Collaborative Unmanned Operations for Maritime Security

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Overview

Lockheed Martin Advanced Technology Laboratories (ATL), in conjunction with Lockheed Martin Maritime Systems and Sensors and Lockheed Martin Aeronautics Advanced Development Programs, performed a set of experiments in cooperation with the U.S. Navy involving collaborative, unmanned surface, and air vehicle mission execution. Our multi-domain, collaborative research focused on increasing unmanned vehicles' ability to be useful partners in maritime security by effectively using intelligent onboard behaviors, collaborative control, and human-system interfacing in environments that support limited communications.

Problem

Maritime security operations offer great promise for the use of unmanned systems resulting in significant force multiplication and attendant manpower reduction by using teams of unmanned vehicles with a small number of human controller/commanders in a collaborative execution environment. To realize this concept, two major technical problems must be overcome. First, the command and control interfaces must allow a human commander to stay at the commanding level, i.e., to provide team-based commands and supervise team execution, monitoring the progress of the overall mission with the capability, but not the necessity, to receive detailed information about individual vehicle operation. This interface should also permit sensor or ISR information to be presented in the context of mission objectives without regard to the individual platform or sensor that is producing the information. The second major problem is complement of the first: the unmanned components of such a collaborative manned/unmanned team must be able to receive and operate on commands at the mission level without human intervention. They must distribute the goals, plan and execute them, and replan as necessary within the parameters of the mission without additional guidance from the commander. As part of the execution, each platform must perceive its own world, respond as necessary, and provide relevant information back to the human operator. Subsidiary to these two overriding technical problems, there are additional technical problems in perception and communications that must be addressed to enable the use of such an concept.

Lockheed Martin has established an experimentation-based research program to provide the ability to command—rather than drive or fly—unmanned assets from remote user locations and transition control between distributed users. Combined with advanced onboard autonomy, the technology allows high-level, complex missions to be executed without human intervention while allowing full tactical command and control. The current experimentation schedule involves air-, ground-, and sea-based resources for intelligence and surveillance of riverine port areas and potential interdiction areas. This paper recounts lessons learned from several internal and external experiments and applies these lessons to the maritime security operations involving the efficient use of unmanned assets to increase the persistence and timely focused coverage needed by the modern warfighter. This paper presents lessons learned from these experiments related to collaborative command and control of unmanned surface operations.

The goal of this research is the collaborative command and control (C2) of heterogeneous unmanned vehicles and unattended sensors by small teams of operators while also extending onboard self-control to non-deterministic collaboration with other vehicles for more independent USV/UAV/UUV (i.e., UxV) operations. Our work has produced technology supporting the ability for a single operator to command multiple unmanned assets from within a variety of environments and seamlessly transition control to distributed users to share control responsibilities or tactically manipulate information on the go. This supports an operational concept in which the teams of operators perform oversight of UxV operation at an adaptable level of autonomy, giving the UxVs mission-related commands by designating patrol areas, requesting imagery or video of objects of interest, and specifying rules of behavior if unexpected events occur. This research strives to improve the effectiveness of controlling unmanned systems while avoiding the workload problems that teleoperation and other low-level UxV control paradigms incur.

The research focuses on exploring collaborative C2 motivated by the need to reduce the number of operators required to control teams of unmanned vehicles while increasing the tactical utility of the "set" of UxVs to the warrior. Our objective is to explore the issues related to graceful handoff of UxV control, including the effective communication of mission parameters, objectives, and commands, among multiple responsible operators. Increases in vehicle autonomy permit a shift in command mode from direct control (i.e., teleoperation or waypoint selection) to one in which an operator can issue mission-relevant, team-level commands such as a "take a picture of X," letting the mission management system decide which asset to task based on a variety of criteria such as vehicle workload, capability, and availability. Collaborative C2 mechanisms support effective mission management without the need for dedicated vehicle operators at stove-piped control stations. This collaborative C2 environment allows operators to specify and share high-level tasks and mission parameters (such as areas of interest or "no-drive" zones) and provides comprehensive situational assessment of the battlespace as well as vehicle and mission status. The C2 environment coordinates displays and command interfaces across multiple C2 nodes and supports the seamless handoff of command for one or groups of vehicles among operators. This approach differs from current operations in which control of one or more unmanned vehicles is tied to a specific console without the ability to handoff control to reduce operator workload or support organic control from the local environment. Our experiments used Navy operators to assist in the development and evaluation of new concepts of operations made possible by advances in vehicle autonomy and collaborative C2 mechanisms, ultimately influencing future unmanned systems operations.

Building Blocks

Unmanned Surface Vehicle

In 2007, ATL worked on ground-based unmanned systems as part of the DARPA Urban Challenge event. This provided a background for the integration of multiple onboard sensors for intelligent navigation in complex urban environments. This included virtual maps of the environment, rules of the road, and the management of stated and implied operational behaviors that could be performed during the six-hour mission. This technology provided the background for surface vehicle operations. Our vehicle design adapted to the nautical domain by substituting onboard LIDAR systems with commercial radar technology, while the programmed rules of the road were replaced with the rules of the waterway.

Early in 2008, the team procured an inexpensive jetboat (Figure 1). This was quickly actuated to provide computer controlled steering and throttle in the matter of weeks. A low-cost commercial radar system was interfaced to provide raw radar data, automated track identification, and secondary heading/weather information. The radar data was used for tracking information and as primary sensor for obstacle avoidance. Additional pose data was made available from GPS and inertial sensors. This was combined on a single laptop (or embedded) computer system. Onboard the computer was a marine version of the ground-based system. The system provided standard (joint architecture for unmanned systems) messages to the steering and throttle assemblies. In addition, rules of the road, including additional safety areas, were put into the overall computer decision process. This architecture became the backbone of the interface between the user(s) elsewhere and the boat operations. The boat was equipped for optionally-manned operations, including safety emergency stops and override methods to ensure safe marine operations under varied circumstances. The navigation system was robust enough to continue missions outside of communications range and provided feedback once the system returned to report status to the mission operator.

In mid-2008, a second commercial vehicle was outfitted similarly so the vessels could perform collaborative missions. This further pushes the user interface into that of a mission commander, not that of a single system user controller. The user provides high-level mission goals to the team, and the user interface and onboard systems break out the appropriate submission and collaboration necessary to complete the mission, including retasking if the original asset is unable to complete the mission.

Figure 1. Commercial-off-the-shelf jetboat (with modifications)

Unmanned Air Vehicle

The Lockheed Martin Desert Hawk (Figure 2) is a representative UAV that involves a modular hardware design that is electric driven (with more than an hour duration) and normally controlled from a dedicated UAV control station. The control station to UAV interface was tapped and updated to provide mission breakouts from the centralized command station. This removed the need for an additional UAV control station. During an experiment in August, a single user was able to task the UAV and USV as a team to provide imagery and status of various items of interest.

Figure 2. Desert Hawk UAV

Network
A commercial-of-the-shelf network was chosen that could provide a 5-10 mile range of operations for the UAV and USV. The primary focus of this research was not the network. However, it could have easily been a bottleneck that limits the testing and operation of unmanned assets. An adhoc communications network provided communications between the center command environment, the unmanned assets, and additional users that could make requests and/ or retask the unmanned system's missions. The network also supported shared video streams from the unmanned assets. Other network approaches are planned to evaluate, for instance, mesh approaches to extend beyond line-of-sight capabilities.

Command Environment
To meet the needs for operator mission-level command and control, we used the Intelligent Control and Autonomous Replanning of Unmanned Systems (ICARUS) system. ICARUS is a component-based autonomous mission planning and execution system originally developed by Lockheed Martin under the Office of Naval Research's Intelligent Autonomy Future Naval Capability program [1] and extended for the purposes of our experiments. ICARUS integrates technologies for collaborative mission planning and dynamic replanning, replan assessment, alert management, situational awareness, and sensor fusion, accessed via a mixed-initiative operator interface to form a distributed software environment applicable to multiple unmanned system domains. ICARUS can simultaneously support the effective control of multiple heterogeneous unmanned systems from a single control station in a manner that reduces operator workload compared to other fielded approaches. ICARUS control station-based capabilities include an operator interface (Figure 3) that provides a unique mixed-initiative interaction to support mission oversight by UxV operators. The ICARUS interface design results from multiple cycles of evaluation and review efforts with Navy operators and subject matter experts, undertaken to improve usability and effectiveness for the operational context.

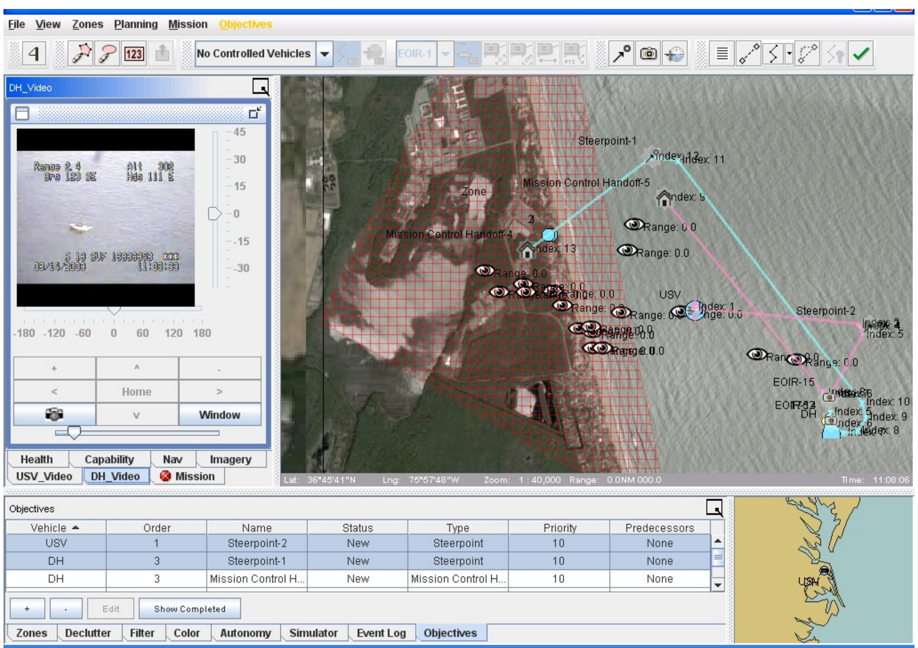

Figure 3. ICARUS Command and Control Interface

ICARUS supports mission planning as well as dynamic mission replanning. The ICARUS interface allows a commander to enter mission-level objectives for the team of vehicles, and the underlying planning functions allocate goals to individual vehicles and plan routes for the vehicles, which are then distributed to the individual vehicles via a communications link. During the execution of the mission, the ICARUS system monitors environmental changes, unmanned system health status, and mission updates to detect and respond to unexpected events that require new plan generation to address. ICARUS enacts a contingency escalation process that formulates dynamic responses to the operational context at the lowest (closest to the vehicle system) level possible. This creates a property of maximized plan preservation that supports operator mission oversight by reducing the confusion that can occur from large-scale, autonomously-generated plan changes. This escalation process trades plan optimization for greater plan consistency and operator situational awareness. Through this process, ICARUS supports maximized unmanned system mission effectiveness while simultaneously helping to reduce operator workload.

Figure 3 shows the ICARUS interface displaying UxV missions as planned; with the USV mission shown in red and the UAV mission in blue. The upper left corner provides access to video feeds from the assets. As planned object of interest targets are captured through still pictures, they are presented on the user interface as an icon, allowing the operator to concentrate on positions and information provided about overall goal states (bottom of the screen) without being overloaded by images and video. A rich assortment of declutter and filtering options allows the operator to maintain a context-relevant, streamlined view of operations without being overwhelmed by extraneous information.

Multiple interacting ICARUS command stations were used to combine missions and retask the team during execution. Portable control stations were used by vehicle-based or dismounted warfighters to insert new mission objectives as unanticipated items of interest were detected throughout the exercises. This provided interesting timesharing of resources transparent to the users as they carried out their individual mission tasks. At no point did any of the users have a joystick to control the UAV or USV assets. Everything was reduced to a point-and-click/tap environment aimed at the mission-level performance.

Architecture Overview

The goal of the architecture was to reduce the user interfaces to provide collaboration of users on the edge of the network. That is, users that do not have the advantage of large internet connections where data and video can be sent from many sources and those that are highly mobile such that multi-day setup of equipment and operations is not realistic. Representative vehicles were used during the experiments to provide an environment for experimentation (Figure 4). Overlaid on the components are sample capabilities of each of the stations. The command operations center was a laptop (without a joystick). Additional equipment was used to allow multiple operators' viewing of the environment and provide a level of reachback for other users that are not located at the experiment. New entities and objects of interest can enter the environment and call the services that are available during the time that they can communicate with the overall environment. The adhoc network capabilities allowed the users to communicate with the USV when out of range of the command center. This did not interfere with the original mission and goals expected by the command center when the USV is not able to communicate. Multiple command centers were tested including mobile, land-based environments and shipboard testing of command coordination and task allocation. This allows this architecture to be used indifferently by shipboard team members as well as those enroute on land to collaborate and share information about the environment.

Figure 4. Operational Architecture connections

Reachback
During exercises, it was desirable for observers not located at the experiment site to watch the experiment progress without being able to interfere with the exercise. The command environment is capable of being located distant from the exercise depending on the network communications between the observer and the exercise. The team did not explore additional compression techniques to provide long haul interactive command environments across the internet. However, it was desired that remote users see and understand what is happening. Figure 5 shows a screenshot of the internet-based reachback based on the Fast Connectivity for Coalitions and Agents Program (FastC2AP), which marshaled and displayed data within a Google Earth™ development environment [2]. UAV (green) and USV (blue) tracks are shown on the display with the normal zoom, rotate and click capabilities built into the environment. Images taken during the execution become small camera icons allowing remote viewing of

Figure 5. Google Earth™-based Web Reachback via FastC2AP

intelligence data from the UAV/USV. Additional onboard information such as vehicle health and internal status was also available through the reachback system. An integrated automatic identification system (AIS) receiver provided tracks of all commercial registered traffic in the area, allowing a better situational picture of what is happening during the exercise.

Experimentation Results

Two experiments were performed during the spring/summer of 2008. The operational area for the first experiment is shown in Figure 6. The operational area for the second experiment is shown in the screen shots in Figure 3 and Figure 5. The first experiment provided a typical narrow river based operation with heavy density of commercial and recreational vessels during the operation. Several mission points were used for examination. This included buildings along the shore, passing ships, and natural features in the environment. Due to the location of the tactical

Figure 6. Experiment #1 Testing Area

operations center (TOC), network communications were not possible in the southern end of the operations area. USV operations were then performed (buoy monitoring and general transit) outside of any feedback to the user. The user would no longer see updated information from the USV once outside of the communications range. As the USV returned to communications range, updated information would be reflected in the command environment. Simulated UAV/USVs supplemented the live testing of the single USV in the environment.

For the second experiment, a beach and open ocean environment was grated by the USN to test the configuration. Additional fast moving target boats were brought into the environment, in addition to commercial traffic and limited recreational boats (including a few kayaks). A target-rich environment was available around the command center for monitoring of activities for the analyzing of situational awareness. Navy warfighters assisted with the operations and worked to evaluate the effectiveness of the user interfaces and overall concept of operations for the use of multiple unmanned assets as a team to perform various missions in cooperation with competing requests. Multiple days of experimentation yielded multiple configurations and collaboration opportunities between the command environment, the mobile command center and several individuals with handheld versions all requesting and providing information with the USV and UAVs.

A third experiment, located in a more riverine operation area, is planned for the early fall 2008 that will provide multiple live USV operations in cooperation with unattended sensors and dismounted soldiers operating on land and as part of shipboard boarding parties. The USVs will provide collaborative imagery based on command center and boarding party requests. Unattended sensors will provide additional tasking for USVs to provide information about the environment before the user informed of the situation. A sample scenario is shown in Figure 7. This utilizes the infrastructure from the previous experiments to expand the reach into more of maritime security application. Figure 7 demonstrates boarding party support via USVs and unattended sensors in the riverine environment.

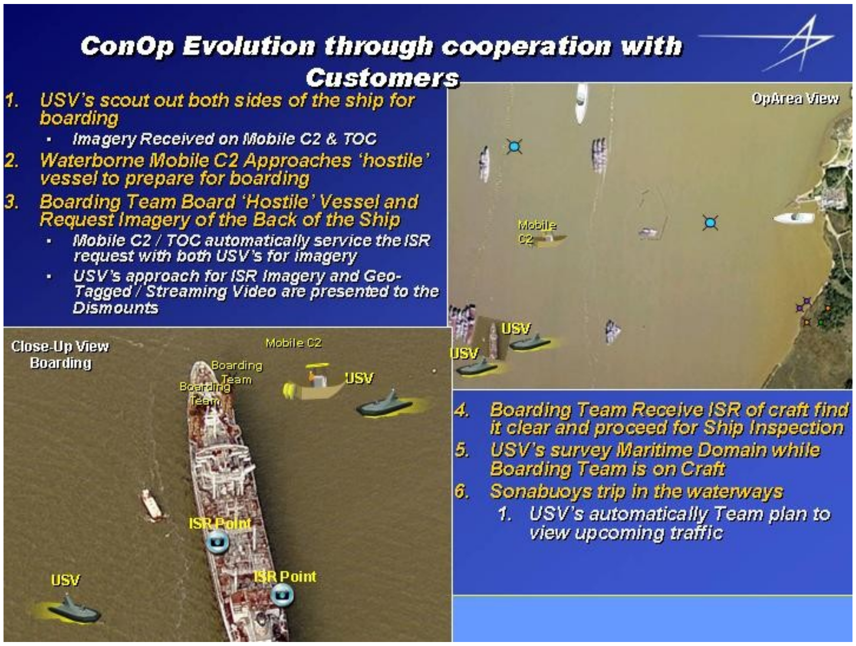

Figure 7. Experiment #3 Concept of Operations

Relevance to Naval Community

There were two focus areas of this applied research: collaborative command environments and USV/UAV autonomy. Collaborative environments that reduce the manpower for operations increase the ability for additional staff to focus on mission elements, not turning the vehicle to a new heading. Increased USV autonomy without the ability for users to understand what is happening is not of much use. These research areas go hand-in-hand in providing a multi-user, multi-vehicle, mission-centric environment. The USV provided a capable vehicle to provide onboard obstacle avoidance and mission execution. This could empower a group of unmanned assets that can be deployed and utilized during times of fleet operations, disaster relief and coordinated security operations. The users in the experiments only needed mouse point-and-click operations to provide missions to the team. The low-level controls were handled through the software applications. In optionally manned vehicles, this intelligent autopilot capability can provide shipboard users the ability to monitor the overall mission, while the movement and sensor packages are coordinated across the entire mission spectrum. This also allows natural extensions like sensor sharing and correlation to increase the reliability of information provided to the mission commanders. Sensor failures can be overcome by using sensors on other vehicles, including triangulation and position information made available to vehicles without that inherent capability. Though providing a more complete mission environment, tied into areas such as AIS commercial traffic, the system users can perform complex security and monitoring missions without inherent knowledge of waterway rules and boat operations.

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