# Autonomous Underwater Vehicles (AUV'S)
# A Look at Coast Guard Needs to Close Performance Gaps and Enhance Current Mission Performance.

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**Abstract:**

The Coast Guard has declared its intentions to exploit emerging technologies as it moves toward its vision of the Coast Guard in the year 2020 (*Coast Guard 2020)*. Attaining this vision requires appropriate integration of technology as part of the solution that will close gaps in the mission performance. For this to happen, the Coast Guard must make concerted and deliberate efforts to exploit technology, moving effectively from ideation through development, acquisition, implementation and life cycle support. The role of the Research and Development (R&D) Center in exploiting technology is to anticipate future needs, to create ideas, and insert new technologies. Autonomous Underwater Vehicles (AUV's) as a platform for various sensors is one such technology with the potential to close the gaps in Coast Guard performance as well as enhancing current mission capabilities. This paper addresses the needs of the Coast Guard for specific mission areas.

The variety and unique nature of Coast Guard missions adds a high degree of complexity to technological solutions. In a world where high complexity often equals high cost, development does not always follow a path that resolves the issues encountered by the Coast Guard. By working to articulate the needs of the service now, we hope to influence the AUV's development in such a way that Coast Guard operational needs can

eventually be met by off the shelf items. Several areas have shown that AUV developments are already taking this path. Complexity issues are being addressed through the ever-reducing costs of computing ability, modularization, sensor packaging, communication networking, and miniaturization.

**Background:**

The mission areas addressed are;

- Fisheries Management – Enforcement of fishing restrictions with a 24/7 omnipresence and a capability of detecting and identifying violators.
- Port Safety and Security - environmental and vessel traffic monitoring. Identification of polluters and pollutants.
- Law Enforcement – Identification and tracking for the purpose of interdicting suspect vessels. Tasks may include acoustic monitoring and identification of vessel types to following

In each area, an application for an AUV will be described that could meet Coast Guard needs for the particular mission. These concepts include;

- Reliability of the sensor and platform. The reliability of the system is integral in determining its effectiveness. This particular requirement cannot be stressed enough. The ocean is a harsh environment and the Coast Guard operates in its worst conditions.
- Identification of potential benefits to the Coast Guard, and the nature of that benefit. Will the Coast Guard save time, reduce costs or be more effective?
- Logistical support and costs for integration of an entire system. Ease of operation, field repair complexity, support equipment, and personnel skills required to maintain working systems.
- Type, quality, and method of data transmission, such as two-way capabilities (for data dumps, alerts, and command overrides), and image capture above and below the surface. Considerations for verification of authenticity and source need to be addressed.
- Deployment capabilities, methods of launch, time on station and obstacle avoidance. There are needs to deploy from different assets such as aircraft, surface ships, small boats, and shore.
- The legal aspects for prosecution such as accuracy, quality, and authentication of sensor data and position.

To be utilized by the Coast Guard, indeed any organization, autonomous underwater vehicles must meet the needs of the Coast Guard and do it in an affordable manner. The potential benefits of conducting missions using AUV's justifies the Coast Guard keeping on top of current developments.

Recently AUV technology has begun to make major strides in the development of accessories and supportable systems. As we look at emerging AUV support technologies such as communications and the resultant saving potential of asset time, personnel on site, and fuel, AUV's become a very attractive mission tool. But, at the same time the Coast Guard

demands extremely rigid performance requirements of any AUV.

**Introduction:**

The Coast Guard is a small agency with a broad scope of responsibilities. It is not the purpose of this paper to address every mission and to identify shortcomings where AUV's could fill a performance gap. Rather this paper will take a closer look at some areas where the potential afforded by an AUV could make a significant difference in achieving mission goals.

Three operational areas selected for review in this paper are fisheries management, port safety, and law enforcement. These areas have a combination of overlapping and unique requirements, and each involve multiple missions. For instance, with port safety and security, the broad scope of the Coast Guard mission profile incorporates many things such as; is the port environmentally safe, protection against the likelihood of terrorist activity, prevention against the introduction of non-indigenous species being brought in via ballast water exchanges, verifying that ships in the port are seaworthy, validating cargo being transported through the shipping lanes, what seasonal traffic considerations are in effect, verifying that shore facilities are operating safely, ensuring that sufficient and appropriate Coast Guard resources are available in case of an emergency, and finally, ensuring that all channels are correctly and adequately marked.

It is understood that there will be no single all-inclusive AUV to conduct all Coast Guard missions. What the Coast Guard needs is a combination of characteristics and capabilities that will make an AUV the better alternative to current methods of operating.

One aspect of importance with AUV's, are up front logistical costs that will go far beyond the cost of the equipment itself. How are the AUV's to be used, where will they be stored, what kind of training is required, what are the maintenance requirements and what is the support system that needs to be in place if AUV's are to become a Coast Guard asset.

Other key areas to be addressed are the requirements for standardization, modularization, miniaturization, and ease of operation. For instance, it would be advantageous to have one generic navigation system. But will one system be able to handle the diversity of Coast Guard missions? There are many missions that would favor a small very portable AUV but will that same AUV be able to carry the needed sensor packages? AUV's with greater flexibility, modular subsystems, and reconfigurable sensor package systems will be key factors in the Coast Guards decision to change the way of doing business and move into a world where AUV capabilities are standard.

**Mission Overviews:**

Lets look at some of the more detailed requirements of Coast Guard missions where there is potential for the application of AUV's to improve Coast Guard mission performance.

**Living Marine Resources (LMR's):**

The Coast Guard is tasked with the guardianship of the offshore Living Marine Resources (LMR's). These are areas of the Oceans where commercial fishing has been restricted or banned. Currently Cutters are sent to patrol these


Off shore Living Marine Resource

areas, typically for two week periods, to make sure that there is no illegal activity going on. The methods of enforcement used involve activities such as multiple boardings with inspections, covertly blending in with a fishing fleet at night, high altitude aerial reconnaissance, and long rang radar detection. The cutters patrolling the restricted or closed fishing areas are typically big and white. While the cutter is onsite, the fishermen will fish just on the outskirts of the restricted areas staying in legal territorial seas. The effectiveness of Coast Guard enforcement efforts on this mission is only guaranteed while there is an on site presence. The ability of the Coast Guard to maintain this presence is minimal. Restricted/ closed areas are often hundreds of square miles, the limitations of the Coast Guard Cutter to traverse, surveill and intercept illegal fishing vessels cannot be met due to many issues including assets, people, equipment, etc. The result is a methodology that cannot meet the mission goal, which is to protect these areas against depletion of fish stocks.

How then might AUVs offer the potential to improve Coast Guard effectiveness in missions such as this? Autonomously operated AUVs coupled with various technologies to detect illegal activity and/or sort/classify targets of interest (e.g., night vision optics/photography, FLIR, long range radar, SOSUS, VMS) may provide the cost effective 24 hour x 7 days a week platform to properly cover large restricted areas. This will not however, provide an effective deterrent superior to the current method of having an on scene Cutter. That is another issue all together.

An AUV will not be able to conduct boardings. What this means in terms of capabilities is fairly substantial. Can the AUV obtain prosecutable evidence? The key word here is prosecutable. That requires quality information of proven accuracy, proven reliability, and authentication. An example of prosecutable evidence would be a real time video of a vessel engaged in illegal fishing. The video would have to show an identifiable vessel in a specific location clearly engaging in the specific illegal activity. This requires quality image capture, own ship positioning capability, and the capability to establish range and distance from the AUV.

Second, assuming the AUV could obtain prosecutable evidence, it would need to be able to communicate it to an interested party. The requires remote transmission of data which may include video, still pictures, recordings, position data, etc. A simpler option in terms of transmission would be an alert for a vessel to come out and download the data. But this would require that the AUV be able to verify the data and its quality on board prior to having an asset dispatched for the download.

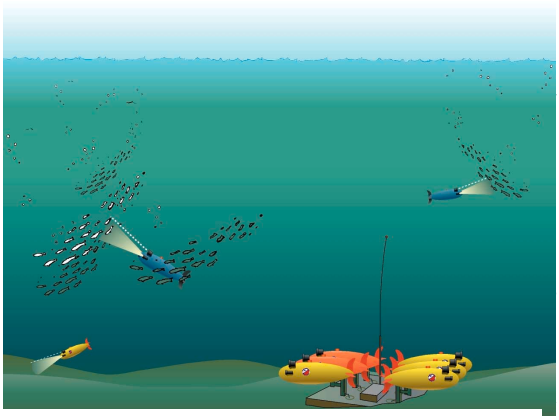
Third, assuming that the AUV could now collect evidenciary quality data and transmit it to an interested party, the AUV would need to be able to get to a position to use these capabilities. This

requires that the AUV perform a series of complex maneuvers including the capability to detect a target, then move to a position where it could gather the required information provide an alert or direct transmission of the data and perhaps relocate itself to a preferred download location. A way to do this is with a properly programmed high-speed, long duration AUV, or with multiply networked AUV's. Due to the size of many of the restricted areas, the multiple AUV option would likely be the most practical.

Finally, again assuming all of these criteria have been met, there is still no advantage to an AUV system vs current operating methods unless the on site presence is measured in months as opposed to days. With the increase in presence, and by this I mean effective presence, the AUV system as a viable option begins to really shine. Based on currently available power supplies, this option would most likely require a recharging or base station type configuration. The number of stations would be determined by the range capabilities and mission requirements of the AUV after a single charging. The Coast Guard would have no problem with the logistical aspect of deploying base stations as we are fully equipped through the Aids to Navigation program. Multiple units and base stations do however affect cost

At this point we have deployed a multiple vehicle system with a recharge station. The vehicles are patrolling the restricted area, listening for targets of interest. A target is detected and one of the vehicles moves to an appropriate (based on sensor capability) monitoring position. An illegal activity is captured on video and is sent to a desktop computer along with the position data. Three days later the fishing vessel pulls into port to sell his catch and is met at the dock by the appropriate authorities where his catch is confiscated. A very neat package with the added benefit that other fishermen will then assume that they are being watch at all times by the new Coast Guard minisubs. Well and good.

This now raises some additional questions that will affect the capabilities of the AUV system if it is to be used more than once. How covert is the data gathering process? Does the sensor that is gathering the prosecutable evidence have a range greater than its counter detection range? It is likely that if these vehicles are detected, that they will be targeted. Up to what sea state does the AUV system need to operate effectively? If the suspect vessels know that the quality of data is compromised by heavier sea states, they may adjust their operations and fish in rougher weather. Does the system have a night capability and what does that cost. If everything were operating as designed, what would be the optimal number of vehicles for a reasonable effectiveness? When all these considerations are taken into account, the system begins to take on some substantial costs.



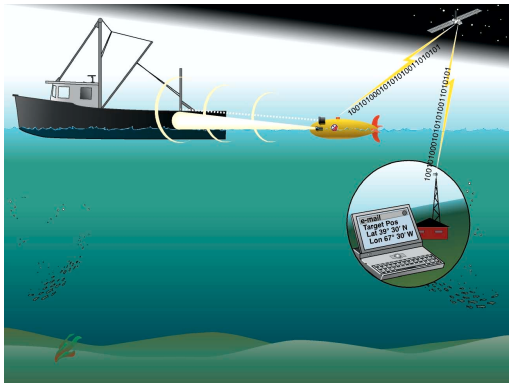
Multi-unit cooperative effort concept

Fish counts could be made, bathometric information gathered, ocean bottom samples could be analyzed, any number of species could be watched, and then when activated, the Coast Guards protection units would be deployed to gather their law enforcement related data. All operating costs of the base station and maintenance would be shared by the participating agencies. This type of cooperative effort would provide the means for the better understanding of our restricted areas and allow the Coast Guard to maintain a full time presence to insure their integrity.

A variant of this mission is patrols of vessel exclusion areas. This is where the automation of the Coast Guard presence would be beneficial. This is a situation where the Coast Guard has regularly scheduled patrols, often aerial, over parts of the ocean where there should be no vessel traffic. The advantage that an AUV would offer is that you could conceivably send one or more out to cover a given geographic area. The AUV(s) would essentially park and listen.

A possible configuration here is a self-recharging AUV. With the proper positioning capability, the AUV could be dispatched from shore. It would go to its assigned area of surveillance and then move to an appropriate depth to monitor for vessel traffic. Here the target of interest is any vessel, which makes the identification programming aspect a little simpler. When the AUV needed recharging, it would rise to the surface, establish its position, check for instructions via satellite, and recharge itself with solar panels. When it had recharged, it would relocate to the appropriate area to continue its mission.

When activated by suspect vessel traffic, it would rise to the surface and report its position and targeting data to an interested party. When vessel traffic was reported, and only then, a Coast Guard asset could be dispatched for reconnaissance. Here is the potential to save substantial Coast Guard asset time




Target of interest alert

by responding only when there was a violation in progress VS a weekly or daily patrol.

**Port Safety and Security:**

The next mission area to be discussed is that the Coast Guard is concerned with is that of Port Safety and Security. Port Safety and Security for the Coast Guard is an issue that involves many operational aspects. The Coast Guard has responsibility to the ports from an environmental standpoint including shore side facilities. This responsibility extends to the area of traffic management, Aids to Navigation, the health or safety of the port addressing traffic management as it relates to the quantity and type of cargoes traversing the port, the seasonal changes in traffic, especially with regards to the pleasure boating traffic, and in today's world the possible threat from weapons of mass destruction.

Lets take a look at one problem frequently encountered in port by our

Marine Safety Offices. This is the problem of the elusive 'Mystery Sheen'. A mystery sheen is oil or gas like coloring in the water that has been spotted and reported to the Coast Guard. The source of these sheens is typically bilge pumped from one of the vessels in the port. With a membership approximately the size of the New York City police force and an area of responsibility being the US coastal waters, the Coast Guard cannot be everywhere all the time. This is no secret and it is a common problem with any law enforcement activity. It is also effectively exploited in various ways. The result being that source of the mystery sheen remains just that, a mystery.

An example of this situation is in one port where there is an active shrimp fleet. The main docking for the fleet is located approximately an hour from the Marine Safety Office (MSO). According to the MSO officer, the fleet produces a mystery sheen three to five times a week. The MSO is not equipped to maintain a watch on the fleet all the time and relies instead on reports of sheens on the water. Typically they will receive a call in the evening that a sheen has appeared. The problem here is that they are that one hour distance away which means one of two things. They may get to the site to find the sheen has dissipated and they cannot sample it effectively. Or they may get to the site and have run out of sufficient daylight to be able to locate the 'reported' sheen. The result being that the nature of their response is typically to log in the report and nothing more.

The situation would take on an entirely different look with the proper application of AUV technology. The area of the sheens is well known and the time of the sheens is fairly constant. One possibility would be to locate an AUV close to the area and have it conduct preprogrammed search patterns at preprogrammed times using an onboard analyzer to essentially fingerprint the sheen. If the unit can sample sufficiently to obtain a 'print', it would notify the MSO. At a convenient time soon after, the MSO would dispatch someone to sample bilges and identify the source of the encountered sheen for appropriate action. This deployment may not guarantee results however due to the transient nature of the sheens.

Remote identification of Mystery Sheen

A more reliable yet more complex solution may be to have a trigger for the search. A passing vessel or a signal from the MSO following the sheen calls would be the trigger to send the AUV on its sampling mission. This would depend on how the sheen is believed to be caused. Pumping a bilge on the way in or cleaning once docked. The second option also means that a two-way communications system needs to be in place. This could be accomplished through a shore connected charging station though it may compromise the covertness of the operation.

The covertness of this application has a positive aspect in that when a successful mission has been accomplished and no

one saw the vehicle take the sample, there will always be the mind set that a vehicle is still out there. This allows for one unit to be moved and /or rotated through several areas of interest. Which bring the ever desirable cost reducing aspects into the system.

Another complication for this application is that the navigation would have to address the collision avoidance issue. This mission would be carried out in areas where there is (potentially) a lot of boat traffic. This would require some sophisticated navigational capabilities.

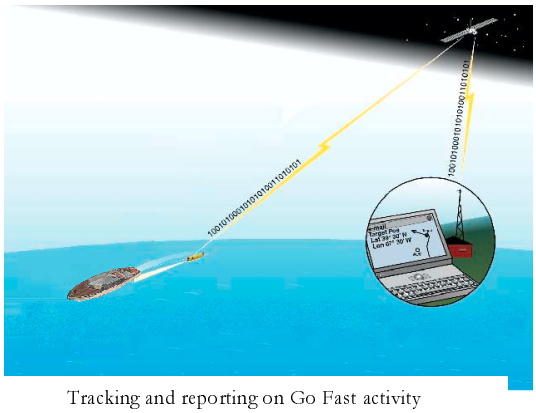
A similar thought along a slightly different vein is to develop an AUV with a longer operational duration. The AUV could then be launched from or based at a Coast Guard station and be sent to patrol the port looking for chemical abnormalities. The patrol route could be varied and/or based on call ins. The navigation could also have sensor inputs that allow the AUV to track the pollutant

Chemical detection to source

to its source. These types of applications would require that the navigational programming be extremely user friendly, which means that the navigation program would probably be very complicated. This is especially important in the initial stages of developing an AUV capability. If the first few units are difficult to use, require lots of specialized training and are too narrow of purpose, the concept of a fleet of Coast Guard AUVs may not come to fruition.

**Law Enforcement:**

The law enforcement mission involves detection, identification, tracking and the interdiction of suspect vessels. The Coast Guard could use a force multiplier in the detecting and tracking areas. This is especially applicable in large areas of operation. There are many instances where the kind of intelligence offered by the AUV could be used to better deploy Coast Guard assets. In this mission area



Tracking and reporting on Go Fast activity

the AUV's offer covert reconnaissance with the option of mobility. Similar to the fisheries operations, once the AUV has detected a target of interest, the AUV would then need to report the contact to an interested party. This would be sufficient capability for the AUV on some LE operations, because the Coast Guard would want to send in a manned asset to conduct the actual intervention. The savings occur when you only have to deploy manned assets when there is a need. So the purpose of the AUV would be to increase the ratio of patrol time to successful interdictions.

Patrolling an area without intelligence on suspect activity looking for a specific target of interest is less than optimal. Patrolling an area of known trafficking

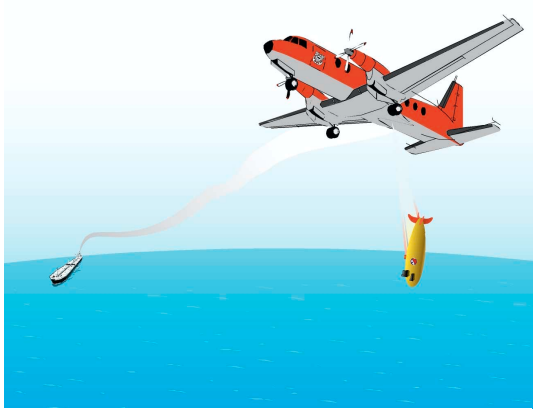
will yield some positive results. Going out to an area of an identified target of interest will likely yield better results. Or at the very least, using the AUV to merely extend the sensor range of the patrol boat can be very effective in increasing the number of interdictions.

In the specific case of GO FAST targets, it is unlikely Coast Guard would want an AUV to identify and then track the vessel as they are typically running at speeds in excess of 30 knots. However it would be of use to deploy an AUV system that could identify the location and course of a GO FAST so that it may be intercepted. This is the picket fence concept where multiple AUV's are deployed across a large area. Many factors such as sensor range and communications set up would determine the spacing and thus the number of AUV's required. This concept of the picket fence could be done with a buoy type arrangement but the AUV's offer the advantage of mobility. With mobility you have the option of putting the AUV on a patrol pattern so that one sensor now covers twice the area for half the time. If the AUV had positioning, targeting and communications, the GO FAST would be reported by location and direction. With the proper spacing of your fences, the area of re-acquisition is substantially decreased. This would allow for far more productive patrol time for Coast Guard assets.

Unlike the buoy system, this entire system can be easily moved to a new area of operation. The AUV's could be sent a message to move to another area or simply be recalled for pick up and transfer. Even if the AUV system is utilizing a base station for recharging, it is conceivable that the base station be designed to be moved to a new location using its own AUV's.

The detection of the GO FAST would not be as difficult as the identification of a specific fishing vessel. In the case of the fishing vessel the AUV was gathering prosecutable evidence. In the situation of the GO FAST detection the Coast Guard would only need to know that there is a high speed vessel transiting a certain location in a specific direction as the interception would be by a more traditional asset. Similar to the fisheries missions, the AUV potential is increased with on station time. To go to an area of interest and maintain watch for months is a highly desirable capability. Combine this with a networked multiple vehicle system and the Coast Guard would have a covert, movable, picket fence that could detect and report on activity of interest.

While the GO FAST interception requires the AUV's to be detectors and trackers, there are LE applications that may require both a tracking and trailing capability. In the Pacific area of operations, a suspect vessel may be found only to be lost while an asset returns for refueling. This is not atypical where the areas being patrolled can exceed thousands of square miles. Here an air dropped AUV could be



Air deployed Tracking AUV

deployed if it had the endurance and speed to maintain contact with the suspect vessel. Reporting back position

data in the process of tracking would allow for better allocation of existing resource time. With an adequate mission time capability, the AUV would be the only asset needed.

**Summary of Coast Guard needs for future AUV capabilities:**

So what is it that the Coast Guard is looking for in an AUV? Currently the Coast Guard is in the process of defining the future capabilities of its Deep-Water fleet. Are the AUV's going to be an integral part of this procurement? If they are, what capabilities will be required? The previous scenarios are speculative and require capabilities that currently do not coexist in any single AUV today. What the Coast Guard hopes to do at this time in the world of AUV's is to work with other entities/agencies in developing the technology for when it comes time to procure this type of asset.

For this technology to be of real value to the Coast Guard, there are many capabilities that need to be addressed.

- One of the most important is mission time, specifically autonomous mission time. There is limited application within the Coast Guard for an AUV with only a 12 to 48 hour mission time. Whether this is extended through the use of recharge stations or through alternative power sources it needs to be measured in months, if not years.

- The navigational capabilities need to be user friendly and very versatile. The Coast Guard will be looking for a single navigation program that minimizes the training time required to use it.

- The basic construction of the AUV and its subsystems will require some sort of modularity so as to facilitate field repairs and minimize mission down time.

- The units must be capable of handling two-way communications and data transfer to remote locations. The range of data will include still images, video imaging, and instrument/sensor data. This may even be extended to a requirement to support encrypted data.

- The data quality will need to be very high and the losses in transmission will need to be almost nonexistent.

- They must be network able. Not only with each other but also with other Coast Guard assets, i.e. planes, helicopters, ships and small boats.

- The AUV will have to have precise positioning and targeting capabilities; the level of precision needs to be able to stand up to the scrutiny of a court of law.

- For some applications the top end speed of the AUV needs to be increased. While AUV's exist with impressive speeds, this is not the norm and usually precludes submergence or extended mission time.

- The units need to handle a variety of instruments/sensors. In this area the efforts at miniaturization are currently yielding some very usable equipments.

- The units must be able to be handled with ease. This can be a specialized launch platform or a small size. The small size lends itself to more versatility thus wider application but this needs to be looked at with the tradeoffs of payload and power capabilities.

- Another important aspect in the design of a future Coast Guard AUV will be the logistical support required to maintain a

fleet of these units. This includes spares replacement parts, failure rates, and the required abilities to affect repairs. It needs to be kept simple or be a subcontracted service.

-Finally, the AUV needs to be cost effective. This is not to say inexpensive or cheap. The cost of the AUV system will need to be justified by its capabilities. All aspects of the cost must be considered including; unit cost, system cost, integration cost, training cost, and the entire life cycle costs.

**Conclusions:**

The Coast Guard is new to the world of AUV's. It is entering this arena in the hopes that development can be influenced to meet Coast Guard operational needs. The Coast Guard is committed to partnering with agencies and institutions that have similar operational needs and the financial capability to advance AUV technologies. The Coast Guard has a wealth of experience with the marine environment and the assets and applications to demonstrate and effectively test the potential of AUV's. The Coast Guard is always looking for ways to accomplish its missions more efficiently and more effectively. The Coast Guard believes it can benefit greatly from automation in many of its mission areas. Fully capable AUV's have the potential to yield these benefits.

When you've built it for the Coast Guard, it will serve the world!