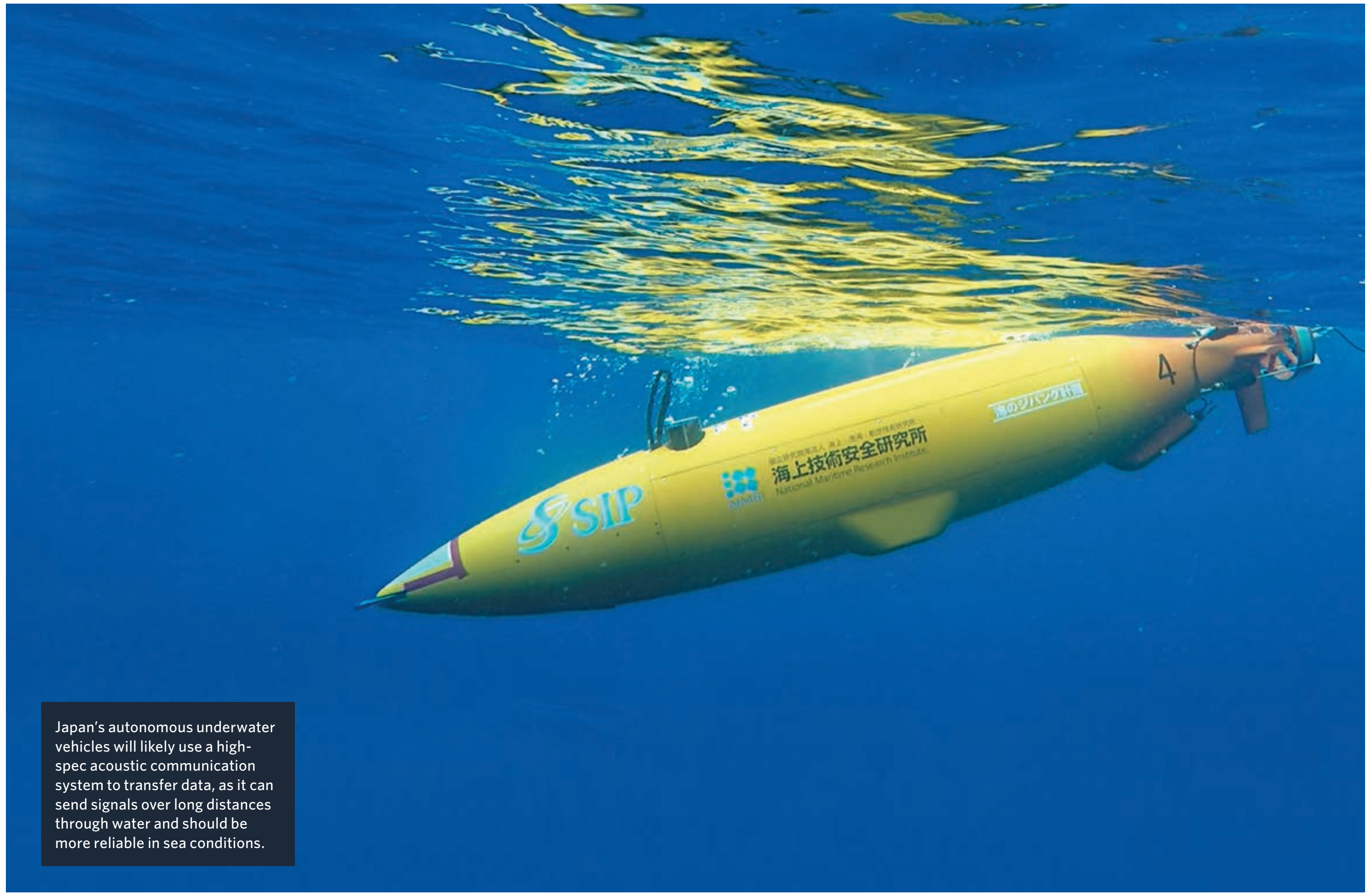
Orchestrating a deep-ocean fleet of explorers

Coordinated TEAMS OF SELF-DRIVING VEHICLES, BOTH ABOVE AND BELOW THE WATER, will scan and map vast areas of unexplored seabed.



Japan's autonomous underwater vehicles will likely use a high-spec acoustic communication system to transfer data, as it can send signals over long distances through water and should be more reliable in sea conditions.

Autonomous surface vehicle KaiKoo was developed by Mitsubishi Heavy Industries.


Communication software systems are being designed so an autonomous surface vehicle can control many autonomous underwater vehicles from different agencies.

Japanese researchers are working toward mapping the country's vast seabed and pinpointing its mineral resources with fleets of autonomous underwater vehicles (AUVs), guided by robust autonomous surface vehicles.

The seas that form the exclusive economic zone (EEZ) around Japan cover an area 12 times larger than the country's landmasses and contain significant deposits of rare-earth minerals.

Used in many devices, these minerals may be vital to a future in which the manufacture of wind-turbine magnet motors, electric motors, certain types of rechargeable batteries, and other technologies, are enabling a move away from fossil fuels to more sustainable energy and transport systems.

Small deep-sea studies have already suggested many of the minerals can be found near Japan's shores. However, the seafloor slopes steeply downward from the country's shoreline, and rare-earth deposits are expected to be found in seabeds some 6,000m below the surface, presenting a considerable challenge.

LOCATION, LOCATION

Each AUV will need to know its precise location underwater – a challenge at depths that don't allow signals from global positioning satellites to penetrate and where powerful currents could easily sweep a vehicle off course.

THE AIM IS THAT SEABED SURVEYING WILL BE DONE BY MULTIPLE AUTONOMOUS SURFACE VEHICLES, EACH SHEPHERDING 10 AUTONOMOUS UNDERWATER VEHICLES.

There is a substantial risk that one of these high-tech, expensive machines could become disoriented and lost, says Toshifumi Fujiwara, director of the offshore advanced technology department at the National Maritime Research Institute (NMRI), one participant in the project.

Manned ships can watch over the AUVs and facilitate communication, but there are limited numbers of these.

NMRI is exploring an alternative approach. Small fleets of AUVs will be continually monitored and, if necessary, guided back on track by a dedicated autonomous surface vehicle produced by Mitsubishi Heavy Industries (MHI).

At the end of the second phase of a government initiative that will culminate in 2022 is a sea trial involving one autonomous surface vehicle supervising five AUVs operating at a 2,000m depth. The ultimate aim is that seabed surveying will be done by multiple autonomous surface vehicles, each shepherding 10 AUVs or more, says Fujiwara.

SURFACE TENSION

Robust and reliable autonomous surface vehicles to watch over the submerged fleet are critical. Their design and production has been entrusted to MHI.

"The aim of our autonomous surface vehicles programme is to produce rugged, cost-efficient and practical vehicles capable of continuous operation for five days, while reliably maintaining their position in harsh sea-surface conditions," explains Tsukasa Hasegawa, a project manager at the company.

Each of MHI's autonomous surface vehicles is approximately 6m long and 2m wide, which are relatively small dimensions for a vessel destined for open ocean operation. Constructed of rugged, lightweight marine fibreglass-reinforced plastic, the vehicle is designed to self-right in rough seas.

Propelled by two 48-volt electric thrusters, the autonomous surface vehicles match the cruising speed of its fleet of AUVs as they survey the seafloor. A diesel generator engine keeps the battery charged for five-day missions.

The surface vehicle is also loaded with communication and location technologies. It's equipped with Global Navigation Satellite System and Inertial Measurement Unit technology for positioning, as well as an electro-optical/infrared camera and a LiDAR.

The last device helps to determine distances by illuminating the target with a laser light and measuring the reflection with sensors, and this helps the vehicle avoid collisions and guides autonomous navigation.

"As for communication between autonomous surface vehicles and the support mother vessel and/or land station, the autonomous surface vehicles have a wireless LAN system, Inmarsat satellite communication system, and Iridium satellite communication system for emergency use," says Hasegawa.

The MHI team has also developed the software that controls the vehicle's autonomous motion across the sea. "Before making algorithms for the control software, we tested a model – about 1.8m in length – to understand the motion performance of the autonomous surface vehicle, including in harsh sea-surface conditions," Hasegawa says.

Armed with this data, the team developed a motion control algorithm capable of functions such as calculating and controlling elements such as the: waypoints, the points that must be visited; way-lines, the direct lines between waypoints; position-keeping at a set point; and emergency stops, for avoiding collisions.

SOUND FOUNDATIONS

Communication between the surface vehicles and their submerged fleet must be via acoustic technologies, says Takuya Shimura, who is leading the development of this technology for the Japan


Mitsubishi Heavy Industries' lightweight autonomous surface vehicle needs to survive the harsh conditions of the high seas.

Agency for Marine-Earth Science and Technology.

Most wireless communication systems, including Wi-Fi and mobile phone networks, are based on radio waves, whose signals offer limited penetration through seawater. Soundwaves, in contrast, can travel long distances through water, although acoustic underwater data transfer poses its own challenges, Shimura explains. "It's difficult to transmit and receive signals frequently, and to achieve a high data-transfer rate," he points out. The speed of sound waves travelling through water is approximately 1,500m per second, which is much slower than the 300,000,000 per second speed of radio waves in air. The available bandwidth is also very narrow, approximately 10-20kHz in cases where several kilometres of range is needed.

Signals passed between the autonomous surface vehicles bobbing on the surface, and the deeply submerged AUVs, are also subject to a distortion known as the Doppler frequency shift, a stretching and compressing of the acoustic waves due to the motion of the two vehicles in the water, and the water's movement itself.

The Doppler frequency shifts of acoustic signals in water are several orders of magnitude larger than radio waves experience through the air. Additionally, Doppler frequency shifts are not uniform and this disrupts signal precision.

As a result of such differences, techniques developed for high-speed radio wave data transmission don't necessarily work well for underwater acoustic signals, research by Shimura and his team suggests.

AN ADDITIONAL CHALLENGE IS CONTROLLING MANY DIFFERENT AUV MODELS.

For example, Wi-Fi and mobile networks use a technique called orthogonal frequency division multiplexing (OFDM), in which channel equalization is implemented in the frequency domain. However, OFDM can be subject to high error rates and low data transfer in long range underwater acoustic data transmission, because variance over time occurs more underwater, especially due to non-uniform Doppler shifts, Shimura's research has shown.

"OFDM is very effective in radio communication, but it is difficult to achieve a high data rate in underwater acoustic communication," explains Shimura. In their system, methods of channel equalization in the time domain, which are robust to the time variance, are adopted.

Based on these findings, Shimura and his team have developed an underwater acoustic communication system that can reach a data transfer rate of 79.1kbps between a surface vessel and an underwater vehicle at more than 6,000m depths. Moreover, the system is designed so that it can also be used to produce acoustic pulses for AUV location tracking.

Integrating the location and data transfer requirements into a single system saves on cost and space in the vessels, Shimura points out, and it prevents signal conflict that may occur between separate location and data transfer systems.

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COMMON LANGUAGE

At the NMRI, Fujiwara leads a third team developing the smart software system by which an autonomous surface vehicle and its AUVs will communicate. The system must help fine-tune the position of each AUV within the overall formation of the fleet, Fujiwara explains.

This is particularly difficult because the machines use a form of sonar survey technology, called multibeam echo sounders, to map the seafloor. But if the machines get too close to one another their sonar signals can interact, corrupting the signal, and losing observation data, Fujiwara explains. The larger the number of AUVs in each autonomous surface vehicle's fleet, the more difficult that fleet formation becomes to program.

An essential role of the system is also to issue corrective orders to any AUV that goes off course, potentially straying outside the autonomous surface vehicle's observation area. The control system can order the AUV to adjust its speed and heading, preventing any AUVs from becoming lost.

An additional challenge is controlling many different models, as NMRI is just one of several organizations in Japan that owns and operates AUVs, explains Fujiwara. "Japanese research institutes and universities, and Japanese companies, have many different models," Fujiwara says. "For some surveys, we would like to use many at the same time." The control software is therefore also being developed as a simple, unified system that all AUVs in a survey could run, so that researchers from multiple institutes can participate in the same undersea project.

The system also accounts for the fact that different AUVs operate at different cruising speeds and navigational performances. In the near future, Fujiwara hopes that they can improve efficiencies using AUV–AUV communication.

Ahead of the larger 2022 sea trials, in October 2020 the project participants put some of the technologies through their paces in ocean testing. "We used one autonomous surface vehicle and three AUVs operated together in the same area using the prototype control software," Fujiwara says. "So far, the results are quite encouraging."

This article discusses research conducted by Mitsubishi Heavy Industries (MHI), the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and the National Maritime Research Institute (NMRI). Their research and development programmes are part of the Cross-ministerial Strategic Innovation Promotion (SIP) Program, which is run by Cabinet Office, Government of Japan. ■

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Early sea trials (one of which is pictured) will be followed up by larger trials in 2022.


In 2019, a prototype underwater acoustic communication system was mounted on a number of AUVs and an autonomous surface vehicle for testing.

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