Unmanned Vehicle Mission-Level Autonomy Applications to the Littoral Combat Ship

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*T*he use of unmanned vehicles in warfare is apparent across all military services, including the surface Navy. The reduction in personnel and the increase in mission capability provide the surface Navy with the potential to accomplish missions at reduced cost. The littoral combat ship, with its mission package concept, is well suited to take advantage of the capabilities of unmanned vehicles in the surface fleet. Application of mission-level autonomy to surface Navy missions offers the Navy great potential to realize the full capabilities of the littoral combat ship.

INTRODUCTION

The littoral combat ship (LCS) is the Navy's newest ship and in many ways represents a departure from traditional surface combatant concepts. Previous classes of surface combatants such as the *Ticonderoga*-class cruisers and the *Arleigh Burke* (DDG-51)-class destroyers are multimission platforms, meaning that they carry a wide variety of weapons systems and are capable of performing more than one mission simultaneously or switching between missions with little or no reconfiguration. DDG-51-class destroyers each displace 9000 tons and have one 5-inch gun, 96 missile tubes, torpedoes, air and surface search radars, towed-array and bow-mounted sonar, 20-mm close-in weapons systems, and a crew of 280.[1] The LCS platforms, referred to as seaframes, carry very little inherent mission capability other than basic self-defense. Each seaframe has one 57-mm gun, one 30-mm gun, and rolling airframe missiles for self-defense and carries a core crew of only 40 sailors.[2] The layout of the systems on each platform is detailed in Figs. 1 and 2.

Beyond these systems, specialized equipment and personnel called "mission packages" must be loaded onto the seaframe to provide additional capability for performance of one primary mission. Switching to another mission requires mission packages to be changed. Given the LCS seaframe's small size of less than 3000 tons and its limited crew size, the Navy has chosen to provide the majority of capability in mine countermeasures (MCM) and antisubmarine warfare mission packages through helicopters and unmanned vehicles.[2] Reliance on unmanned vehicles, combined with the radically reduced crew size, presents some constraints; unmanned vehicles that operate autonomously can greatly increase the capability to accomplish mission objectives under these constraints.

Most unmanned vehicles have some level of autonomy—that is, they have some software on board that performs functions without human interaction. The National Research Council defines three types of autonomy, as follows:

"There are three types of autonomous vehicle systems: scripted, supervised, and intelligent. Scripted autonomous systems use a preplanned script with embedded physical models to accomplish the intended mission objective. Examples of these systems include smart bombs and guided weapons. Such systems can be generally described as "point, fire, and forget" systems that have no human interaction after they are deployed. Supervised autonomous systems automate some or all of the functions of planning, sensing, monitoring, and networking to carry out the activities associated with an autonomous vehicle, while using the cognitive abilities of human operators via a communications link to make decisions, perceive the meaning of sensor data, diagnose problems, and collaborate with other systems. Most conventional autonomous vehicles and their controlling elements form an autonomous system that fall into this category. Intelligent autonomous systems use intelligent autonomy technology to embed attributes of human intelligence in the software of autonomous vehicles and their controlling elements. This intelligent autonomy software does the following: (1) it makes decisions, given a set of (generally automated) planned options; (2) it perceives and interprets the meaning of sensed information; (3) it diagnoses vehicle, system, or mission-level problems detected through monitoring; and (4) it collaborates with other systems using communications networks and protocols."[3]

In this article, we refer to the autonomy to assist in accomplishing LCS missions as "mission-level autonomy."

Mission-level autonomy is intelligent autonomy that enables unmanned vehicles to collaborate and autonomously execute a mission. The operator gives the vehicles a mission, and the vehicles execute the mission. Advances in artificial-intelligence technology have enabled the development of systems that can adapt to changing variables. Some complex naval missions require adaptation that exceeds the capability of existing technology. Other missions can be defined within parameters narrow enough to allow execution by autonomous technologies. LCS currently has three mission packages under development: MCM, surface warfare (SUW), and anti-submarine warfare. Proof-of-concept prototypes of the MCM and SUW mission packages have been successfully deployed.[2]

APPLICATIONS TO MCM

In mine warfare, mines are used to deny an adversary access to an area of the sea. MCM seek to protect sea lines of communication by making mine-containing areas of the ocean safe for vessels to maneuver.[4] MCM objectives are accomplished by sweeping an area that might contain mines and identifying mine-like objects. Based on the information collected during the sweep, Q-routes are then established through the area. Q-routes are preplanned shipping lanes in waters that potentially contain mines, and these routes are used to minimize the area the MCM commander has to keep clear of mines to provide safe passage for friendly shipping. Q-routes are monitored and kept clear of mines.

The LCS MCM concept is to use distributed offboard systems to accomplish mission objectives. This approach involves the use of one type of unmanned surface vehicle, the Fire Scout vertical take-off and landing tactical unmanned aerial vehicle (UAV), and two types of unmanned undersea vehicles (UUVs).[4] The Office of Naval Research's Mine Warfare Future Naval Capability program supports unmanned vehicle autonomy science and technology development by APL and collaborating
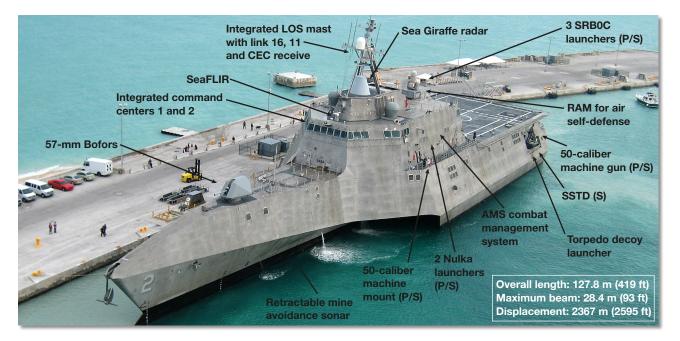

Figure 1. Preliminary core configuration of mission and combat systems (General Dynamics design; other options under review during preliminary design). P/S, Port/starboard. (U.S. Navy photo by Naval Air Crewman 2nd Class Nicholas Kontodiakos.)
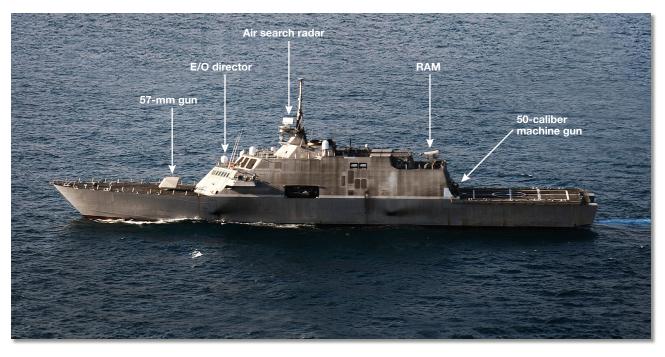
Figure 2. Outline of weapon system placement (Lockheed Martin design). (U.S. Navy photo by Mass Communication 2nd Class Aaron Burden/Released.) [ERRATUM: The originally published figure and caption have been replaced with corrected versions.]

organizations. APL's contributions include the development and demonstration of autonomy logic that is applicable to sweeping for mines and identifying mine-like objects.[5] Demonstration of this technology showed that applying autonomy can reduce the time required to identify mine-like objects from days to hours by eliminating the need for unmanned vehicles to return to the host platform for operators to conduct data analysis.[5] Instead, the data analysis is pushed forward and is done autonomously on the unmanned vehicles. By pushing even more analysis and decision logic forward to the unmanned vehicles, workload can be shifted from human operators to hardware and software. The role of the operator then becomes more focused on planning the mission and evaluating its effectiveness. Once the mission is planned, it is assigned to the autonomous vehicles for execution. The operators monitor the execution of the mission but do not actively control the vehicles. Potential applications of mission-level autonomy include searching for and identifying mine-like objects in a specific area and neutralizing mines in an area.

APL has demonstrated that when assigning a route or area to be searched, a specific search pattern can be assigned to an unmanned surface vehicle.[5] The unmanned surface vehicle detects mine-like objects during its search and communicates the locations of those objects to UUVs loitering on the surface. It has been demonstrated that once these locations are given, the UUVs can autonomously develop routes to visit each mine-like object and collect data to determine whether it is a mine.[5] Once the search and data collection are complete, all vehicles would return to the LCS seaframe

where operators could interpret the information, develop Q-routes, and designate which mines need to be neutralized. Once the mines to be neutralized have been identified, the UUVs would be deployed again to perform the neutralization. Once the Q-routes are established, the autonomous vehicles could conduct the periodic monitoring as well. The routes could be programmed into the vehicles, and the vehicles would autonomously sweep the routes and identify any new mine-like objects that need to be identified and removed.

APPLICATIONS TO SUW

SUW is a broad mission area that refers to any action taken against vessels on the surface of the sea. Searching the surface, maintaining a tactical track picture of surface vessels, engaging small boats within the visual horizon, and engaging large vessels to ranges over the horizon all fall within this mission area. The LCS is not intended to perform the full range of SUW operations, but it does have capability in each of these areas. When integrated into the LCS, the SUW package augments the ship's capability to conduct surface surveillance using offboard sensors and to engage surface threats both in the line of sight and over the horizon. These components include electro-optical/infrared sensors mounted on a vertical take-off and landing tactical UAV to provide over-the-horizon detection, 30-mm guns to kill close-in targets, and the MH-60R armed helicopter for surveillance and attack missions.[6]

SUW can benefit from autonomy in the same way that MCM can—by pushing data analysis and decision

tasks forward to autonomous vehicles instead of requiring those tasks to be performed on the LCS seaframe. As an example, autonomy can be used for airborne searching and tracking of surface targets over the horizon. The LCS concept already includes sensors deployed on UAVs for over-the-horizon detection. Autonomy could be used on the UAVs to build and maintain a track picture and to coordinate among UAVs to hand off and maintain tracks as they pass from the field of view of one vehicle to that of another. As operators classify tracks as friendly or hostile, the UAVs can take action based on preplanned doctrine.

Another complex area of SUW in which autonomy could provide great assistance is the protection of assets from small boats in congested waters such as shipping lanes.[6] Although the environment is complex and the tracks are numerous, the rules of engagement are clear. The initial forms of engagement in these situations are nonlethal, typically visual and audible warnings to deter suspicious vessels. In this environment, autonomous vehicles could patrol a defined perimeter and, without the need for operator involvement, deter vessels that violate the perimeter. Vessels that are not deterred would be passed along to the operators for prosecution using the seaframe's weapons or manned air assets. By pushing the control and nonlethal engagement functions to the autonomous vehicles, the operator's workload would become focused on only those vessels that pose a potential threat and not the majority of the surface traffic.

FUTURE APPLICATIONS OF AUTONOMY

As stated previously, most unmanned vehicles have some level of autonomy. To date, the military implementation of vehicle autonomy has been limited to surveillance and nonlethal engagements. Autonomous vehicles do not conduct lethal engagements without a human in the loop to make the decision. The military has also developed autonomous weapons, generally referred to as smart weapons. Global positioning satellite (GPS)-guided missiles and artillery rounds, torpedoes, and cruise missiles use autonomy to deliver ordnance precisely on target.[3] With the deployment of weapons on unmanned vehicles and the addition of data links and cameras to smart weapons, the lines between autonomous weapons and autonomous vehicles are becoming increasingly blurred. In the future, these two technologies are expected to merge and produce a family of autonomous combat vehicles capable of autonomous search and engagement. There is an established precedent for autonomous engagement. It has been used in situations such as air defense, which requires reaction too fast for human operators to perform, and in situations when communication with operators is not possible (such as when undersea).

This future paradigm has many advantages. Because autonomy logic resides on the vehicle and not the host platform, upgrades to the weapon systems can be made with less impact to the seaframe. The use of common control and communications standards will allow vehicles deployed from one platform to collaborate and communicate with vehicles deployed from other locations. By pushing search and engagement forward to the vehicle, the operator is freed from one task that is tedious and time consuming and one task that is dangerous. Vigilance tasks required for searching and tracking consume large amounts of operator time. Engagement puts pilots and vehicle operators at risk. By implementing autonomous search and engagement, the operator's role becomes focused on identifying which tracks are threats and need to be neutralized. Implementing this paradigm is important for the future of naval operations. As crew sizes shrink, the importance and value of each crewmember to the execution of the mission increases. Autonomy provides methods for simultaneously reducing the workload and reducing the risk of loss of each crewmember.

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