Challenging the Marine Frontier with Unmanned Marine Vehicles

Autonomous Unmanned Maritime Systems (UMS)

In recent years, as offshore resources, not only fishery resources, including oil, natural gas, rare metals, and other minerals attract increasing attention, national surveys have been underway in the vast seas that surround Japan. IHI applied own robot technologies to take another step forward in achieving autonomous unmanned maritime systems for conducting detailed surveys at a water depth of 1 000 m or more.

Corporate Research & Development,
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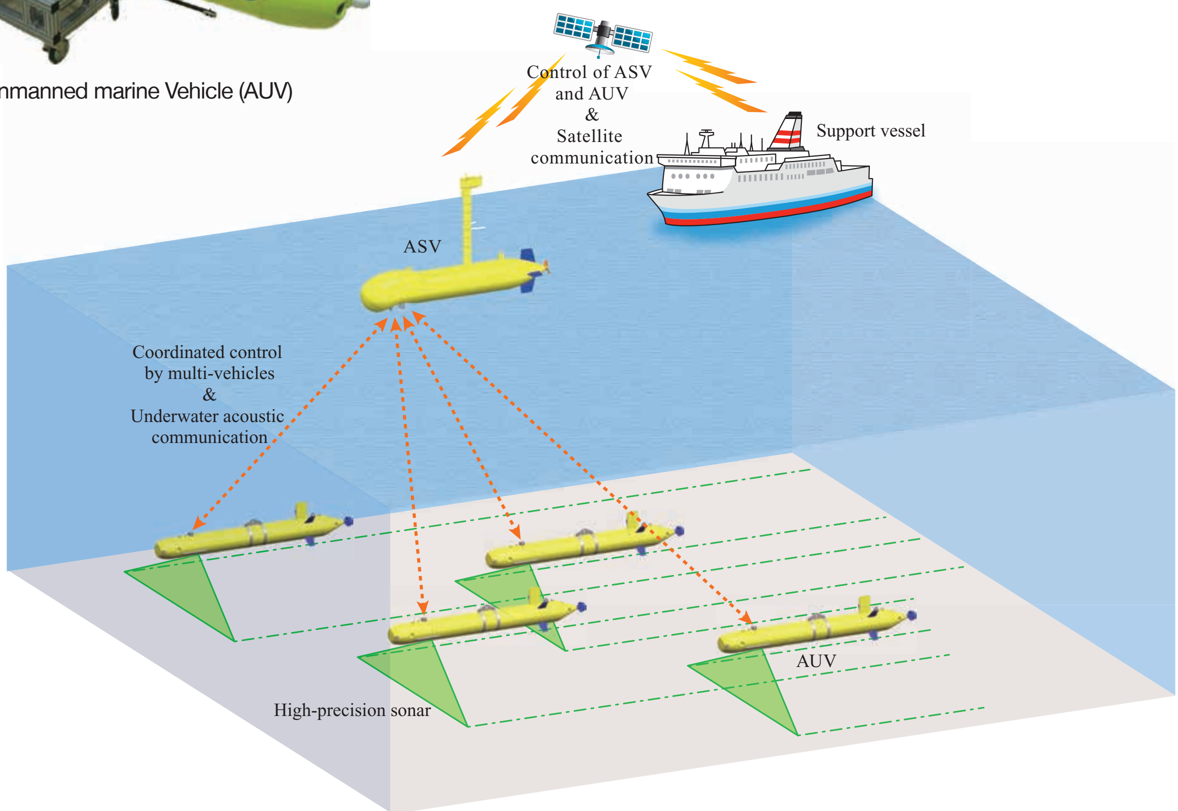
Autonomous Unmanned marine Vehicle (AUV)



Offshore exploration with multiple unmanned marine vehicles

Marine frontier

Japan has the world's sixth largest area (4.47 million km^2) when including the territorial seas stretching in all directions and the surrounding Exclusive Economic Zone (EEZ). Our maritime nation has been using these waters mainly for fisheries and maritime transport. The recent discovery of methane hydrate under the seafloor, as well as the confirmed presence of hydrothermal deposits and other mineral resources, has led to rising anticipation for their acquisition. Moreover, the potential of new applications of the surrounding seas has attracted greater interest of late. Examples include development of power generation systems that utilize natural energy, such as offshore wind power, tidal power, and ocean currents, as well as new biology that effectively makes use of marine microbes.

Still, the deep waters hold many mysteries. This is because of the nature of the prohibitive marine environment that keeps humans from easily going, seeing, and conveying what's down there. The world below the water's surface is unforgiving indeed. The water pressure increases by one atmosphere every 10 m. On average, the world's oceans are roughly 3 800 m deep, which translates into a water pressure on the order of 380 atmospheres. Simply reaching a destination is impossible without addressing the high pressure. Moreover, light can only reach 200 m deep even in unpolluted seas, which makes it difficult to observe the sea bottom from the surface. Worse still, communication is significantly constrained as commonly used radio waves can traverse only several meters in the sea.

This harsh environment continues to hamper the advance of humankind into the oceans. The application of unmanned marine vehicles is drawing attention as a way to overcome this impediment. This article presents technologies cultivated by IHI for unmanned marine vehicles.

Unmanned marine vehicles

Marine vehicles used in oceans are divided into surface vehicles and underwater vehicles. Their tasks include data collection on the sea surface, in the water column, and on the seabed by measuring instruments mounted on them, as well as operations with manipulators and so forth. This section describes on underwater vehicles.

Underwater vehicles are roughly classified into manned and unmanned vehicles.

On the one hand, manned vehicles have the advantages of, for example, more accurate and quicker manipulator operations, and effective performance of operations according to the priority set on the spot by human operators based on the information caught through their eyes and ears. On the other hand, these vehicles may suffer the following disadvantages:

- Requirements for greater reliability and safety of their entire systems for persons on board typically result in increased cost and size as compared to unmanned vehicles.
- Operation of a manned vehicle requires substantial assistance from the mother vessel.
- The operation time is limited by constraints such as the energy involved in ensuring environmental conditions (air-conditioning, food, etc.) necessary for human activities.

The abovementioned constraints are relaxed for unmanned vehicles.

Unmanned vehicles are either remotely operated from the mother vessels through cables (ROVs: Remotely Operated Vehicles) or autonomously operated without cables (AUVs: Autonomous Underwater Vehicles).

ROVs are undersea vehicles operated by human operators via communication through cables. Energy can be supplied through cables to some models. The problem with this option is that cables inevitably become thicker to supply larger amounts of energy, which in turn requires larger mother vessels and greater power for ROVs to overcome the greater water resistance during maneuvers in the deep sea. ROVs with a built-in energy supply are less constrained and have more maneuverability as they communicate through optical fiber cables. There is, however, a greater risk of the cables being severed.

AUVs are free from cables. Analogous to robots, these autonomous unmanned vehicles are able to automatically achieve given objects when prompted to start an assignment. No human involvement is necessary once the command to explore a certain area of water is given to an AUV. Unhindered by any cables, the vehicle can autonomously and precisely follow the trajectory to the predefined locations with a small amount of energy. AUVs can automatically continue exploration as long as their energy lasts. They are quite suitable for the exploration of vast oceans.

Confronting challenges

The next chapter will describe the establishment of autonomy as the biggest challenge faced by unmanned marine vehicles. There are some more hurdles that underwater vehicles must clear before they can be used in harsh environments.

To begin with, they must resist the water pressure of great depths. Hopes are placed on the development of hydrothermal deposits in Japanese EEZ at depths from 700 to 2 000 m. But a depth of 2 000 m means that every 1 cm^2 is under nearly 200 kgf of pressure. Even a small mobile underwater vehicle with a diameter of 20 cm and a length of 100 cm will be under about 1 400 tf of water pressure. A pressure-tight vessel that can withstand such a huge amount of pressure needs a thick wall, which makes the vehicle heavy. The most common way of avoiding this disadvantage is the pressure balanced oil-filled technique, wherein insulating oil or the like with the same compressibility as seawater is filled inside a vessel designed to equalize the internal pressure with the external pressure. In this manner, this technique allows the vessel wall to be thinner and lighter as the vessel no longer needs to resist pressure. This approach is used in batteries and the like.

Another hurdle regards the difficulty in conveying information under water. Underwater vehicles must rely on underwater acoustic communication, which has a shorter range and is slower than radio waves used in ordinary environments. Communication is expected to improve by relaying underwater acoustic communication over multiple underwater vehicles. IHI is also attempting to overcome the short range and slowness of underwater acoustic communication through the coordinated control of multiple vehicles in addition to enhancing the performance of acoustic communication equipment.

The problem of power supply is yet another major hurdle. Given the lack of oxygen under water and exclusion of internal combustion engines as an option, secondary cells are solely used for underwater vehicles. At present, most underwater vehicles operate for about 12 hours. Next-generation lithium-ion secondary cells may double the energy capacity. If this comes true, they will be able to continuously operate for 24 hours. As another way to extend the operation time, IHI is developing wireless underwater power transfer technology.

Additionally, research and development are underway to overcome other challenges faced by underwater vehicles, such as difficulty in self-localization under water where GPS cannot be used, and launch and recover of vehicles in severe weather.

Advanced autonomous control

The key autonomous performance required of AUVs may be the ability to generate a route to the predefined destination and to follow the route at an appropriate speed and attitude; identify abnormalities (abnormality detection); continue the assignment as much as possible despite the abnormality; suspend the assignment when deemed impossible due to the abnormality and move on to the recovery process (response to abnormality). Coordinated control will be added to the list when multiple unmanned vehicles are operated.

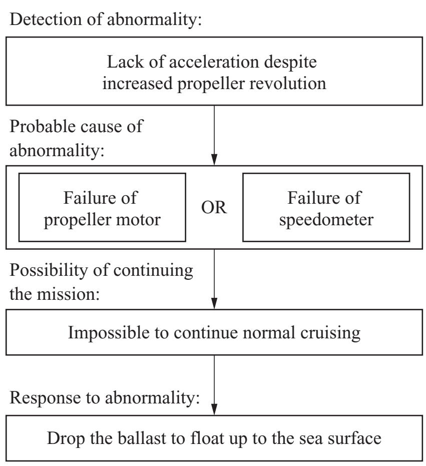
In general, detection and response to abnormalities by an AUV is structured by a collection of rules to “respond in this way under this circumstance.” In other words, each of these building blocks is a rule based on a measurement range of a sensor predefined as normal or an estimated value under certain conditions beyond which is considered abnormal to prompt response according to the type of abnormality. As an example, the following figure presents the flow of a response to an abnormality involving lack of acceleration despite the increased propeller revolution.

The steady compilation of regulating rules defining “what is to be identified as an abnormality” and “what is an appropriate response to such an abnormality” comprises the technical data that makes or breaks AUVs and other autonomous unmanned vehicles. IHI is accumulating such technical data through actual AUV operations.

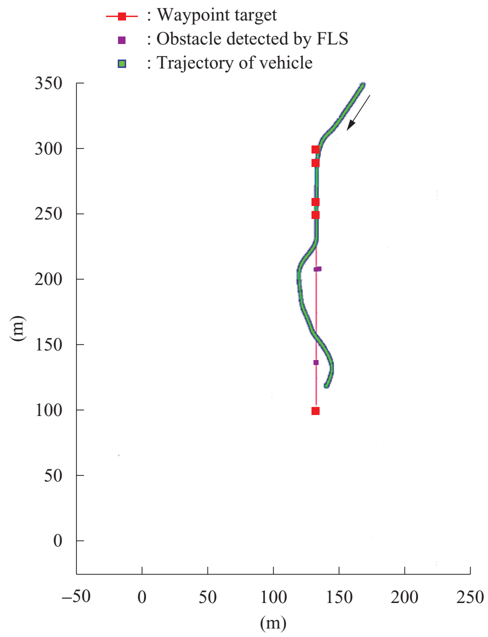
There is another scenario that requires autonomous response to abnormalities not necessarily involving any systemic failure of an AUV — namely, avoidance of obstacles in the route. Typically, such avoidance actions are also achieved by a set of rules and predefined processing flow.

The left-hand figure on the next page presents an example of avoidance action taken when an obstacle has been detected by the Forward Looking Sonar (FLS) installed on the nose of an AUV. Two obstacles were placed directly in the path of an AUV, which successfully avoided them to the right and left in succession while cruising at a speed of 3 kt.

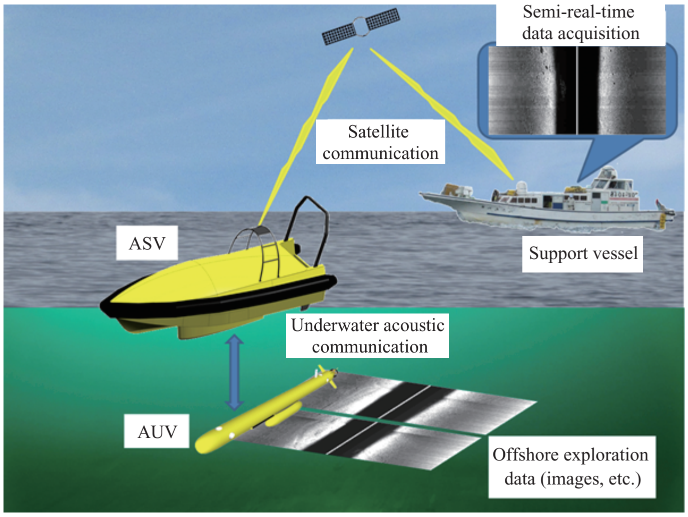
Further advancement in autonomous performance may also be enabled by coordinated cruising with multiple unmanned vehicles. In conventional seafloor exploration, a support vessel transports an AUV to be released into a target site, which is then operated and monitored one-on-one by the support vessel. Simultaneous operation of multiple AUVs could achieve more effective exploration (see right-hand figure under the title). The efficiency can be further boosted when an Autonomous unmanned Surface Vehicle (ASV) can monitor an AUV instead of a support vessel to reduce the operation cost. Remote monitoring with data from such an ASV would enable the support vessel to do something else in the meanwhile. The ASV would use data on the position, speed, and destination of the target AUV for coordinated cruising and semi-real-time data transmission from the AUV to the support vessel through radio communication. The right-hand figure on the next page is a schematic illustration of coordinated cruising by an ASV and an AUV, and semi-real-time data transmission as achieved by IHI. In this example, the ASV obtained data from exploration by the AUV through underwater acoustic communication during their coordinated cruising at a speed of 5 kt. The ASV then transmitted the data to the support vessel in semi-real-time by satellite communication. The key to coordinated control using an ASV is its response to the failure to obtain the position of the AUV and communicate acoustically with the AUV.



Sample flow of abnormality detection and response



Example of avoidance of obstacles in ocean at 3 kt



System for coordinated cruising and semi-real-time data transmission

Further steps ahead

From 2010 to 2014, IHI participated in the "Study of UUV and USV Technology," a research prototyping program organized by the Japanese Ministry of Defense. The company's AUV technologies were effectively applied to achieve coordinated ASV-AUV operation and semi-real-time transmission of sonar data from an AUV. IHI is pursuing an even more efficient seafloor exploration system by developing a single ASV unit that can perform coordinated operation with multiple AUVs and control through ongoing participation in the initiative called "Next-generation technology for ocean resources exploration" in the Cross-ministerial Strategic Innovation Promotion Program (SIP) led by the Cabinet Office. In the company, development of an AUV for operation at a depth of 3 000 m is underway to stimulate development of component technologies (see left-hand figure below the title). The output is applied in pursuit of greater autonomous performance and enhanced coordination, as well as development of technologies for underwater networking, wireless underwater power transfer, underwater docking, among other needed technologies.

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