includes the capability to correct path following during operation. This is referred to as bias correction, or bump steer, and is described below.

Supervised autonomy is intended to be the primary navigation mode of RMDS while carrying out missions. It allows the operator to focus on the mine sensor while supervising navigation. This implies that the basic navigational competence (path following in the case of RMDS) and responsibility is transferred to the robotic system from the operator. This offloading of responsibility results in a dramatic reduction in operator workload. Waypoint navigation is the main semi-autonomous component of RMDS. In this mode the robotic vehicle is following a specific directive and is responsible for all of the details involved in carrying it out, but it must rely on the operator to intervene when there is potential danger.

The ability to record new waypoint paths during operation is a basic RMDS functionality that is important given the possibility that the environment, circumstances and even routes could change. One vital consideration when using waypoints is how they are entered into the system. RMDS will support multiple methods of generating waypoint paths, which are described below.

Prerecorded Path

Any waypoint path in the right format can be followed by the system. It is possible to use paths from many sources, but it should not be assumed that such paths are available. For this reason, RMDS is capable of recording any path that the Husky travels and using it later as a waypoint path to follow. It is possible for waypoint paths to be transferred between vehicles. All RMDS navigation modes support waypoint recording, making it possible for the operator to generate a path for any route without the need for high accuracy maps or any other external information. Recording a traveled path, typically from a manned Husky mission, is intended to be the primary method of generating waypoint paths.

User-Generated Path

RMDS waypoints are globally referenced, so it is possible to generate paths with map information. The RMDS OCU allows the operator to layout a path using maps in software. This method allows a path to be generated quickly without first traversing it, but with limited accuracy and could potentially be used to send the vehicle on a path that is not drivable. Bias correction may allow the operator to mitigate the effects of a lower accuracy path, but not to the degree required during missions. This method is not intended to be used during most missions.

Path Bias Correction

In the event that waypoint following on a particular path does not keep the Husky within an acceptable range of the route, the operator must have a method of reducing the error between the vehicle's actual and desired paths. RMDS includes a bias correction, or bump steer, capability that allows the operator to offset the vehicle to the left or right of the waypoint path. The amount of the offset is predetermined by the route clearance team. This allows the operator to alter the vehicle's path without resorting to teleoperation. If a path is bad, requiring repeated correction, another can be recorded during the mission. Given the accuracy and precision of global localization methods and the complexity of robotic path following, it is probable that bias correction will be used regularly, even with good waypoint paths.

Allowing the operator to correct for path error while staying in waypoint following mode decreases the need to use teleoperation, therefore reducing workload. The ability to bias the vehicle's path relaxes accuracy requirements of the paths used and should result in a more robust system. It is possible for the operator to use this bias factor to navigate around obstacles. The inclusion of this capability could make the difference between completing a mission with an imperfect waypoint path and aborting to obtain a new path. This also addresses the dynamic nature of the environment by providing the ability to adapt to minor changes in surroundings or situation.

Go No-Go Window

This mode of supervised autonomy allows the operator to set the parameters of a go, no-go window. The operator chooses the nominal separation distance the RG31 is to follow behind the Husky, and then they choose a window size, which is a +/- around the separation distance. For example, the Operator may choose to follow the Husky by 300 meters +/- 50 meters. As long as the RG31 stays between 250 meters and 350 meters behind the Husky, the system will continue to operate in supervised autonomy. If the window is breached, the Husky will come to a stop and the operator will be alerted.

VISUAL SERVOING

While using the RMDS system, the operator may need to send the robotic vehicle to a point that is not in the current waypoint path without teleoperating. The RMDS visual servoing mode allows the operator to designate a point, or sequence of points, in the video stream as a destination which acts as a new path. The location of the point is estimated and the Husky drives autonomously, monitoring and updating the estimate until the path is achieved. This mode is a low workload alternative to teleoperating the vehicle over short distances, such as guiding the vehicle around local obstacles. The operator must be careful not to send the vehicle to a point that will cause it to pass over dangerous terrain or encounter obstacles, otherwise the robot will stop when it senses its path is blocked or impassable. This mode is intended to offer the operator more options when unexpected situations are encountered, particularly situations that do not allow him to focus on teleoperation.

OPERATOR CONTROL UNIT

The OCU is the operator's point of interaction with the robotic Husky and the mine detection sensor. All controls to the Husky and sensor are sent over the radio link from the OCU. The OCU consists of two computers. The first has a touch sensitive display and steering wheel input device (see Figure 2) used primarily to control the Husky. The second is a smaller touch sensitive display that interfaces to the GPR sensor and displays higher resolution mine detection data.

Primary OCU computer

The primary OCU computer handles all commands to the Husky and some mine detection sensor interaction. It offers two methods of user input, a customized steering wheel (shown in Figure 2) with a number of buttons and controls for frequently used functions, and a touch sensitive display (shown in Figures 2 and 3) with software buttons and configurable display windows. The display shows selected video streams, map information, vehicle status information, vehicle controls and a limited mine detection sensor interface. The steering wheel allows the operator to control the robotic vehicle steering, throttle and brake naturally and its buttons allow some functions, such as cruise control and bump steer, to be accessed without releasing the wheel to touch the screen.

Figure 2: Primary OCU display with steering wheel input device

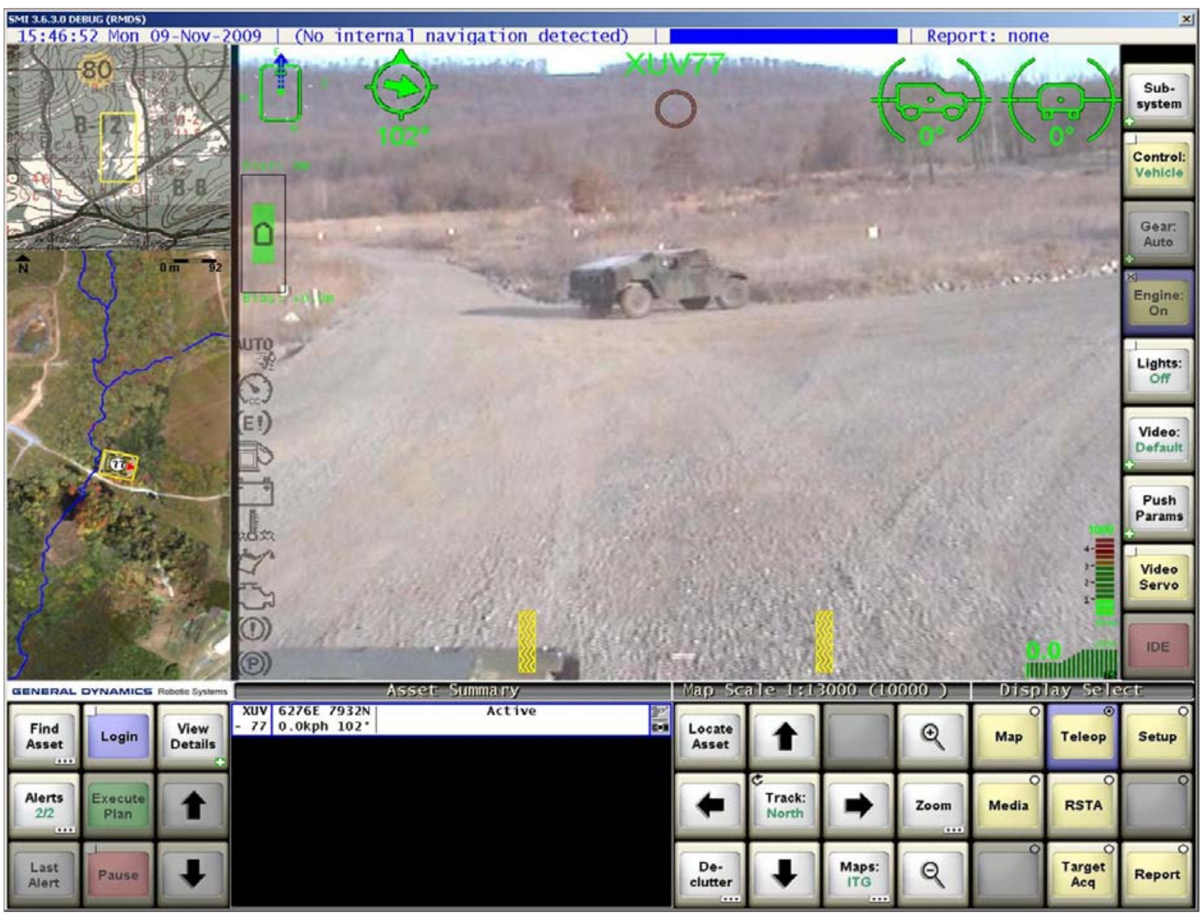

Figure 3: Control interface screen of primary OCU display

CONCLUSION

RMDS was initiated to roboticize an existing Husky route clearance vehicle with a mine detection payload. This program provides the user with standard teleoperation control of the vehicle as well as semi-autonomous modes including cruise control, precision waypoint navigation with operator error correction and a visual mode allowing the operator to enter waypoints in the current video feed.

This provides a well-defined mission with limited scope which allows the application of robotic technology to be tailored to the specific intended use of the system. Many aspects of the mission are well suited to robotics, the most significant being the danger of the mission, the low speed of operation, the predetermined path, and the monotony the operator must endure. The mission is dull, dangerous, well defined and, perhaps most importantly, within the sphere of current robotics capabilities.

The route clearance mission is too dangerous and critical to allow the expert operator to be removed, so his expertise and capabilities have been leveraged for the RMDS control system. This leads to a system view that regards the robotic vehicle as a tool for the operator rather than a potential replacement for him. For this reason, the robotic control software requires operator input when it encounters situations requiring high level reasoning about mission requirements.

The OCU is designed to provide the operator with easy access to information needed during missions while allowing full control of the system in an intuitive manner. The system developed for RMDS moves the operator to another vehicle and provides multiple control methods that allow him to focus on the aspects of the mission that require his attention while automating those that do not. This maximizes the operator‘s ability to carry out the mission with a robotic vehicle.

The capabilities demonstrated on RMDS are applicable to many other robotic missions including IED detection, neutralization and defeat missions on other vehicle platforms.