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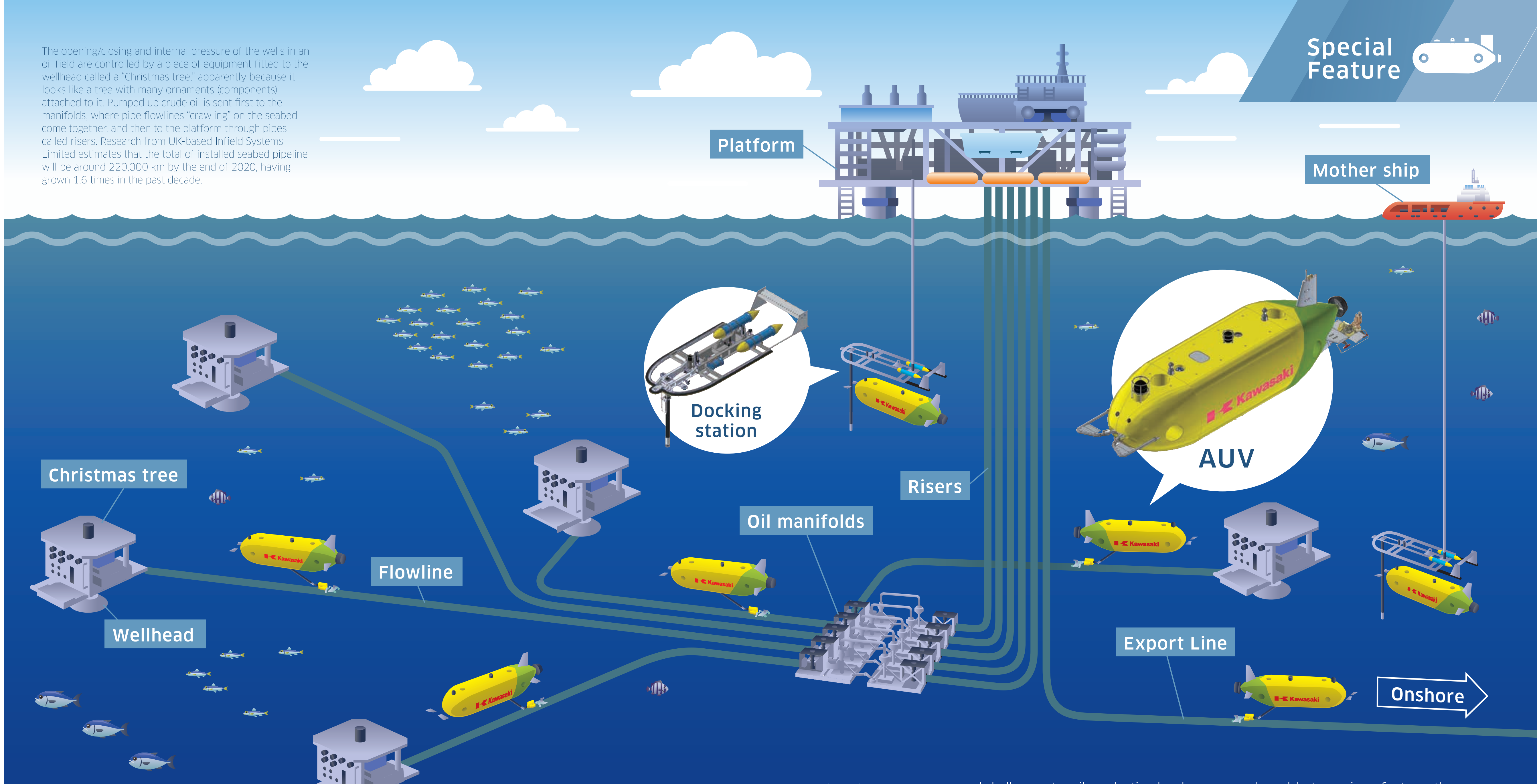
Contents

About the Cover

An AUV undergoing a demonstration test (Numazu City, Shizuoka Prefecture). For details, see *Special Feature* (this page).

Special Feature

The opening/closing and internal pressure of the wells in an oil field are controlled by a piece of equipment fitted to the wellhead called a "Christmas tree," apparently because it looks like a tree with many ornaments (components) attached to it. Pumped up crude oil is sent first to the manifolds, where pipe flowlines "crawling" on the seabed come together, and then to the platform through pipes called risers. Research from UK-based Infield Systems Limited estimates that the total of installed seabed pipeline will be around 220,000 km by the end of 2020, having grown 1.6 times in the past decade.



Ingeniously Designed to Protect Subsea Oil Fields: Kawasaki's AUV

As the development of subsea oil fields continues to grow, the efficiency with which the maintenance and inspection of pipelines can be done underwater or on the seabed is becoming a major challenge. Kawasaki has been a global pioneer in the development of autonomous underwater vehicles (AUVs) for these purposes, and to resolve the challenge, it plans the commercial launch of a new AUV in 2021, tasked with the mission of protecting this underwater energy source.

Autonomously Maintains/Inspects Oil Field Facilities Located Deeper Than 400 m

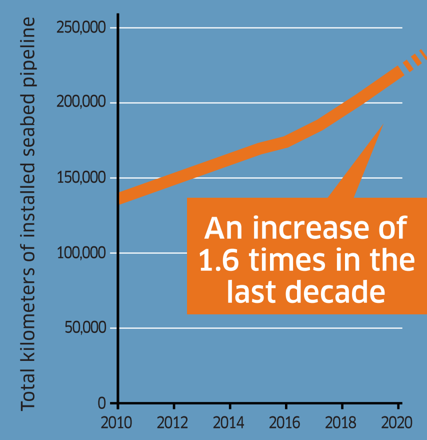
Of the world's primary energy, 30% is oil and 20% is natural gas. The International Energy Agency (IEA) forecasts that demand for oil will remain strong, and that even in the period up to 2040, 30% of primary energy will still be supplied by oil.

Recently, however, trends regarding the locations of oil fields have changed, and the volume of oil extracted from those in deeper waters has been increasing. According to the IEA, subsea oil fields produce 2.7 million barrels of oil daily, accounting for 30% of global oil production. The agency also estimates that proved reserves of subsea oil fields amount to 260 billion barrels, or 15% of total global reserves, but because onshore and shallow water oil production has been declining, it is forecast that production from fields located at a depth of 400 m or more will increase.

At an offshore oil field, what we see is a "drilling derrick on a platform standing upright in the sea" and most people would think that the derrick platform is standing over a single well, pumping up subsea oil after drilling the seabed from the derrick platform. In reality, although there are variations, subsea oil is sucked up at the seabed, and a more representational picture would be an octopus sticking its head out of the sea, with the ends of its tentacles clinging to the ocean floor.

Crude oil from wells scattered across the seabed is pumped up and delivered to a platform via pipelines in the sea or on the seabed. These pipes, however, are vulnerable to various factors: they can become corroded because of seawater or buried in the seabed, or they may become suspended in the sea if the bed below becomes eroded. Although regular

Demand for Pipeline Inspection



Source: Infield Systems Limited (based in the UK)

Under a platform standing in the ocean, multiple oil wells are scattered around.

maintenance and inspection are indispensable to sustaining subsea oil extraction, divers can operate only in relatively shallow water, up to 300 m deep, and it is a dangerous mission. Unmanned submersibles (robots), the most popular of which currently are remotely operated vehicles (ROVs), were developed to replace these divers.

Powered by cables connected to the mother ship, ROVs can be operated in real time. However, they can only be manipulated by skilled and dedicated operators, and the range of operations is limited to the area near the mother ship. Because these factors make the use of ROVs costly, AUVs are now regarded as an alternative “guardian of the subsea oil fields.”

AUVs do not require cables and, as the name indicates, perform tasks autonomously even in deep waters without the operational limits imposed by being tethered to a mother ship. The downside has been that the power supply on AUVs was limited, and that sophisticated control technology was required to enable them to perform complex tasks. Kawasaki broke through these technological challenges and developed an innovative commercial AUV for subsea oil field maintenance.

In June 2020, off the coast of Awaji Island in Hyogo Prefecture, the company successfully completed a demonstration test for the inspection of a subsea pipeline by an AUV with a robot arm. The great success of the test suggests that its commercialization is rapidly approaching.

Inspecting 20 km of Pipeline at a Maximum Depth of 3,000 m in a Single Dive

The AUV that Kawasaki plans to commercialize in 2021 is a streamlined vehicle with rounded ends, approximately 4 m long, 1.2 m wide, and 0.9 m high. It travels underwater at up to 4 kt (1kt = 1.852 km/h), and using a sensor, locates pipelines so the robot arm can come into contact with them. A sensor for inspection is attached to the tip of the arm, which collects various data from the pipes.

When fully charged, this AUV can operate underwater for about eight hours, performing inspections at a speed of around 1.5 kt, which means it is capable of inspecting more than 20 km of pipeline in a single dive. After a mission, it will dock at the docking station, which is suspended from the mother ship, and start recharging its batteries while transferring collected data to the ship. After four hours, recharging is complete and the AUV can return to its subsea mission. Compared to an ROV connected to the mother ship via cables, the AUV can operate without this constraint, giving both the AUV and the ship greater flexibly, which is one of its prominent advantages.

Although cruising-type AUVs developed by American and European companies for subsea exploration already exist, maintenance and inspection of pipelines by AUVs in offshore oil fields require completely different capabilities. It should be able to come close to the pipeline, track it automatically, inspect it, and collect the data

Noriyuki Okaya
Manager
AUV Department, Kobe Shipyard
Ship & Offshore Structure Company

effectively. These operations demand that the AUV clear the following major technological challenges: 1. A body that withstands enormous water pressure in deep seas, 2. Means to receive power, 3. Autonomous navigation controllability, and 4. Capability to accurately collect data for maintenance and management.

Kawasaki’s commercial AUV is designed to navigate at depths up to 3,000 m, which applies 30 megapascals (MPa) of pressure to the AUV or 3,000 t of load to a 1 m x 1 m area of the vehicle. To resolve these challenges, Kawasaki’s submersible technologies were utilized, which involved the use of water-pressure-resistant and anti-corrosion components.

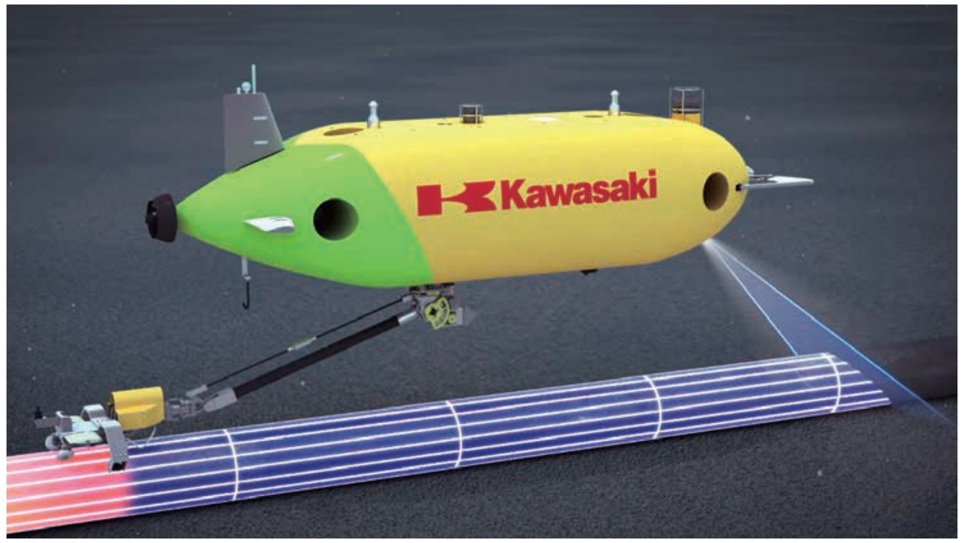
First-of-Its-Kind Docking Station Ensures Operator Safety

To supply power to the AUV, Kawasaki has developed a completely new docking station method. Commenting on the idea behind the development, Noriyuki Okaya, Manager of the AUV Department at Kawasaki’s Ship & Offshore Structure Company, says, “The most dangerous phases in the operation of an AUV are when it is launched into the water and when it is recovered. Underwater power charging and data transfer can reduce the danger and improve operational efficiency.”

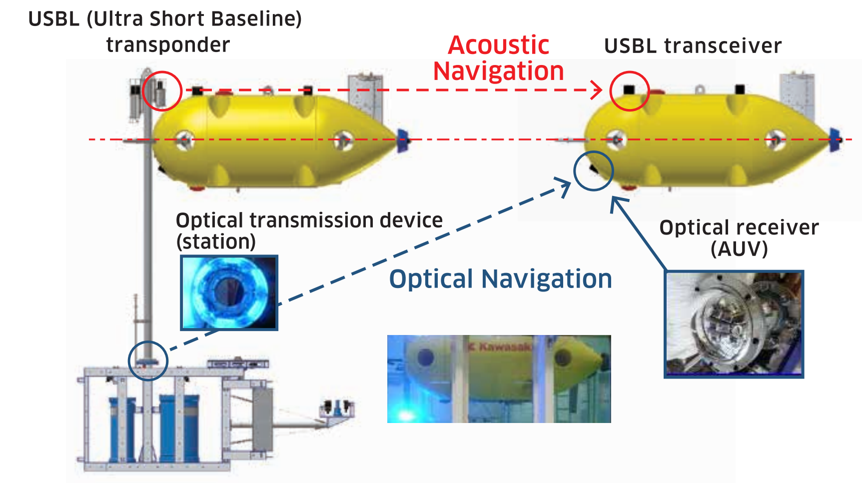
This is the procedure: When its battery requires recharging, the AUV locates the docking station using acoustic signals. As it approaches the station, it is navigated optically and the vehicle catches the pole of the docking station using an M-shaped connecting device found on one end of the AUV. The vehicle's position is then fine-tuned using optical communication, the docking is completed, and power

Kawasaki's Commercial AUV Specifications (Summary)

Length	4.0 m
Width/Width including fins	1.2 m/2.0 m
Height/Height including fins	0.9 m/1.5m
Weight	About 1.7 t
Speed	4 kt
Mission depth	3,000 m
Battery	Lithium-ion polymer batteries
Mission time	8 hours
Charging time	4 hours
Propulsion system	1 main thruster 2 horizontal thrusters 2 vertical thrusters
Navigational instruments	Inertial navigation system, sonar
Safety systems	Ballast release system Iridium communication device

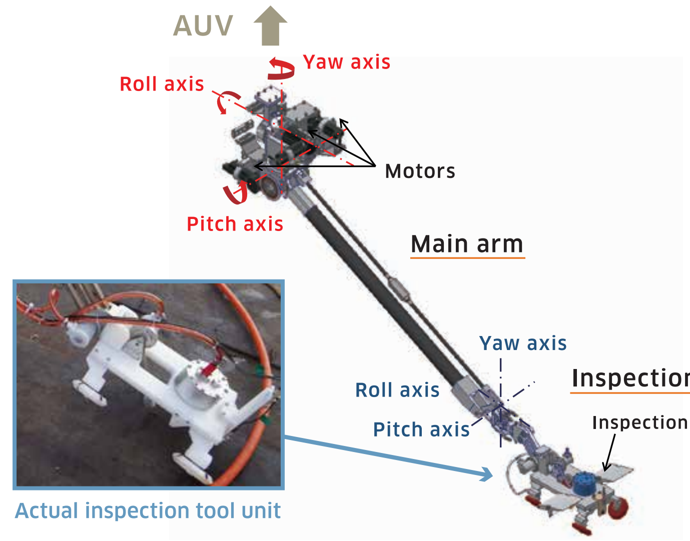


Automated Docking Technology

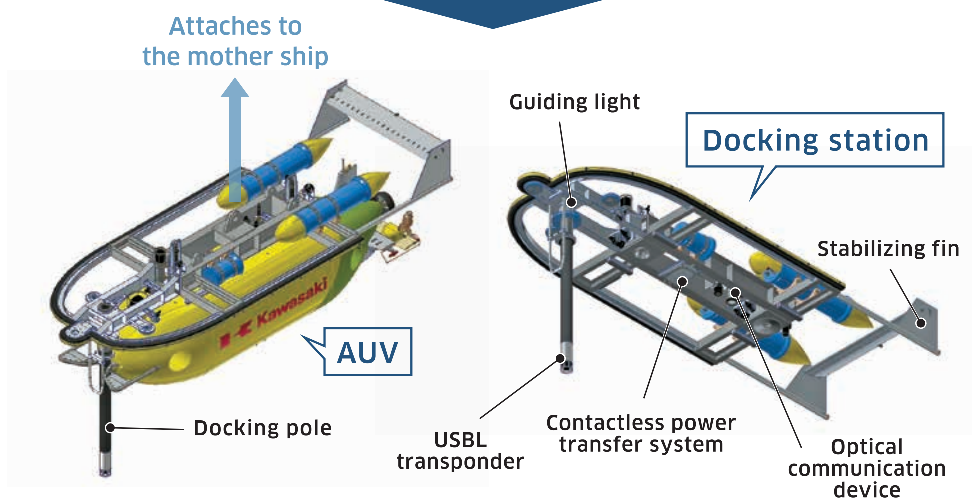


The above shows a docking station for the prototype AUV. Using both acoustic signals and optical communication, the AUV is connected to the docking station for battery charging and data transfer.

Robot Arm Technology for AUV



Commercialization of AUV for Pipeline Inspection



For the commercial AUV, we flipped the docking station, so that both the AUV and the station can be recovered together. Because this method involves no divers, operational safety has significantly improved.

recharging and data transfer begin. Charging is done using a contactless power transfer system, and data transfer is accomplished via optical communication.

The demonstration prototype AUV "sat" on the station to dock, but for the commercial version, Kawasaki completely reversed the concept so the station is suspended from the mother ship. Okaya adds, "By suspending the station from the ship, the AUV can be recovered or launched together with the station since the AUV is firmly tethered to the station. This is a more efficient and safer mechanism because it doesn't involve divers or boats to deploy or recover the AUV."

Accurate Inspection by Robot Arm — Another World's-First Achieved Through Technological Collaboration

Control technologies required for the vehicle's autonomous navigation were developed mainly by the Corporate Technology Division in Kawasaki. A method for automatically tracking pipelines was developed through a collaboration with Heriot-Watt University in Scotland, which is known for its excellent research on AUVs.

Kosuke Masuda
Assistant Manager
AUV Department, Kobe Shipyard
Ship & Offshore Structure Company

Another unique development in this system is the robot arm used for inspections, since an AUV equipped with a robot arm inspection device is a world's-first. The arm swiftly detects the condition of the pipes so maintenance work can begin as early as possible. This results in improved overall productivity and longer asset life.

For the commercial version, the arm is extended from the bottom of the AUV and has a wheeled base at the arm's tip which is packed with various sensors for inspection. The wheels of the base roll on the pipes as the base advances.

Kosuke Masuda, Assistant Manager of the AUV Department, who was in charge of developing the robot arm, explains, "Many of the AUVs developed by other companies inspect the pipeline from a distance, which makes it difficult to collect precise data. However, the robot arm can place the sensors close to the pipes and collect precise and accurate data."

When the AUV sways due to tidal currents, the arm absorbs the movement and continues to operate stably. Because the arm must function under the harsh conditions of 3,000 m below the surface, as mentioned earlier, its designing was far from easy.

Masuda adds, "We applied technologies developed through designing and constructing submersible vessels to the mechanism and structure of the arm dedicated to the AUV. We also received technical support from the Precision Machinery & Robot Company in Kawasaki to incorporate the accuracy and precision of industrial robots. Commercial AUVs are packed with Kawasaki's cutting-edge technologies."

Public Demonstration Praised by Oil Field Developers

Performance tests for commercial AUVs are currently being conducted in Okinawa and Awaji Island. Using the previous generation prototype, we conducted a public demonstration in Scotland in November 2017, to which local personnel associated with the subsea oil industry were invited.

According to the industry journal which immediately covered the event, the guests gave high ratings to the tests. Their comments included, "I was impressed by its high hovering performance during the time it was subjected to a 1 kt-class fast tidal current," "I found the system compact, considering that its contactless underwater power output was 5 kW-class," and "It's important for AUVs to have more applications, such as inspection systems. I'd like to talk to Kawasaki more specifically about them."

Okaya comments, "Speaking of the future of oil field maintenance, we expect that the roles of ROVs and AUVs will be more clearly divided: ROVs will be used for heavy-duty projects such as pipe replacements and AUVs will perform inspections and other less heavy-duty missions."

In 2021, the world will see the first commercial AUV tasked with the mission of protecting subsea oil fields and thereby supporting global energy use.

A pipeline inspection simulation test held in the sea off Okinawa.

A Leader's Voice

Hiroshi Sakaue
Senior Manager, AUV Department
Kobe Shipyard, Ship & Offshore Structure Company

Innovative Technology Quietly Supporting Global Energy Supply from the Ocean Floor

For decades, Kawasaki has been building Soryu-class submarine vessels, deep submergence rescue vehicles (DSRVs), and other submersibles. We have thereby accumulated a wealth of technologies for underwater operations over the years. Actually, before we completed the AUV *Marine Bird* in 2003, we had already established the basic technologies for automated docking and contactless supplying of energy.

For the development of this commercial AUV, and in continuation of our R&D efforts, we reverified component technology to resolve various challenges, including the supplying of energy, autonomous navigation control, and underwater communications. Fortunately, Japan enacted the "Basic Act on Ocean Policy" in 2007, to promote the protection of maritime rights, and decided to support the development of such technologies. As a result, our development program for the AUV was subsidized, allowing us to continue with our research on unresolved challenges.

This program supported our undertaking to develop not only automated docking and contactless power transfer technologies, but also measurements to be carried out by the robot arm and autonomous navigation control algorithms — both world's-first achievements. We intend to collaborate with our customers to upgrade the inspection unit at the tip of the robot arm. We also plan to utilize the robot arm for applications beyond the maintenance and inspection of subsea pipelines and would like to see it used with umbilicals for power transfer and control signal transmission, for offshore wind farm cables used for transferring power to onshore facilities, etc.

In 2019, we established Kawasaki Subsea (UK) Ltd. (KSUK) in Aberdeen, Scotland, UK, which is a hub city for North Sea oil firms, to focus not only on the sale of AUVs, but also on reinforcing our ability to collect information on customer needs regarding AUV features. Based on the knowledge gained, we plan to launch the first commercial AUV into global markets in 2021.

Because the world's demand for oil as an energy source is still strong, the trend to go deeper into the sea to extract oil will accelerate. This means that the length of subsea pipelines will be extended, and various types of control equipment will have to function under harsher operational conditions. I am proud that we can deliver AUVs to the world in order to support global energy demand — quietly, from the bottom of the sea.

Looking Forward to Tomorrow

Commercial AUV Achieves Higher Speed and Longer Mission Time than Demonstration Stage

Kawasaki developed a prototype AUV for demonstration tests in FY 2017 after verifying the technology for each component. Concurrently, the company was engaged in a separate project to develop the robot arm, which was completed and later attached to the prototype AUV for verification tests that began in FY 2018. The test results were used to improve the commercial version, resulting in a more streamlined shape, significantly faster navigational speed, and longer mission time — features which led to a drastic improvement in the inspection distance needed for commercial AUVs.