Automatic Payload Deployment System

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ABSTRACT

The ability to precisely emplace stand-alone payloads in hostile territory has long been on the wish list of US warfighters. This type of activity is one of the main functions of special operation forces, often conducted at great danger. Such risk can be mitigated by transitioning the manual placement of payloads over to an automated placement mechanism by the use of the Automatic Payload Deployment System (APDS). Based on the Automatically Deployed Communication Relays (ADCR) system, which provides non-line-of-sight operation for unmanned ground vehicles by automatically dropping radio relays when needed, the APDS takes this concept a step further and allows for the delivery of a mixed variety of payloads. For example, payloads equipped with a camera and gas sensor in addition to a radio repeater, can be deployed in support of rescue operations of trapped miners. Battlefield applications may include delivering food, ammunition, and medical supplies to the warfighter. Covert operations may require the unmanned emplacement of a network of sensors for human-presence detection, before undertaking the mission. The APDS is well suited for these tasks. Demonstrations have been conducted using an iRobot PackBot EOD in delivering a variety of payloads, for which the performance and results will be discussed in this paper.

Keywords: robot, payload, delivery, sensor node, communications relay

1. INTRODUCTION

Unmanned systems are increasingly used in the battlefield for a variety of operations. Unmanned aerial vehicles have been used to carry out surveillance missions and occasionally engage in air-to-ground attacks when required. Unmanned ground vehicles (UGVs) have been primarily used in neutralizing improvised explosive devices (IEDs), but they have also been used as look-ahead and surveillance tools. Active research areas in mobility, mapping[1], exploration[1], human-robot-interaction, and advanced behaviors promise to further increase the role of robots in the battlefield environment. Robotic patient transport[2] and load carrying[2, 3] are other on-going research areas that will likely transition into the battlefield environment to assist the warfighter.

An area that has not been as heavily researched is robotic payload delivery and placement, which is the focus of this paper. A stand-alone system has been developed at the Space and Naval Warfare Systems Center (SSC) Pacific that enables UGVs carrying the Automatic Payload Deployment System (APDS) to carry and deploy a mixed variety of payloads to desired locations. This capability can have far reaching consequences. For example, UGVs can be used to run provisions into hostile environments to replenish food, ammunition, and medical supplies, eliminating the need of placing warfighters into harm's way. UGVs can be used in covert operations to deliver and emplace a network of sensors used for surveillance and detection. In fact, the Defense Advanced Research Projects Agency (DARPA) funded the Camouflaged Long Endurance Nano Sensors[4] (CLENS) program that has produced small sensor nodes for exactly this purpose, but they must be hand placed, which can be dangerous. The APDS is designed to alleviate this danger.

Remote nighttime surveillance is another area of interest. For example, covert delivery and placement of an infrared (IR) illuminator payload within proximity of a structure of interest can aid remote surveillance teams equipped with night vision goggles (NVGs). But a robotic payload delivery system need not only be used in the battlefield environment. The site of a mine collapse is another area where the APDS can assist in rescue operations. For example, delivering a payload equipped with a gas sensor can aid in gas analysis and data gathering activities to help rescue teams deal with unexpected events.

The APDS is fully capable of carrying and delivering a mixed variety of payloads, which is important when the robotic platform must be driven beyond line-of-sight (LOS) to deliver its payloads. In this case the payload delivery system can also be equipped with radio relays that automatically deploy to maintain the RF link with the base station, allowing it to continue on its path to deliver the payloads.

Section 2 of this paper will discuss the previous projects and systems on which the APDS is based, while section 3 will discuss the system in detail. Test results will be reported in section 4, and section 5 will provide a summary and current status of the system.

2. BACKGROUND

Two previous projects led to the development of the APDS, which will be discussed in chronological order here.

2.1 AMCR

Digital radios have overwhelmingly replaced older analog radio technologies due to improved link quality, reliability, and increased immunity to noise and multipath fading. Digital radios, however, usually operate at much higher frequencies, requiring that a RF LOS be maintained between the robot and its operator. This can severely limit the use of tactical robots, especially in urban environments.

A solution to the LOS issue was formulated under the DARPA-funded Autonomous Mobile Communication Relays[5] (AMCR) project (2002 – 2004), where radio relays were used to maintain the link with the control station as the tactical robot is driven beyond LOS. The radio relays were carried by small mobile robots, turning them into mobile relay nodes that followed the lead tactical robot in convoy fashion along its exploratory path. When the last mobile node in the convoy detected that the link to the base station was about to break it stopped and became a stationary relay as the remainder of the convoy continued. This process was repeated until all mobile relay nodes had stopped.

The heart of the AMCR system was the relay radio[6] carried by each robot. The network software onboard the relay radio, developed by BBN Technologies under a separate DARPA-funded effort, used the proactive Hazy Sighted Link State[7] (HSLS) routing protocol and a predictive filter. The output of this predictive filter was compared to a predetermined threshold, below which a mobile node would stop to maintain the link.

2.2 ADCR

As successful as the AMCR project was at maintain the RF communications link, it was not a practical system. Providing a tactical robot with non-line-of-sight (NLOS) operational capability will be expensive and come at a high logistical cost under the AMCR approach, due to the fact that the mobile node will be much more expensive than the RF relay it carries. Additionally, each mobile node must carry sensors to provide autonomous navigational capability required to follow the lead robot wherever it explores, increasing system cost. Logistically, transporting and setting up the convoy before undertaking a mission is completely unrealistic.

Therefore, a more practical and cost-effective solution was developed under the Automatically Deployed Communication Relays[8] (ADCR) project (2004 – 2008), funded by the Joint Ground Robotics Enterprise (JGRE). The relay radio previously developed under the AMCR project was transitioned over to the ADCR project and integrated into the ADCR system.

The ADCR system consists of two devices; the Deployer and the Relay Brick, shown in Figure 1. Up to six Relay Bricks are carried by the Deployer, which in turn is carried by the UGV (e.g. iRobot PackBot EOD shown in Figure 1) that requires NLOS operational capability. The UGV interfaces with the Deployer via an Ethernet connection. The Deployer and the Relay Bricks each contain an AMCR radio and are self powered.

Unlike the AMCR system, where each mobile node monitors the previous one-hop neighbor, under the ADCR system only the Deployer monitors the network. As the UGV moves away from the base station and the Deployer senses that the link is about to break it will automatically trigger the release of a Relay Brick. This process is identical to that used under the AMCR system to trigger the halting of a mobile node. The Deployer uses the same predictive filter along with a predetermined threshold setting to trigger the release of a Relay Brick. Once released, the Relay Brick self rights, extends its antenna, and becomes a static relay radio. This process is transparent to the operator and repeats itself automatically until all Relay Bricks have been spent.

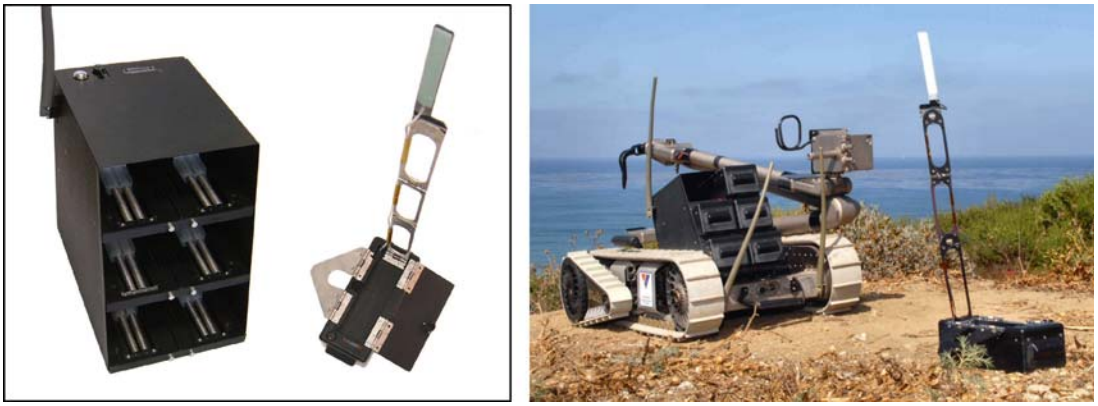

Figure 1. Left image shows the ADCR Deployer and Relay Brick. Right image shows the iRobot PackBot EOD carrying the Deployer containing five stowed Relay Bricks and one deployed with extended antenna.

In 2007, a test of the ADCR system was conducted along a NLOS path with various curvatures, hills and dips, for which the test results shown in Figure 2 depict the deployed locations of the Relay Bricks. The test was conducted under threshold levels of 40 and 45 indicated by the red discs and blue boxes, respectively (see reference 8 for more details). The threshold level represents the amount of power above the minimum required by the receiver to communicate at 1Mbps. For example, if the minimum power level is -94dBm and the threshold level is 45, than a Relay Brick will be deployed if the received power level of the Deployer falls below -49dBm. Generally speaking, lower threshold levels increase the distance between deployed Relay Bricks, but this is highly terrain and multipath dependent. Because the Relay Bricks did not support diversity antennas that can alleviate the effects of multipath, the system was especially vulnerable to premature deployment of Relay Bricks when relatively large local nulls were present.

Figure 2. Travel path with threshold set to 45 (blue box and line), threshold set to 40 (red disc and line), and PackBot without the ADCR system (orange line). Black triangle shows final location of the PackBot when the link with the base station is lost.

Various conference publications and successful demonstrations of the ADCR system generated a great deal of interest from the Naval EOD Technology Division (NAVEODTECHDIV) for use in providing extended range for EOD robots in defeating IEDs. Significant interest also arose from the Environmental Protection Agency (EPA) and the Mine Safety and Health Administration (MSHA). The EPA requires extended range and NLOS operation for their UGVs used to investigate hazardous spills. MSHA is interested in using robots to investigate mine collapses, requiring the robot to travel beyond LOS. Even NASA showed interest in investigating the use of the ADCR system for setting up a temporary network on the lunar surface. This degree of interest resulted in the signing of licensing agreements by three commercial entities for production and sale of the ADCR system.

As successful as the ADCR system is, it is not without its drawbacks. The roundtrip delay between the operator and the robot grows to impractical levels with the increasing number of deployed Relay Bricks. It is not uncommon to experience several seconds of delay measured from the time the robot is commanded to move forward until the change in the video is seen by the operator. This is unacceptable if the robot is to be used in IED defeat missions. The cause of the delay comes from the 802.11b radios being overwhelmed by the high-frame-rate video streams generated by the PackBot. Dropping the frame rate by half significantly reduces the roundtrip delay, but it is still above acceptable limits.

As discussed earlier the single antenna approach is more prone to multipath effects. The self-righting and antenna-lift mechanisms are mechanically complex and not well suited for use in a sandy environment, which sometimes prevents a Relay Brick from self-righting. The antenna mast height needed to be lowered to reduce weight and ensure proper extension, but low antenna height is undesirable as it reduces the Fresnel Zone clearance.

Because the ADCR system was designed specifically to provide extended range and NLOS operational capability, it lacks the flexibility to deploy non-Relay Brick payloads. This was evident in 2007 when a collaborative effort took place between SSC Pacific and CornerTurn LLC in an attempt to deploy the BOTDROPS[9] leave-behind surveillance sensors from the Deployer. Though successful, the lack of flexibility of the system rendered this effort non-trivial. The need for this capability became clear in 2008 based on feedback from Marines at Camp Pendleton, where the desire to deploy various other types of payloads was discussed. With all this in mind, a next-generation version of the system was designed from the ground up to address the drawbacks, improve upon the system, and provide a capability to deploy various types of payloads.

3. APDS

The design approach taken in the development of the Automatic Payload Deployment System (APDS) was to incorporate what worked well in the ADCR system and improve upon its limitations based on lessons learned, while providing built-in flexibility to allow support for various payload types. The work began by redefining the architecture to be inherently more generic and flexible. Then, a new APDS Deployer was designed along with a new Next Generation (NG) Relay Brick, but this time the Relay Brick represents only one of many different types of payloads supported by the APDS Deployer.

3.1 APDS architecture

The purpose of the ADCR system was quite specific: to deploy Relay Bricks. The system architecture was therefore limited and not flexible enough to handle other types of payloads. In contrast the APDS architecture is designed to rectify such limitations. Similar to the ADCR system, the APDS replaces the native wireless communications system of the UGV with the mesh network formed by the Deployer radio, Relay Bricks, and Base Station Unit (BSU) radio, shown in Figure 3. It is important to note that the native radios are not physically removed from the UGV and its controller, but merely deactivated (usually via software commands) to eliminate interference with the APDS radios. Should the Relay Bricks not be used, the wireless link formed by the Deployer radio and the BSU radio will be equivalent to the point-to-point topology of the native system.

The APDS architecture is designed with built-in flexibility to allow for the deployment of not only Relay Bricks but also other types of payloads by incorporating the following:

- Infrared Data Association (IrDA) transceivers – All payloads are required to have an IrDA transceiver to properly communicate with the Deployer when stowed.
- APDS communications protocol – This protocol defines a standard messaging system used to communicate with the APDS Deployer and its payloads.
- Support for deploying double-wide and triple-wide payloads – The APDS Deployer is able to accept payloads that are 2 or 3 times the width of a standard single-wide payload, providing more volume as required.

The integration of IrDA transceivers is a key feature of the APDS architecture. This allows complex information to be exchanged between the APDS Deployer and the stowed payloads. The NG Relay Bricks, for example, are “blank” radios that require the proper network parameters to fully boot. Instead of preprogramming an NG Relay Brick with fixed values, the Deployer simply provides them via the IrDA interface when the NG Relay Brick is stowed. Similarly, a payload reports its size (e.g. single-wide, double-wide, or triple-wide) to the Deployer via the IrDA interface so that the correct servo-motors are actuated for payload release.

Figure 3 shows the communications connections between various devices. The messages exchanged between these devices through the channels shown use the APDS communications protocol. The Ethernet and 802.11 protocols are unchanged and simply transport the APDS packets in their data frame.

Support for various sized payloads adds a great deal of flexibility in the types of payloads that can be deployed. For example, some supplies such as food and ammunition will not fit within a single-wide payload, but will fit within a double-wide or triple-wide payload.

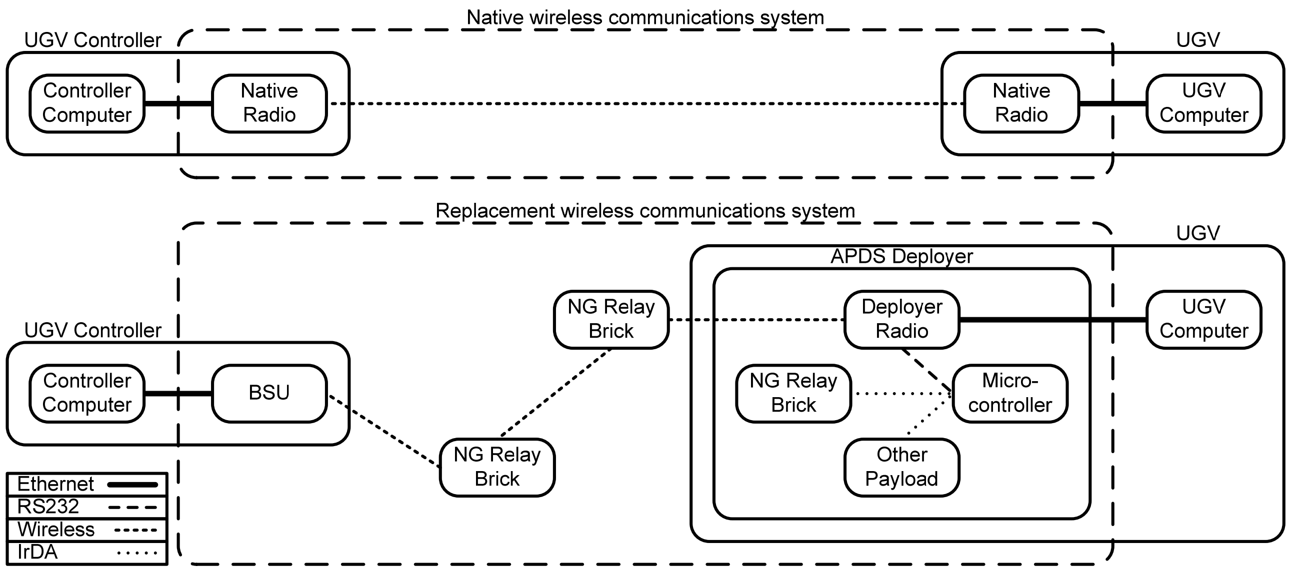

Figure 3. Illustration of the APDS replacing the native wireless system of the UGV. Data is relayed between the UGV and its controller via two deployed NG Relay Bricks. The APDS Deployer still carries one NG Relay Brick and one other payload type.

The purpose of the BSU (Figure 4) developed for the APDS is to provide a user interface that displays system status information, allows devices on the network to be remotely accessed for specific functions, and provides a manual deploy command for each payload.

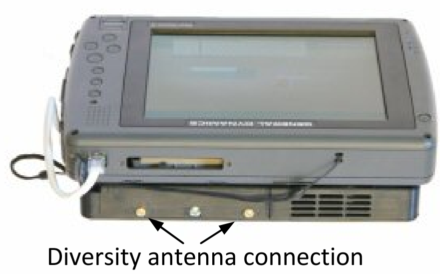

Figure 4. BSU showing tablet PC on top and radio enclosure mounted on the bottom.

Certain information, such as remaining battery capacity and link connectivity (for NG Relay Bricks), is automatically forwarded to the BSU. If the Deployer only carries Relay Bricks and such information is deemed non-critical, the BSU need not be used. The Deployer will automatically and without operator intervention deploy the Relay Bricks when and where needed to maintain the link. If the BSU is not used, the UGV controller must be interfaced to a radio identical to what resides in a Deployer and Relay Brick for proper functionality of the network.

If other types of payloads are used, such as those discussed in sections 3.5 and 3.6, then the BSU is required, in order to allow the operator to manually command the release of these payloads at the desired locations. Once deployed, the payloads can also be remotely accessed via the BSU.

The BSU hardware consists of a tablet PC interfaced to a mesh network radio, an Ethernet switch, a battery pack, and power regulation circuitry. Since UGVs usually have a dedicated control unit, the addition of the BSU will add to the required hardware at the base station. Development efforts, such as the Multi-robot Operator Control Unit[10] (MOCU), are underway to design a software-based common controller for unmanned systems. Installing MOCU on the BSU tablet PC will eliminate the need for the UGV controllers, which typically are much larger and heavier than the BSU.

3.2 APDS Deployer

Similar to the ADCR Deployer, the APDS Deployer consists of six chambers and an internal power source. They differ in that the chambers of the APDS Deployer are arranged in a 2x3 array as opposed to the 3x2 array of the ADCR Deployer. Additionally, the APDS Deployer can be externally powered while its battery pack is charging; a feature not available in the ADCR Deployer.

The APDS Deployer is volumetrically smaller than the ADCR Deployer by about 21%, and half its width, which allows it to occupy only one of the three payload bays of the iRobot PackBot. Unlike the ADCR Deployer, where a linear latching and launching mechanism are used, the APDS Deployer uses rotational mechanics, which is much less susceptible to jamming, thus improving system reliability. The constant-force rotational spring found in each chamber of the APDS Deployer has the added benefit of easing the loading of payloads. It is no longer necessary to push with increasing force to load a Relay Brick into the Deployer. When loaded, a rotational latch holds the payload in place until actuated by a servo-motor when the payload is released.

A significant addition to the APDS Deployer that is not found in the ADCR Deployer is an IrDA transceiver located at the end of each chamber. The IrDA transceiver provides bidirectional communications at a maximum rate of 115.2 Kbps between the Deployer and a payload.

The APDS Deployer contains a dedicated microcontroller (µC) board that includes all the circuitry needed to control the servo-motors, communicate with the radio through a RS-232 interface, manage communications with the payloads via the IrDA interface, charge the onboard Lithium-ion battery pack, and provide battery capacity via a fuel gauge chip.

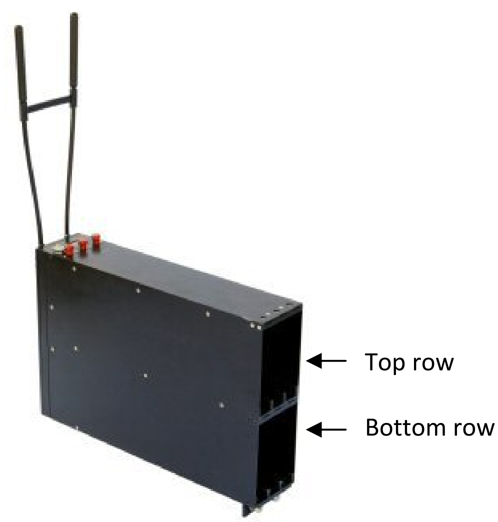

Figure 5. Each row of the APDS Deployer can support a single-wide, double-wide, or triple-wide payload.

3.3 Next Generation Relay Brick

The NG Relay Brick, shown in Figure 3, is a few inches longer than the ADCR Relay Brick, but it is about one-third its height and volumetrically less by about 26%. Another significant mechanical difference is in the self-righting and antenna-lift mechanism. As discussed earlier, the self-righting mechanism of the ADCR Relay Brick can sometimes fail on sand. Another issue is the wear and tear of the RF cable running along the mast as its spring-loaded linkages (see Figure 1) are folded and stowed in the antenna compartment for reuse. Additionally, under certain gusty conditions the base spring may not be strong enough to prevent wild flapping of the mast, which may cause link disruption. This problem is further magnified on a slope where the base spring must also fight against gravity.

The new design eliminates these issues. The NG Relay Brick is geometrically constrained to land face up or face down and not on the thin edges. Once deployed, it uses its onboard accelerometer to determine when it has come to rest, then rotates the antennas up until parallel to the gravity vector, regardless of the slope upon which it lands. (Note that the antennas will be parallel to the gravity vector only along a single axis if the NG Relay Brick is pitched around the axis that runs along the length of its body. Furthermore, the pitch angle must be within a certain limit before antennas are raised.) The servo-motor rotating the masts continuously reacts to external forces, such as a gust of wind, to keep the masts in the desired orientation. The RF cable running through the mast and the rotating shaft at the base is prevented from wear and tear as it is only twisted by a small amount, even when the antennas are rotated to the maximum limits.

The NG Relay Brick supports a custom µC board that is used to interface to the radio via an RS-232 connection, interface to an IrDA transceiver as required by the APDS architecture, and control a servo-motor to rotate the antenna masts based on the onboard accelerometer data. An internal Lithium-ion charging circuit is also included that only requires a low cost external voltage source to charge the battery pack. Additional power and serial ports are available to interface to other circuit boards for increased functionality. For instance, sensors can be placed between the antenna masts as an added benefit and powered from these ports, examples of which will be discussed in sections 3.5 and 3.6.

Figure 6. Next Generation Relay Brick with raised antennas that are 24” above ground.

3.4 Mesh network radio

The APDS Deployer and NG Relay Bricks have been upgraded with a high-data-rate 802.11g radio. As evident from the dual antenna masts shown in Figures 5 and 6, diversity antennas are supported, which help lessen the effects of multipath interference. The radio hardware is composed of a single-board-computer interfaced to a miniPCI 802.11g radio via an interconnect board developed by Rajant Corp.

BBN Technologies has ported the network software developed under AMCR to the new radio hardware. The aspect of the code that runs the mesh network is proprietary and cannot be modified; however, the portion of the code that deals with the radio boot sequence, network monitor, relay release trigger, and microcontroller communications can be modified. The in-house modifications of these portions of the code, listed below, have greatly enhanced the performance of the network and deployment system:

- Rapid availability of a relay for deployment – When the APDS Deployer is first activated, all available NG Relay Bricks are powered on and fully booted. The transmitters of all but one of the Relay Bricks are deactivated however, to prevent overdriving of receivers due to close proximity of all the radios. When a Relay Brick is deployed, the next Relay Brick in the Deployer becomes available for deployment in approximately 3 seconds. This is an improvement of over an order of magnitude as compared to the ADCR system in which the Relay Bricks took about 40 seconds to boot up. This type of delay is unacceptable when operating in complex urban environments where the robot may be required to deploy multiple relays in rapid succession.

- Implementation of a moving average (MA) filter – The output of the BBN predictive filter is compared to a preset threshold, below which the release of a Relay Brick is triggered. Sharp variations or spikes due to local RF nulls can cause the output data to drop below the threshold, prematurely releasing a Relay Brick. The MA filter eliminates this problem and results in more consistent performance in the deployed locations of NG Relay Bricks when the results of several test trials are compared.
- Deployer payload monitoring – The Deployer is constantly monitoring its chambers to detect the insertion and removal of payloads and their current status. This is used for verification that a payload is functioning and ready for deployment.
- Payload fault detection – The Deployer monitors for faults in the startup status of Relay Bricks and attempts to correct any issues that arise. The goal is to always have one Relay Brick ready for deployment at all times. If a Relay Brick fails at any stage of the startup process the Deployer chooses a new Relay Brick for deployment and attempts to reset the offending relay.

3.5 Camera Node

The Camera Node is a new payload type that was developed to demonstrate the flexibility of the APDS Deployer and payload designs. It is essentially a double-wide Relay Brick with a camera and supporting electronics used to transmit the video over the wireless link to the BSU. The height of an existing NG Relay Brick was doubled to provide extra volume needed to contain a commercial-off-the-shelf video server, voltage regulators, and an in-house developed Ethernet switch. An automotive-grade Sony camera with a field-of-view of greater than 180º vertical and 360º horizontal was mounted between the antenna masts (see Figure 7). Power is provided to the camera and supporting electronics via the extra power ports of the NG Relay Brick µC board.

Figure 7. Camera Node showing Sony camera mounted between the antenna masts, pointing up.

Because the camera node contains a relay radio, the Deployer can automatically deploy it as if it is a NG Relay Brick. On the other hand, since the camera node reports its type and size to the Deployer, the Deployer can be programmed to ignore the camera node as a possible candidate for a relay, allowing the operator to release the camera node at a strategic location through a manual deploy command sent from the BSU. The video stream displayed on the BSU can be initiated in several ways; 1) from the initial power up sequence while it is stowed in the Deployer, providing a rear-view perspective from the UGV, 2) after the brick has been deployed and the antennas have been raised, 3) remotely triggered by the operator via the BSU, and 4) triggered based on vibration sensed by the accelerometer.

3.6 Infrared Illuminator Node

The near-infrared (IR) Illuminator Node, another payload type based on the NG Relay Brick, is a single-wide payload that supports an IR LED package mounted between the antenna masts (see Figure 8). The package contains an array of five high-power wide-field-of-view LEDs on each side. Although each array can be independently activated as required, activating both arrays can provide a fairly uniform illumination of the surrounding area. With both sides active, a total of approximately 10W is consumed, providing a radiant flux of about 3W. The LEDs can be activated automatically after deployment or remotely at a later time by the operator via the BSU. The node allows covert remote night-time observation of critical locations or high-value targets.

Figure 8. Illuminator node showing IR LED package housing an array of five LED clusters on both sides.

4. TEST RESULTS

4.1 Outdoor NLOS Test

This test was conducted using an iRobot PackBot EOD carrying the APDS Deployer (Figure 9) along the same NLOS path used in the ADCR testing (see Figure 2). The objective of this test was to drive the PackBot continuously along this road until beyond the range of the last deployed relay, then measure the distance and obtain a subjective measure of performance from the operator's point of view in terms of link reliability and latency. The range and performance was then compared to the ADCR system.

Figure 9. EOD PackBot carrying the APDS Deployer containing three stowed NG Relay Bricks and one deployed with raised antennas.

As a purely subjective measurement, link reliability is defined as the tendency for the link between the BSU and the robot to remain connected as perceived by the operator. The latency is defined as the operator's perceived delay from the time a command is issued until the corresponding response is seen on the video feedback. As an example, under the ADCR system, link reliability began to decline and latency began to grow with increased number of deployed Relay Bricks. A latency of several seconds was observed with all six Relay Bricks deployed. Cutting the frame rate of the two video streams of the PackBot by half (to 15fps) improved link reliability but the roundtrip latency did not drop below about 1 second, which is an unacceptable delay. With these settings the PackBot travelled approximately 540m.

With the upgraded radios the PackBot travelled about 550m. Even though the travel distance is roughly the same as compared to the ADCR test, the link reliability and latency have been significantly improved. The roundtrip latency, for example, is unnoticeable even when the video streams are set to 30fps and six NG Relay Bricks are deployed. A significant improvement in link reliability allowed the operator to continuously drive the PackBot from the starting position until the final locations, under both the "normal" and "fast" speed modes set by the PackBot controller. The deployed locations of the NG Relay Bricks (with a threshold setting of 45) for both speed modes are shown in Figure 10.

Figure 10. Travel path of PackBot showing deployed locations of NG Relay Bricks (RB1 to RB6) and final position of PackBot (triangle) with a threshold setting of 45. Blue disks and red boxes indicate deployed locations under "normal" and "fast" speed modes, respectively.

4.2 Mixed Indoor/Outdoor NLOS Test

The system was tested in a WWII bunker constructed of 12-foot thick steel-reinforced walls that highly attenuate radio signals. The BSU was set up outside the structure and the operator continuously controlled the PackBot as it was driven through the bunker and around the large hill, completing the loop. The deployed locations of the NG Relay Bricks are shown in Figure 11. More NG Relay Bricks are deployed inside the structure due to the severe NLOS nature of the path.

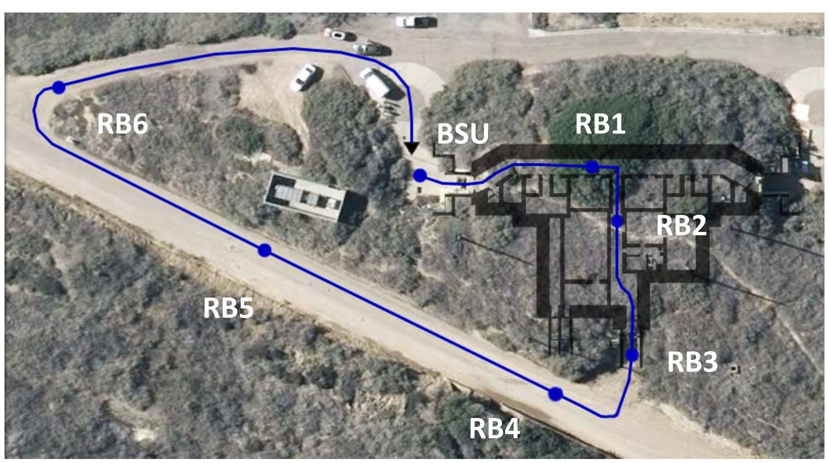

Figure 11. Travel path of the PackBot carrying the APDS system showing deployed locations of the NG Relay Bricks through the WWII bunker and around the hill, with threshold level set to 45. Black triangle at top center shows the final location of the PackBot.

4.3 Camera Node Test

The capability of deploying a mixed variety of payloads was tested by loading the APDS Deployer with four NG Relay Bricks and one Camera Node (shown in Figure 7). The Camera Node is a double-wide payload taking up two of the three available chambers on the bottom row. This allowed the APDS Deployer to be loaded with four single-wide NG Relay Bricks; three on the top row and one on the bottom.

The system was tested along the same NLOS path discussed in section 4.1. As the PackBot was driven along this path, the NG Relay Bricks were automatically deployed at locations that are in very close proximity to the locations of RB1 to RB4. At the approximate location of RB5 the operator commanded the release of the Camera Node from the BSU. The node deployed, its antennas rose, and video began streaming to the BSU through the network. At this point the network was handling three video streams; two streams from the PackBot and one from the Camera Node. The PackBot was still under the control of the operator, although there was a slight increase in latency due to the increase in data traffic.

Figure 12 shows sample images from a captured video sequence received from the Camera Node. The left image shows a rear view when the Camera Node is stowed on the PackBot. A newly deployed NG Relay Brick can be seen. The right image shows the view from the Camera Node when it has been deployed and its antennas raised. Even though the camera is pointing up, its wide field-of-view allows objects lower than the height of the camera to be seen, such as the PackBot as it drives away.

Figure 12. Screenshots of the video received from the Camera Node when stowed (left image) and when deployed (right image).

4.4 Illuminator Node Test

To examine the effectiveness of the Illuminator Node in a dark environment, a test was conducted inside the WWII bunker with all the doors shut and the interior lights turned off. With the aid of the onboard headlights, the operator situated outside the structure drove the PackBot inside and into a designated room. Here the progress of the PackBot was tracked by an individual with the aid of a pair of Gen-III AN/PVS-7C NVGs. Once inside the room, the operator commanded the release of the Illuminator Node. The operator then drove the PackBot out of the room to eliminate any source of light (e.g., visible LEDs on PackBot and Deployer) from contributing to the light of the Illuminator Node, with result is shown in Figure 13. The photos come from individual frames from a video camera looking through the NVGs.

Figure 13. Before (left image) and after (center and right) images of the illuminated room. Center image shows direct view of Illuminator Node. Right image shows a better representation when not directly viewing the IR LED source.

This test demonstrated the significant difference in illumination when looking through the Gen-III NVGs, which are currently fielded units. Without the Illuminator node the NVGs essentially see nothing as shown in the left image of Figure 13, whereas with the node the room is effectively illuminated. When looking directly at the source of light, the iris of the video camera auto-adjusts and therefore the background looks darker than it appears when looking through the NVGs. The left image is a better representation of what is seen through the NVGs when looking away from the source of light.

5. CONCLUSION

The evolutionary path of the APDS began from the AMCR project where the operational range of a lead robot was increased via mobile relay nodes following in convoy fashion. These mobile relay nodes stopped automatically to maintain the link with the base station. Although the project was successful, it was impractical for use in the field. Hence, the AMCR system evolved into the more practical ADCR system, where the mobile relay nodes were replaced with the static Relay Bricks carried by the tactical robot and deployed when needed to maintain the link. The concept of deploying Relay Bricks naturally led to deploying other types of payloads from a robotic platform. The need for this idea was reinforced by Marines at Camp Pendleton, who provided ideas on various other payload types as well as the demonstration conducted to deploy the BOTDROPS from the ADCR Deployer.

The development of a new Deployer began under the APDS project to provide a robotic platform the capability of carrying and deploying various types of payloads. To demonstrate this capability three different payloads were developed; the NG Relay Brick, the Camera Node, and the Illuminator Node. The NG Relay Brick was designed to improve upon the earlier Relay Brick developed under the ADCR system by using a higher-bandwidth radio with diversity antenna support. System tests confirm significant improvement in link reliability and reduction in roundtrip latency, which is critical in urban missions. The Camera Node was designed to demonstrate the capability of the mesh network to handle an additional video stream along with the existing two video streams transmitted from the robotic platform, as well as the ability of the APDS Deployer to handle a larger payload size. The Illuminator node is yet another payload type designed to illuminate an area of interest for remote observation via NVGs. The BSU designed under the APDS project provides the operator the capability to observe the status of the system when the robot is out of sight, and to command the release of payloads (such as the Camera Node and the Illuminator Node) at desired locations.

Based on positive feedback received from NAVEODTECHDIV regarding the performance of the APDS Deployer and the NG Relay Bricks in providing NLOS operational capability to a robotic platform, efforts are underway to further improve the radio hardware and network software for system evaluation by the users in theater. Our current work consists of developing a modular system that simplifies payload design and introduces further flexibility by allowing the system to be used on other platforms, manned or unmanned.

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