A MODULAR DESIGN APPROACH FOR THE AUTOMATIC PAYLOAD DEPLOYMENT SYSTEM

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The ability to emplace stand-alone payloads in hostile territory has long been on the wish list of US warfighters. This type of activity is often conducted at great danger. We have developed a capability for automated payload placement from unmanned ground vehicles (UGVs) using the Automatic Payload Deployment System (APDS) that can greatly reduce this danger. For example, payloads equipped with a radio repeater and a camera can be deployed to support the securing of tunnels, caves, and other previously cleared areas. Example 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, or infrared illuminators at high-interest locations. The APDS architecture is extremely modular, allowing third-party developers to produce these capabilities, and more, for a wide variety of unmanned vehicles. APDS design and demonstrations will be discussed in this paper.

INTRODUCTION

The use of robotics in the battlefield continues to grow. Unmanned aerial vehicles (UAVs) have been used to carry out surveillance missions and occasionally engage in air-to-ground attacks. 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. The role of UGVs will become more diverse as research in areas such as mapping[1], exploration, human-robot-interaction[2], and collaborative behaviors such as the UAV refueling system[3], eventually transition to the battlefield environment.

Payload delivery and placement is another area that will contribute to the ever increasing role of robotics. The Space and Naval Warfare (SPAWAR) Systems Center (SSC) Pacific has developed this capability under the Automatic Payload Deployment System[4] (APDS) project. A UGV carrying the APDS can deliver a mixed variety of payloads to desired locations. For example, a UGV can run provisions into hostile environments to replenish food, ammunition, and medical supplies, thereby eliminating the need of placing warfighters in harm's way. In covert operations a UGV can deliver a network of surveillance sensors to a desired location, which may lie beyond the radio line-of-sight (LOS) needed to control the UGV. In this case, additionally carrying radio repeaters that automatically deploy can extend the range of the UGV en route to the location where the sensors are to be emplaced.

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Now in its second iteration, APDS has been redesigned to be extremely modular. The modular architecture allows APDS to easily interface with a wide variety of UGV platforms and eases the development efforts necessary for payloads designed by third-parties. The Background section briefly summarizes the previous systems that have led to the current APDS. The Modular APDS section defines the hardware and software architectures of the current system. The System Verification section will discuss testing and demonstrations.

BACKGROUND

The predecessor of APDS was the Automatically Deployed Communication Relays[5] (ADCR) system, developed to provide non-line-of-sight (NLOS) operational capability to any UGV capable of communicating over Internet Protocol (IP) and interfacing to the system via an Ethernet connection. The ADCR system essentially replaces the native radios of the UGV and its associated controller (in most instances they are merely deactivated through software and not physically replaced). The ADCR Deployer can carry up to six radio repeaters called Relay Bricks, which are automatically deployed when and where needed to maintain the communications link with the control station of the UGV. Once deployed the Relay Bricks self-right and extend the antenna to maintain connectivity with the control station. This system has been demonstrated onboard an iRobot PackBot EOD (See Figure 1) with great success, which led to the licensing of the technology to three commercial companies.

Figure 1. ADCR system onboard iRobot PackBot EOD showing Deployer with five stowed Relay Bricks and one deployed with extended antenna.

During ADCR system demonstrations, military users pointed out several other useful payloads that could be deployed by the system. Therefore, development of APDS began specifically to add the capability of deploying a mixed variety of payloads along with the ability to deploy Relay Bricks. Therefore, a new APDS architecture was developed to address this capability. This led to the requirement for the Deployer and its stowed payloads to communicate bi-directionally, which was not possible with the ADCR system. The messages exchanged between the Deployer and its payloads can be as simple as reporting the size and type of the payload in each bay of the Deployer or as complex as network parameters necessary for successful boot up of Relay Bricks.

A new APDS Deployer was designed based on the new architecture. To satisfy the bi-directional communications requirement, each bay in the Deployer contains an Infrared Data Association (IrDA) transceiver, which is used to communicate with the associated payload in half-duplex mode. Because APDS was also designed to improve upon the network performance of the ADCR system, the onboard radio of the APDS Deployer was upgraded. This upgrade significantly improved the network reliability and roundtrip latency. The payload ejection mechanism was simplified for improved reliability. The width was reduced to half that of the ADCR Deployer, which allowed it to occupy only one of the three bays onboard the PackBot EOD (see Figure 2).

A new Next Generation (NG) Relay Brick was also developed as part of the improvement upon the ADCR Relay Brick. The NG Relay Brick was designed to work with the APDS Deployer so it also supports an IrDA interface and an upgraded radio. The design of the antenna lift mechanism was simplified to increase reliability. The active antenna lift mechanism ensures that the antennas will be vertical regardless of the slope and surface material on which the NG Relay Brick lands after deployment.

Figure 2. The APDS Deployer onboard iRobot PackBot EOD with three stowed NG Relay Bricks and one deployed with extended antenna.

In addition to the NG Relay Brick, two other payloads were developed to demonstrate the ability of the APDS Deployer in handling a mixed variety of payloads. The illuminator node (Figure 3) is a payload that supports an array of near-infrared LEDs, mounted between the antenna masts, providing approximately uniform illumination of the surrounding area. The LEDs can be activated remotely allowing covert night-time observation of critical areas or high-value targets. The camera node (Figure 3) is a double-wide payload (i.e. twice the width of an NG Relay Brick) and supports a camera with a field-of-view of greater than 180° vertical and 360° horizontal. The camera is mounted between the antenna masts and is oriented pointing up allowing observation of the horizon via the streaming video.

The control station of the PackBot EOD requires the same radio hardware found in the APDS Deployer and NG Relay Bricks in order for APDS to properly form a mesh network between the UGV and its controller. The Base Station Unit (BSU) was developed for this purpose as well as to provide status information reported by the APDS Deployer and the various payloads. Manual deploy commands can also be sent from the BSU to eject payloads at strategic locations.

Figure 3. The illuminator node (left) and camera node (right).

MODULAR APDS

Part of the motivation for developing APDS was to improve upon the NLOS operational capability offered by the ADCR system. Similar to the ADCR system, APDS replaces the native wireless communications system of the UGV and its controller (see Figure 4).

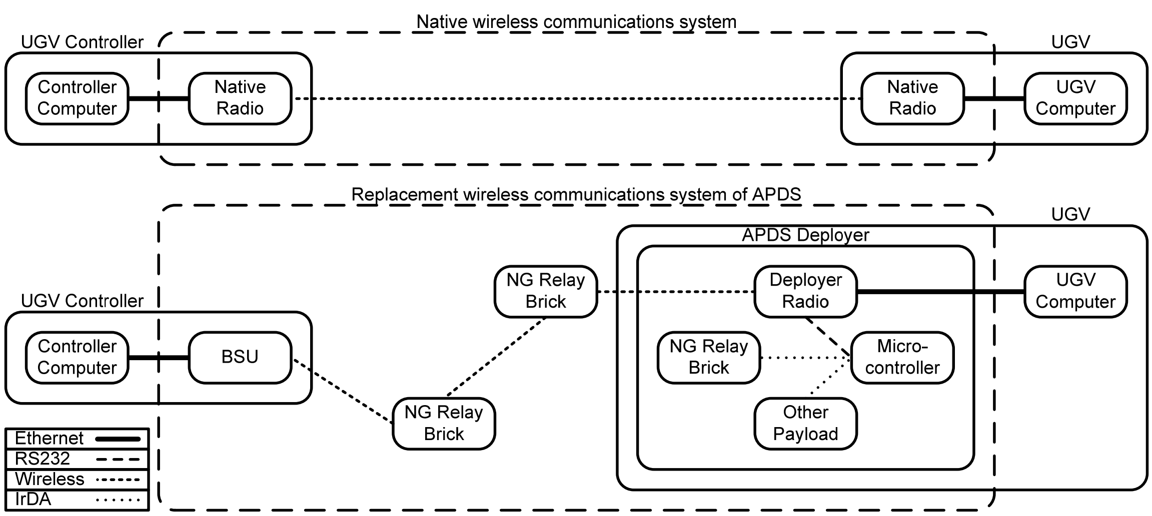

Figure 4. Illustration of the APDS wireless replacement system. Data is relayed between the UGV and the BSU via the deployed NG Relay Bricks.

In order to form the mesh network necessary in providing NLOS operational capability for the UGV, the APDS Deployer must carry onboard the same radio found in the NG Relay Brick and the BSU. An Ethernet interface is also required to connect the UGV controller to the BSU and the UGV to the APDS Deployer. These necessities and the requirement to support various payloads pose three issues.

Issue 1: Not all UGVs that could benefit from APDS communicate over IP.

For example, the Foster Miller Talon, a widely used UGV for counter-IED missions in theater, uses an analog radio to transmit video to its controller and a secondary, non-IP based radio to link Command and Control (C2) data, preventing the Talon from interfacing with the APDS Deployer. This is not an issue for the PackBot, which communicates over IP and provides an external Ethernet interface.

Issue 2: The APDS communications system may not be suitable for the mission at hand.

In some cases, the APDS operating frequency may be inappropriate or the network performance may be inadequate. In fact, the native communications system of the UGV may be more appropriate. For these cases, APDS can still be used for other non-networking tasks, such as emplacing surveillance sensors in a specific location, running provisions into hostile environments, or delivering a payload like the illuminator node to a desired area. These types of tasks, however, have no need for the onboard APDS Deployer radio and so its occupied real estate and cost can be eliminated.

Issue 3: Every payload, no matter how simple, must communicate over IrDA.

Because the APDS architecture requires each payload to communicate with the APDS Deployer, every payload must include the necessary IrDA electronics and support the mechanical interface needed for latching and ensuring alignment of the IrDA windows in stow mode. These requirements complicate the electronic and mechanical design of the payloads.

To solve the issues described above, a modular approach to the APDS design is taken. Under the Modular APDS (APDS-M) architecture the Deployer and the payloads are each divided into two separate sections, as shown in Figure 5. The Deployer is now composed of the Deployer Module (DM) and the Deployer Module Adapter (DMA), which communicate over the Deployer Module Interface (DM-I). Similarly, the payload is composed of the Payload Carrier (PC) and the Payload Carrier Adapter (PCA), which communicate over the Payload Carrier Interface (PC-I). The PCA and the DM communicate over the IrDA interface when the payload is stowed within the DM.

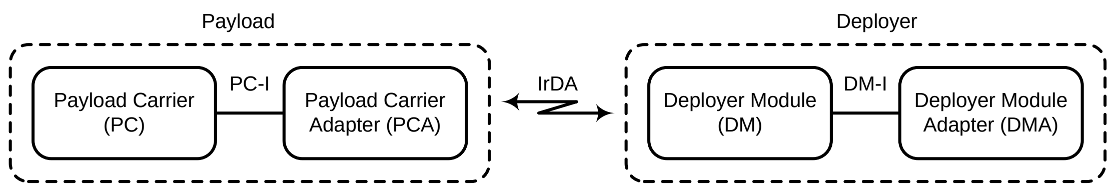

Figure 5. Separate sections of the payload and Deployer under the Modular APDS architecture.

The purpose for separating the APDS Deployer into two parts is to place all essential functions of the Deployer into the DM and all other functions (including functions specific to the UGV hosting the system) into the DMA. The DM functions include releasing payloads, managing communications with the payloads over IrDA, and displaying battery capacity and other status information for the user on the LCD screen. Therefore, the DM hardware consists of the individual bays where the payloads are stowed, the release motors, IrDA transceivers, battery pack, fuel gauge, LCD, and the microcontroller that manages all the functions and communicates with the DMA.

The purpose for separating the payload into two parts is to place all functions related to communicating and interfacing mechanically to the Deployer into the PCA and the main function of the payload into the PC. Quite literally, the PCA is an adapter that allows any type and size of payload to interface with the DM.

This separation of functions is best illustrated by referring to Figure 6, which is an equivalent representation of the APDS architecture (see Figure 4) under the APDS-M architecture. The APDS Deployer radio notifies the microcontroller when a Relay Brick is to be released. This is determined automatically based on signal strength information or by receiving a manual deploy command from the BSU. In either case the microcontroller takes the necessary steps in releasing one of the Relay Bricks. Because the function of the APDS Deployer radio is specific to the wireless communications system and does not contribute to the essential functions of the DM, it must be placed in the DMA under the APDS-M architecture.

The illustration of Figure 6 also shows that a PCA is attached to each PC regardless of the type and size, to provide a common means of interfacing to the DM.

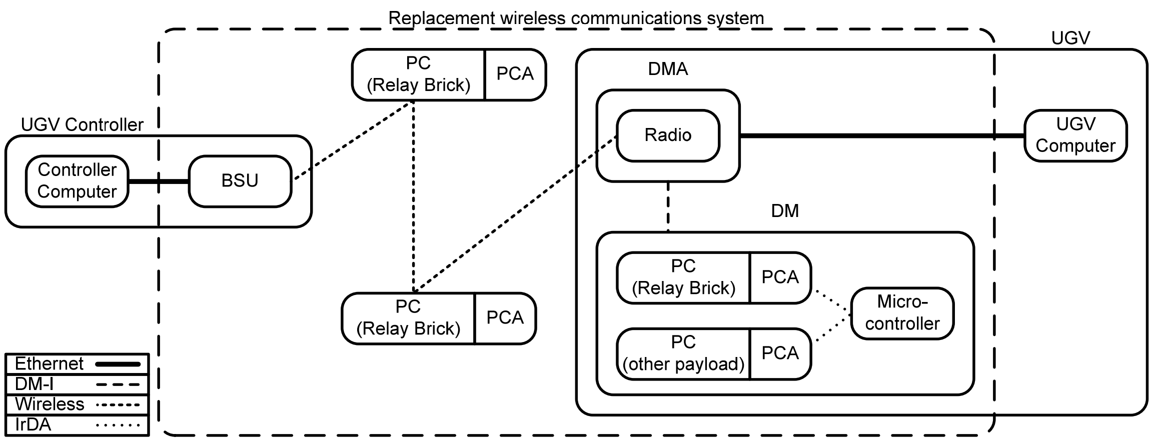

Figure 6. Equivalent representation of the NLOS operational capability offered under the Modular APDS architecture.

The APDS-M architecture addresses issues 1, 2 and 3 discussed earlier. It is easy to see that the DMA can allow a greater variety of UGVs to benefit from APDS-M. For example, a Talon-DMA can be developed that converts the non-IP based C2 and video data into IP traffic that can be relayed via Relay Brick payloads providing NLOS operational capability for the Talon. The traffic would have to be converted back into the original non-IP C2 and video data on the controller side, which would require additional hardware. However, ongoing development of common software controllers, such as the Multi-robot Operator Control Unit[6] (MOCU) will render the original controller of the UGV obsolete and there will not be any need for additional converter hardware. Only a radio identical to the radios inside the Talon-DMA and Relay Brick payloads will be required to interface to a MOCU-based controller. Finally, the modular payload approach will ease development of payloads since third-party developers will not have to be concerned with the required IrDA electronics, IrDA window, and mechanical interface to the Deployer.

Deployer Module and Adapter

The DMA and DM prototypes are shown in Figure 7. The DM is identical to that shown in Figure 2 but with the radio removed and placed in the DMA. The external face of the DMA shows the UGV interface connector. The internal face shows the DM-I connector. For this prototype the DM-I interface contains RS232, power-in, and power-out pins. The DMA radio communicates with the DM microcontroller via the RS232 connection. Since the DM is internally powered and the DMA is not, the DM provides power to the DMA radio via the power-out pins. The power-in pins are used to charge the internal battery pack of the DM.

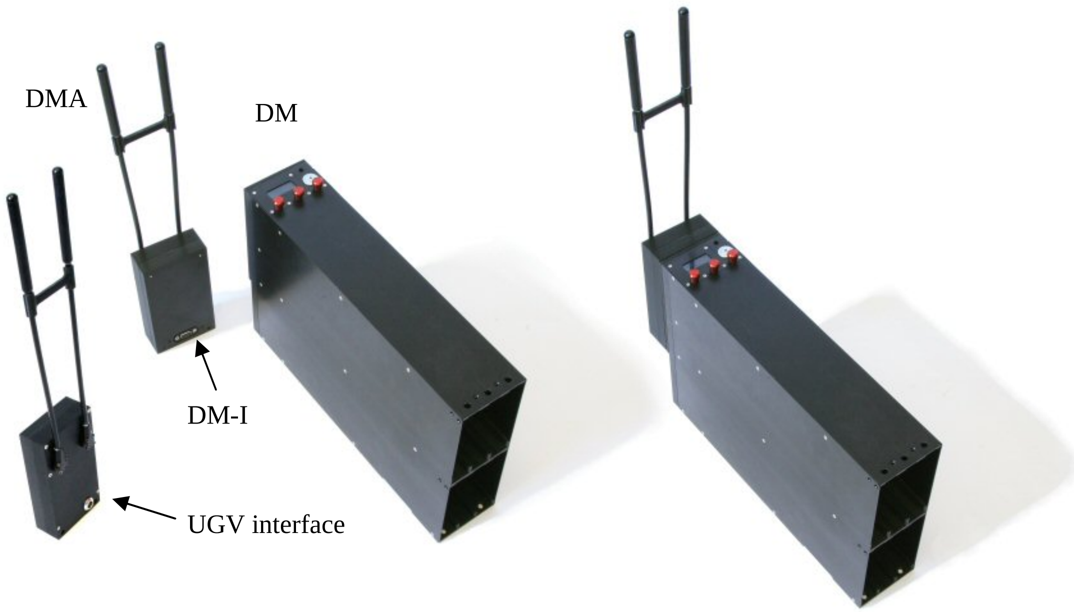

Figure 7. DM and PackBot-DMA prototypes

The DMA can be made to be UGV-specific as well as function-specific. For example, the DMA shown in Figure 7 is PackBot-specific and its function is to provide NLOS operational capability with the use of Relay Brick payloads. If a Talon requires NLOS operational capability the DMA can contain the required electronics to convert the video and C2 data to IP traffic. If NLOS operational capability is not required but there is a need to robotically deliver other types of payloads the DMA may simply hold a bank of battery packs to extend the operational period of the host UGV as well as the DM. The objective is to swap the DMA based on mission requirements and the UGV utilized.

Payload Carrier and Adapter

The PCA and PC are shown in Figure 8. The internal face of the PCA shows the PC-I. The external face shows the IrDA window and latch catch. Two PC examples are shown to illustrate that different size payloads are supported by the DM. The triple-wide and the single-wide payloads are both empty containers that can carry food, medical supplies, extra batteries, or whatever else is required for delivery. The length of the empty payload may be increased to allow for more space and is limited only by practicality.

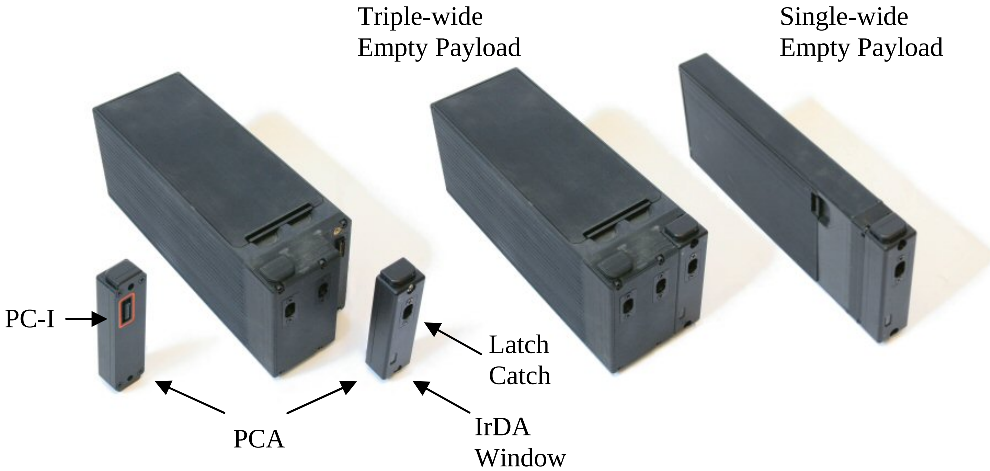

Figure 8. PCA and examples of triple-wide and single-wide payload prototypes.

The PCA electrically interfaces with the PC via the PC-I connection and mechanically mounts via two screws. This allows the payload to interface with the DM. If another payload type is required the PCA can simply be removed and attached to the new PC. The PC-I contains power-in, TTL serial, and many IO pins. Since the PCA is not internally powered it requires power from the PC. The PCA has a wide input voltage range of 3V to 30V, typical current consumption of 60mA at peak activity and 43μA in sleep mode. The PCA is typically in sleep mode when the payload is stowed and always in sleep mode after deployment. The sleep mode allows the PC to last many months without recharging if the only current drain comes from the PCA. These specifications help to ease the design requirements of the PC.

The TTL serial and IO lines help to support a variety of payload types. For the empty payload the IO lines provide the size and type information by simply pulling low a specific set of lines. Another payload type, like the illuminator node, may require activation just prior to deployment. Again the IO lines can be used to not only read the size and type of the payload but also to activate the IR LED array just prior to payload ejection. Finally, more sophisticated payloads like the Relay Brick can use the TTL serial lines to provide size and type information and receive network parameters, such as service set identification (SSID) and operating channel. Whatever the payload size and type, the internal electrical requirements for interfacing with the PCA are simply a battery and the PC-I mating connector.

Communications Architecture

All of the devices under the APDS-M architecture communicate with one another by using the APDS Internal Communications (AIC) protocol. The DMA may translate the AIC protocol to something the host UGV can understand, like Ethernet. The AIC protocol is based on the S-expression structure and was chosen because of reduced memory requirements, faster parsing, and ease of implementation.

The APDS-M architecture employs a master-slave scheme. The master devices are the DMA, UGV, and BSU. The slave devices are the DM, PCA, and PC. The purpose of a master device is to manage the payloads stowed within the DM. This requires learning the size and type of each payload, providing any required information to a payload, obtaining status information by polling each payload, and commanding their release. Communication with a slave device is always initiated at the master level and is either generated onboard the DMA (e.g. command the release of a Relay Brick payload) or comes from the UGV or BSU (e.g. request remaining DM battery capacity, command manual deployment of supply payload, etc.). Regardless of which master device generates the command, it is always forwarded to the target slave device via the DMA. When a master device is to communicate with the PC, the DM and the PCA simply act as relays for the command and the corresponding acknowledgement. The communications flow is shown in Figure 9.

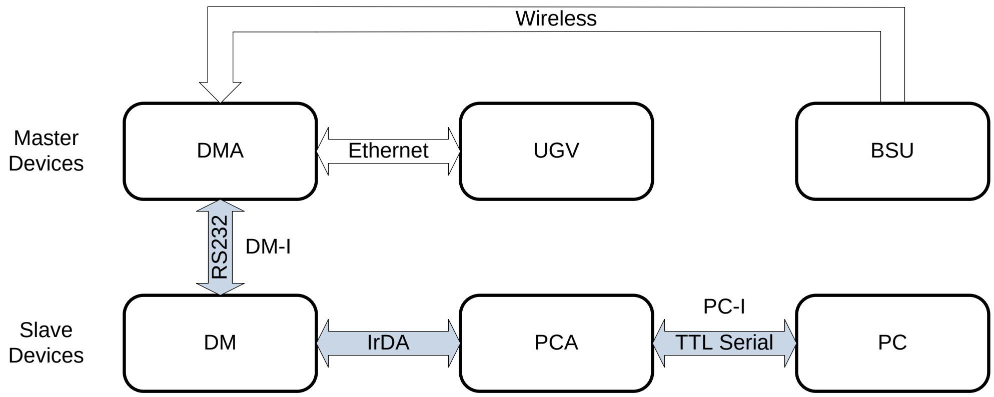

Figure 9. Communications flow. The Ethernet interface is subject to change as required by the UGV. Shaded arrows signify communications using the AIC protocol.

Payload Delivery Tasks

As discussed under Issue 2, the native wireless communications system of the UGV may be more appropriate for a mission where payloads must still be delivered to a desired area. In this case the payloads can be deployed in one of four ways:

<u>Method 1: Manually deployed by operator.</u>

This requires the UGV controller to interface with the BSU and forward any messages from the BSU to the UGV. The UGV then forwards the manual deploy command to the DMA, which is then forwarded to the DM microcontroller for deployment of the payload.

<u>Method 2: Automatically deployed by UGV.</u>

The decision to deploy a payload can come from the UGV. For example, the UGV can be programmed with GPS location data where a set of surveillance payloads are to be deployed. Upon arrival at a specified location the UGV forwards a deploy command to the DMA.

<u>Method 3: Automatically deployed by DMA.</u>

The decision to deploy a payload can come from the DMA. Suppose the mission is to explore a building. The UGV is sent to investigate each room but if the room is too dark then it may be difficult to see what is inside. In this case the Deployer can be loaded with several illuminator nodes and the DMA equipped with a sort of light sensor. When an area is too dark the DMA can command the release of an illuminator node that is activated just prior to deployment.

<u>Method 4: Automatically deployed based on payload data</u>

Suppose the mission is to continuously monitor a mine for harmful gasses by the use of gas-sensor payloads delivered by a UGV. The payloads can be polled to determine if they have detected any gasses. If so, the DMA will issue a deploy command to release the payload for continued monitoring of the area.

SYSTEM VERIFICATION

Demonstrations of APDS-M were conducted onboard a PackBot EOD. The Deployer was loaded with a triple-wide empty payload (shown in Figure 8) and a few NG Relay Bricks. As of this writing a Relay Brick payload utilizing the PCA has not yet been developed, so a NG Relay Brick was substituted. This is a valid substitution since the NG Relay Brick communicates using the AIC protocol and already employs all the required IrDA circuitry.

With a mixed variety of payloads loaded into the Deployer the PackBot was teleoperated away from the base station. The NG Relay Bricks were automatically deployed to maintain the link. At a desired location a manual deploy command for the triple-wide empty payload was issued from the BSU. This command was received by the Deployer and the empty payload ejected.

This simple demonstration validates the communications flow of Figure 9, the AIC protocol, the modular payload concept, and the ability to handle mixed size and type payloads by the Deployer.

CONCLUSION

The ADCR system evolved into APDS to not only enhance the wireless communications system used in providing NLOS operational capability to the host UGV but also to allow robotic delivery of a mixed variety of payloads. Because APDS is based on the ADCR system the host UGV must be capable of communicating over IP to properly interface with the APDS Deployer. Furthermore, the operating frequency and network performance of the current APDS may not be suitable for some missions. For these reasons the APDS-M architecture was developed, which is no longer constrained to a specific UGV interface and wireless system. This allows UGVs that do not communicate over IP to still attain NLOS operational capability. Or the UGV can use the Deployer to deliver a mixed variety of payloads to desired locations. Furthermore, the modular payload approach under the APDS-M architecture eases the design requirements for third-party payload developers.

This modular architecture is currently being used to develop a wireless communications system for NLOS operational capability that is suitable for operation in theater.

DEDICATION

We dedicate this work to our good friend and colleague, Mike Wills, for his extraordinary contribution in the field of unmanned systems and personal generosity to us all at the Unmanned Systems Branch at SSC Pacific. He will be missed and always remembered.

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