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Autonomy in Counter-Improvised Explosive Device Unmanned Ground Vehicles

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Author Note: Cadets O'Brien, Chatel, Robison, and Wasdyke are seniors at the United States Military Academy. They will commission as Second Lieutenants in the United States Army in May 2018. Dr. Bishop is a visiting professor from Georgia Tech. The client for this project is Joint Improvised-Threat Defeat Organization located in Washington D.C. .

Abstract: This project analyzes the use of Counter Improvised Explosive Device (C-IED) Unmanned Ground Vehicles (UGV) in urban Explosive Ordnance Device (EOD) operations and recommends technological solutions to address certain inefficiencies. The two areas of focus for the project are in extending communication with a UGV beyond Line of Sight (LoS) and increasing autonomy/automated functions of the UGV. To extend communication beyond LoS the team has identified a Cellular/LTE network solution and Wi-Fi puck repeater solution, and has designed a framework for comparison of the two. To address the integration of autonomy in C-IED UGVs the team is using IMPRINT software to identify areas of an EOD mission where the workload is exceptionally high for the operator. The IMPRINT model was run again with autonomous technologies integrated in these areas, and the workload decreased substantially, showing that autonomy is a viable option to improve EOD mission efficiency.

Keywords: UGV, Autonomy, Human Factors, Communication Architectures

1. Introduction and Purpose

The most dangerous setting in which soldiers have to operate today is the urban environment. Urban environments are particularly difficult for soldiers due to the lack of visibility, dense civilian population, and overwhelming amount of information to process (FM 3-06: Urban Operations, 2003). In these urban environments, one of the most deadly threats to our soldiers is Improvised Explosive Devices (IEDs). When a patrolling unit encounters an IED, they request support from an Explosive Ordnance Disposal (EOD) Team. EOD teams are trained to locate, assess, and neutralize explosive threats. They do so with a variety of specialized equipment, the most crucial of which is their Unmanned Ground Vehicle (UGV).

Responding to IED threats in an urban environment presents just as many challenges to the EOD team as it does the patrolling unit. The first step in a typical EOD mission is to set up a security cordon to ensure the area is free of enemy combatants. This is difficult in an urban environment where a stationary target is exceptionally vulnerable, so reducing time on target is vital. As the operator attempts to navigate the UGV from their position to the IED, they have to simultaneously be conscious of maintaining line of sight (LOS). The radio frequencies currently used by EOD UGVs are incapable of penetrating solid objects, meaning the UGV is unable to round corners or enter tunnels while maintaining contact with the operator.

In addition to the line of sight struggle, UGV operators are managing a generally excessive workload during portions of the mission. They process a significant amount of sensory information at certain points in the mission, resulting in possible sub-optimal performance and a loss in overall mission efficiency. Our project aims to address both of these inefficiencies in the EOD mission by identifying and assessing potential technological solutions. These possible solutions include adding autonomous functions into the system that will reduce that level of stress.

EOD mission efficiency directly effects soldier safety on the battlefield. Every minute that an EOD team spends addressing a threat is a minute that soldiers are at risk. The purpose of this project is therefore to directly confront this risk by introducing technology that improves EOD mission efficiency. Both extending line of sight and introducing autonomy will enable EOD teams to integrate their UGVs more fully into the mission, keeping soldiers out of harm's way.

2. EOD CONOP and Gap Identification

EOD units are specialized units trained to respond to any explosive threat. Their mission is to "provide EOD support to unified land operations by detecting, identifying, conducting on-site evaluation, rendering safe, exploiting, and achieving final disposition of all explosive ordnance, including IED and Weapons of Mass Destruction (WMD); provide support to joint, interagency, intergovernmental and multinational operations as required" (ATP 4-32 Explosive Operations Disposal, 2013).

The EOD mission relies heavily on counter IED UGVs in order to provide safety and maximize the ease of operation EOD teams. The EOD mission is initiated by the receipt of an EOD 9 Line Unexploded Ordnance Report. The EOD team (Team Leader and operator) link up with the security element and move to the designated location. While the EOD team is en route, the patrolling unit secures the area to avoid the risk of exposure to the threat. This is done by establishing a safe perimeter around the threat area and ensuring there is no enemy, trigger device, or possible threat. Upon arrival, the EOD team conducts an initial "0, 5s, 25s" search surrounding the vehicle to clear the area. Once the search is complete, the EOD Team Leader establishes a security cordon which is out of the danger area of the potential IED and far enough to mitigate enemy threat to EOD operators. At this time, the team will typically utilize a counter IED UGV to identify the threat on scene. The team evaluates the threat and conducts necessary procedures to render the area safe. While the EOD team is operating the counter IED UGVs, line of sight often becomes an issue when the team conducts operations in diverse environments, including tunnels and urban areas. Based on this standard outline of an EOD mission, the capstone team worked in conjunction with current and past EOD robot operators to identify gaps and inefficiencies in this mission that a technological solution could address.

The first gap identified is the ability of UGV operators to maintain contact with their robot. This can occur during any phase of the operation, but especially as the UGV closes in on the IED. IEDs are rarely placed in the open, therefore as the UGV rounds a corner or enters a tunnel to interrogate the threat, line of sight is often broken and the signal is lost. This issue is the foundation of the network portion of our project, where the team has investigated alternative networks to communicate with the UGV.

The second gap is the workload on the operator due to the complicated robot controls and busy environment. The operator has to process information from the UGV quickly to be able to efficiently operate the robot. At certain phases of the operation the information becomes overwhelming, and the operator is likely performing sub-optimally. We have used a human factors software called IMPRINT to assess workload on the operator throughout the mission. After identifying areas of peak stress, we have identified specific autonomous/automated technologies to alleviate the stress on the operator.

3. UGV Platform

Due to the variety of explosive ordnance operations, different UGV platforms are required to meet different mission requirements (TALON, 2017). A survey conducted by United States Air Force Academy Capstone team requested several EOD teams' preference of UGVs. Over 40 teams responded with the TALON system was favored by a substantial margin, therefore TALON robot will serve as the framework for the mission analysis conducted in our project. Additionally, the survey revealed certain functions that operators value in the TALON, such as minimizing time on target and maintaining video feed in tunnels, which our project will specifically aim to improve. Additionally, the TALON is a convenient robot to use for this analysis because of the built-in TALON mission model on IMPRINT software, which will be described in depth below.

Figure 1. TALON Counter IED Vehicle

4. Communications

The purpose of our communications analysis is to outline the general capabilities of the current TALON communication methods, a Wi-Fi puck repeater alternative, and a cell tower communication alternative. We will then recommend the metrics of assessment for future work in comparing these alternatives.

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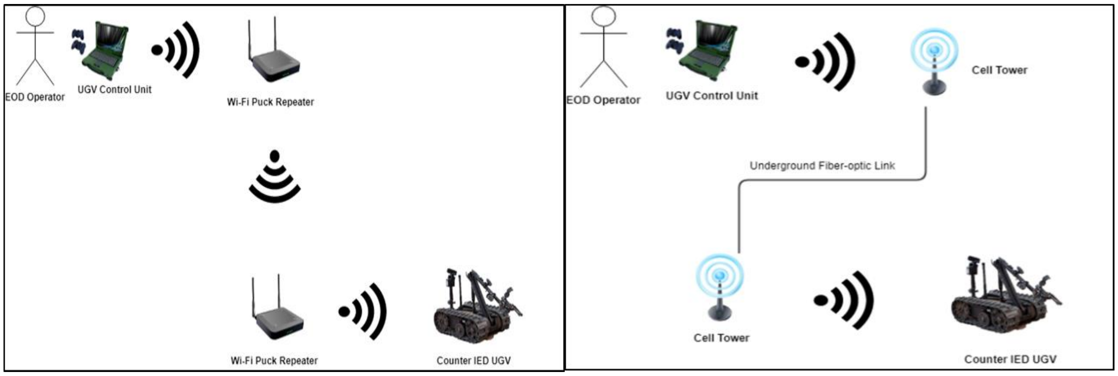

Figure 2. Wi-Fi Repeater Structure (Left) LTE Network Structure (Right)

4.1 Current TALON Communications Structure

The current communication systems for counter IED UGV follow a general structure that involves an EOD operator communicating specifically to the UGV robot through direct, line-of-sight radio signals that are transmitted from a UGV control unit and its connected transceiver device. The UGV receives these signals directly with onboard transceiver(s), and processes this information through its onboard computer. Radio transmissions are sent back out to the UGV control unit via line-of-sight radio signals for the EOD operator to interpret.

4.2 Wi-Fi Puck Repeater Structure

An alternative approach to combatting line of sight issues involves using Wi-Fi puck repeaters to create a Wi-Fi based network that can extend much farther than the original source point for a radio transmission produced from the UGV control unit. The puck repeaters use radio frequencies within the Wi-Fi range to receive and retransmit the same signal to be picked up by yet another puck repeater closer to the UGV robot until the signal reaches the robot's own transceiver to receive the intended signal. This is useful when the UGV moves into enclosed positions, where it can strategically place these pucks in order to maintain communication with the operator. Figure 2 located above shows a depiction of how a simple Wi-Fi puck repeater network would be structured.

4.3 Cellular LTE Structure

A second alternative to combatting line of sight issues with communications would be a cellular communications system. This system would be modeled on the cellular LTE structures that already exist in the commercial markets. Depicted in Figure 2 is a simple diagram of how a cell tower relay system would be structured to support a counter IED UGV communications system. In this model, the UGV control unit transmits radio signals within the cellular frequency range to the nearest cell tower. This cell tower then receives these signals and is able to relay the signals to another cell tower that is close to the UGV robot. These signals are then relayed via underground cables that connect the cell towers, most likely in the form of a fiber-optic cable, which is the current standard in underground data transfer. The signal makes its way to the other cell tower, where that cell tower transmits the control signals to the UGV robot via a powerful line-of-sight wireless microwave antenna. The UGV would then receive these signals through its transceiver, process them with its onboard computers, and then transmit its own signals back to the line-of-sight cell tower closest to it. The signal is then converted and relayed underground to the cell tower that is closest to the EOD operator, where the UGV control unit receives line-of-sight radio signals from the adjacent cell tower.

4.4 Future Assessment

A full assessment of these alternatives is not within the scope of this project. However, the team has identified metrics which should be used as a basis for comparison of each alternative. These metrics are bandwidth, cost, ease of integration, range, repeater capability, open architecture, security, and redundancy. These metrics were identified through independent research, consultation with network specialist from the Army Cyber Institute, and EOD operator feedback from the USAFA survey and interviews. These metrics were chosen because of their relevance to robot performance, network reliability, and

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feasibility for Department of Defense application. A preliminary application of these metrics shows that the LTE network would be the most reliable but most expensive and logistically difficult option, while the Wi-Fi repeaters would be relatively inexpensive but potentially vulnerable alternative.

5. Autonomy

Full autonomy, or automated functions integrated into the robot, would alleviate stress on the human operator of the robot. To identify points in an EOD mission where autonomous functions would be beneficial, a human factors analysis was conducted. Human factors is the study of how people interact physically and psychologically with their environment. This analysis utilizes IMPRINT software, which was developed by Army Research Labs and allows users to design a mission comprised of individual tasks, and measure the sensory workload associated with each task. This analysis illuminates points in the EOD mission using a TALON robot where the operators are under the most stress, and therefore are working the least efficiently. It is in these areas of the mission that autonomous/automated technological solutions were identified and recommended.

The IMPRINT technology uses all aspects of human factors by creating a simulated mission. The situation used in our model is based off a previous situation that was developed previously by members of Army Research Labs. Within this mission are each function and task an operator must perform in order to accomplish the mission. Each of include the fine skills that an operator has developed, and how each portion of the machine will require a certain amount of attention from the operator, which combine to equal the total workload.

5.1 IMPRINT Evaluation and Solutions

IMPRINT software comes with a built-in TALON robot mission model which breaks the mission down into individual soldier tasks. For this analysis, the TALON model was modified to specifically fit the EOD mission, which differs from the default IMPRINT engineer mission. Values for sensory stress are assigned to each task in the mission. The sensory value categories are all-inclusive, ranging from fine motor, to gross motor, to auditory. These values are set on a relative scale, allowing the final mission model in IMPRINT to show the stress on the operator during specific mission tasks relative to others. Many of the values used in this analysis come from the default TALON model, and therefore were tested and verified by Army Research Labs. The values that are unique to this study are those pertaining specifically to the EOD mission, these values were determined based on a combination of general research and discussions with current EOD soldiers regarding the difficulty of certain mission tasks. With this information, IMPRINT can create a series of outputs that look at how the system is running and the success level of the operator based on the tasks he is completing. The most beneficial output to our project is the operator workload graph. This graph is calculated by looking at the difficulty of each task in the system, and the amount of attention the operator must use to operate the system. This provides the ability to look at where the focus of autonomy should be in the system in order to enhance the soldier.

The list of fine motor tasks can be found in the IMPRINT User Manual (*IMPRINT,* 2009*)* to provide clarity on the human factors portion of this system. The fine motor categories can also be seen in the figure below, which can be filled with values based on the task being performed. Each part has a difficulty factor that requires a certain portion of the user's attention. The goal of autonomous functions in this design suggestion is to reduce the stress level in each category by significantly lowering the values. The accumulation of these values and the stress related to it can be visualized as well in the following section. Figure 3 shows the list associated with the human factors of the TALON robot. Each category has a predesignated list to score the difficulty of tasks.

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Interface	Used Here	RI Pair Demand Values						
		Auditory	Cognitive	Fine Motor	Gross Motor	Speech	Tactile	Visual
Arm Lock	☐							
Camera Pan/Tilt	☐							
Camera Select	☐							
CrewStation	☐							
Drive Joystick	☐							
Environment	☐							
Focus Auto Iris Switch	☐							
Gripper	☐							
Lower Arm Adjust Joystick	☐							
Monitor	☐							
OCU Volume Knob	☐							
Roll Stop	☐							
Speed Control	☐							
Stow Arm Switch	☐							
Upper Arm Joystick	☐							
Wrist Joystick	☐							
Zoom In Out Control	☐							

Figure 3. Human Factors Task List

Our proposed solution to enhance soldiers ability is a semi-autonomous navigation system. Not only will autonomy in this area reduce the stress on the soldier, it will assist communications by aiding in the recovery of the robot if communications are lost. This was selected because of the high workload on a soldier while he must navigate using a series of joysticks, look at the robots visual feed as well as viewing it from a distance. This can be quite stressful on the operator, so a possible solution would be a landmark-based navigation system that allows the user to program in landmarks that would reduce the amount of stress on the operator during this time (Endo et. al., 2016). Navigation is the first identified area in need of autonomy to enhance the soldier. The robot would then navigate by using these landmarks as reference points. This same system would be in place when the robot returns to the operator. This solution has the potential to reduce time on target, increase safety of robot and operator, and allow for a quick escape route once disabling of the IED is complete. This solution was run through the IMPRINT software and the results are explained in section 5.2.

The next area of improvement is the interrogation process of the robot. This portion of the mission includes full reconnaissance of the IED site, slow maneuvering and control of cameras, the arm, the position of the robot, and fine motor skills of the robot itself. A semi-autonomous possibility has been developed by Applied Physics Laboratory (APL) that includes tasks to reduce workload on operators. This includes a more adaptable hand with its own pressure function, sensors to prevent slipping, and more flexibility in the wrist motion (Baker, 2014). This assistance would allow the user to divert attention to other details and improve chances of success in the mission.

The final suggestion changes the way the IED disposal is handled with the robot itself. This area is the actual investigation and disposal of the suspected IED, and requires a large amount of concentration from the operator to complete this mission according to IMPRINT software. He will be manipulating cameras, grip system, joystick, and the TALON arm in order to accomplish this task. The amount of concentration can spread his attention thin between the objects, increasing the likelihood of a mistake. The suggestion is a more dexterous hand, such as the Sandia Hand (Sandia National Laboratories, 2012). This glove will relay information from the operator to the robot and allow them to more easily disable the IED. It will reduce the amount of systems the operator would focus on to just a glove and camera, decreasing the likelihood of mistakes.

5.2 IMPRINT Results

The operator workload graph results from IMPRINT, seen in figure 4 below, yielded two points in the mission during which the operator is under excessive stress. The graph on the left displays the workload prior to the introduction of autonomous technologies. The spikes in workload during navigation and IED interrogation are what led to the identification of the technological solutions. The figure on the right shows the workload during a mission after navigation assist introduced to the TALON model on IMPRINT. The results are promising for the use of navigation assist to reduce stress on the UGV operator. The workload required by the operator was reduced by nearly 75% after the introduction of navigation assist.

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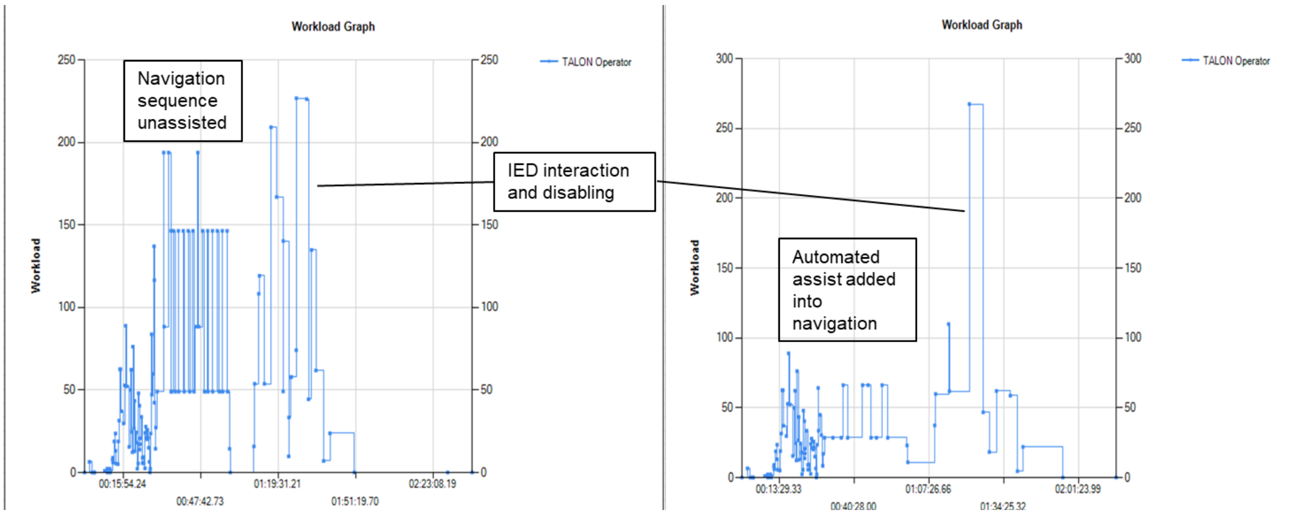

Figure 4. Workload Before and After Navigation Assist

6. Summary and Conclusion

The goal of this project is to identify issues with the use of robots in the EOD mission for which there are technological solutions. More specifically the project focused on autonomous solutions, with an additional focus in network improvement after receiving consistent feedback that the communications network is a weakness of the system. Analysis of the EOD mission exposed two issues: communication with the robot beyond line of sight, and over-stressed robot operators. In response to the issue of communication beyond line of sight, the team identified two potential technological solutions in the LTE network and puck-repeater network. The preliminary assessment of each led the team to lay out a recommendation for further work to analyze each alternative. The issue of over-stressed UGV operators was analyzed via IMPRINT software developed by ARL. This software exposed the two areas in which operators are most stressed: navigation and IED interrogation. Technologies to address these two areas of operation exist in the form of autonomous navigation assist and automated robotic assistance functions. After integrating these function into the IMPRINT model the workload on the operator decreased substantially, showing promise for real-world application of these technologies. This work shows that autonomous function in C-IED robots would likely have a positive effect on EOD missions by reducing stress on EOD operators and enabling robots to regain connection with the operator autonomously.

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