The Development of the Deep Sea Cruising AUV Urashima

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1. INTRODUCTION

In order to elucidate the mechanism of global warming, it is necessary to study the global moving process of CO_2 in the sea. Many geochemical scientists want to gather efficiently a lot of water samples of various sea depths all over the world for this purpose. The manned submersibles and ROVs, which have been used in the deep-sea observation, are not suited for such role. These mission require not the traditional submersibles for minute observation of one point but the new marine robot which runs about more widely in the sea and collects data automatically. One of the answers is the Autonomous Underwater Vehicle (AUV).

JAMSTEC (Japan Marine Science and Technology Center) started on the research and development project of AUV capable of performing long range missions in the deep sea in 1998 fiscal year. The first experimental AUV was constructed, and some performance tests in a dock were carried out by 1999 fiscal year. The vehicle was named Urashima (Code name : AUV-EX1) after a hero of a Japanese famous old tale. He rode on a sea turtle and went to the castle in the deep sea.

In this paper, we briefly summarize the development of the AUV Urashima.

2. THE VEHICLE

A general arrangement of the vehicle is shown in Figure 1, and the key design parameters are listed in Table 1. As Urashima can choose his power source from battery and fuel cell, there are two general arrangement plans. This figure shows the arrangement with lithium-ion battery.

As the nominal speed of the vehicle is relatively higher than ROVs, it has a streamlined shape and an oval cross section for reducing hydrodynamic drag. The sub-

Table 1 Principal Particulars

Design Parameter	Value
Length-Over-All	9.7 m
Width-Over-All	2.55 m
Height-Over-All	2.4 m
Width (Shell)	1.3 m
Height (Shell)	1.5 m
Working Depth	3,500 m
Displacement	8 ton
Range	300 km
Speed (Cruising)	3 kt
Speed (Maximum)	4 kt

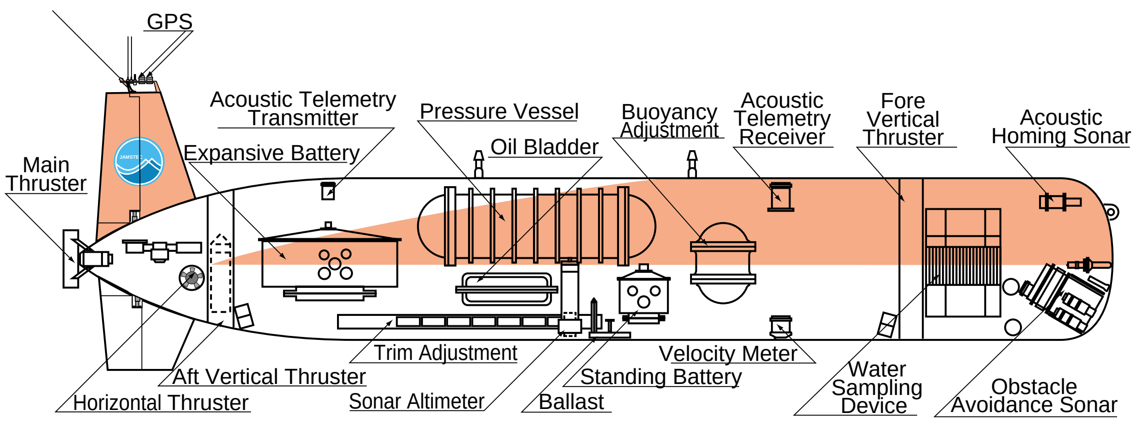

Fig. 1 General Arrangement of Urashima (Lithium-Ion Battery)

Fig. 2 Inside of Urashima

Fig. 3 Photograph of Urashima

marine type, which has one pressure hull with a ballast tank, is not a suitable structure. This type can not be used over about 1000 meters deep, because the plate thickness of pressure hull increases proportionally to the working depth. The vehicle consists of titanium frames with some pressure hulls and buoyancy material covered with FRP cover. (Figure 2) This type entails a severe quality control, and the maintenance operations are complicated, but it has many excellent features. The working depth of the AUV is 3500 m, and it can dive deeper if buoyancy material and pressure hulls are changed.

Figure 3 is a photograph of Urashima in the dockyard. The AUV has a main thruster (about 1.5 kW), two up-and down thrusters (500 W x 2) and a side thruster (500 W). The cruising speed is 3 knots, and the maximum speed is 4 knots. Combining these can control all thrusters and both vertical and horizontal rudders, the moving of the AUV.

3. POWER DEVICES

3.1 Lithium-ion Battery

A new lithium-ion rechargeable battery developed for the AUV is very high capacity, and it is more than 100 Ah cell. The energy density is 150 Wh/kg that is 1.5 times higher than that of silver-zinc battery used for the manned research submersibles "Shinkai 6500" and "Shinkai 2000." The lithium-ion battery is rechargeable more than 500 times, and that is a remarkable improvement over those currently used.

This battery will be installed in the initial stage of development.

3.2 Fuel Cell

The battery is heavier if its capacity is larger. It seems that the long-range vehicle with battery is too heavy and large to handle it easily. In order to extend its cruising range, we plan to replace out the battery with the fuel cell. The fuel cell is electrochemical devices with no moving parts that convert chemical energy into electrical energy without combustion and releasing only pure water into the atmosphere. The reactants in this conversion are hydrogen (fuel) and oxygen (oxidant). The main difference between these two power sources is that a fuel cell's energy is supplied continuously by converting external sources of fuel and oxidant, while a battery stores its energy internally. Unlike the battery, the fuel cell has no finite storage capacity, as long as it can be continuously supplied with reactants.

The fuel cell has lately attracted considerable attention as a power device for automobile in the next generation. Rapid development follows the competition, but the fuel cell for automobile cannot be adapted directly to that for using in the special environment such as in the deep sea.

Of various fuel cell systems considered, the polymer electrolyte fuel cell technology (PEFC) seems to be most suitable for aquatic transportation applications. The PEFC operates at efficiencies above 50%, at low temperature (about 80 ˚C). It is best type for using in a closed space. We have been performing the research and development of the fuel cell for operating in the deep sea during the past ten years, and the 1.5 kW type testing fuel cell was already developed and tested in 1993[1]. It was installed

Fig. 4 Photograph of Fuel Cell

in the pressure vessel, and the product water circulated among it.

Based on these experiences, we have developed the new fuel cell for the AUV. Figure 4 is a photograph of the new fuel cell installed in the tentative pressure vessel. It has two stacks in parallel. As each stack generates 2 kW electricity, the output of this fuel cell is 4 kW, enabling the vehicle to operate at three knots for 54 hours. A 300 km cruise can be completed. In case of operating with fuel cell, a hydrogen tank and an oxygen tank are installed on the AUV.

4. NAVIGATION MODES

4.1 Autonomous Navigation Mode

According to its mission, we can adopt an operational mode of the AUV from three modes shown in Figure 5.

The meaning of "autonomous" in "AUV" seems different from that used in the robotics. It means only "untethered" or "preprogrammed". Almost all AUVs do not have the artificial intelligence, and neither does our Urashima.

In this mode, the working schedule is preset on the on-board computer before each mission. The schedule includes the cruising course, procedure of observation and exploration device. The mother ship only used at the landing and pickup, and the AUV cruises independently without any communication.

When the AUV notices some obstacles in front of it, it takes an avoidance action by itself. In case of long range cruising, some acoustic transponders as an acoustic lighthouse are arranged along the cruising course to make a positioning accuracy higher.

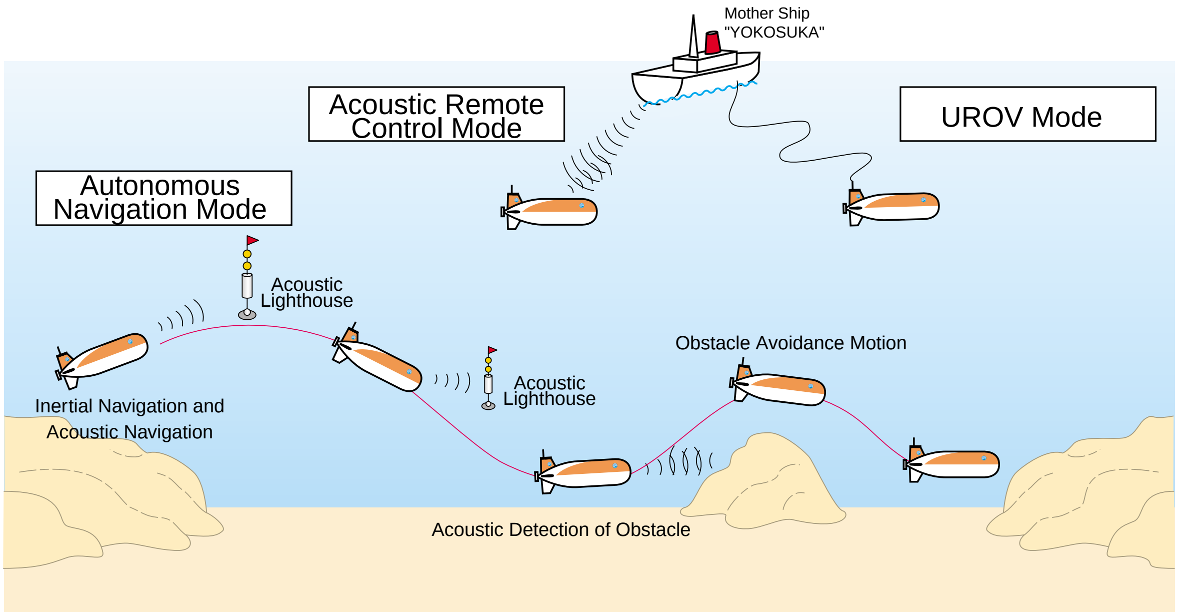

Fig. 5 Three Navigation Modes

4.2 Acoustic Remote Control Mode

In this mode, the mother ship follows the AUV at any time, and they communicate each other. Though the on-board computer is preset as same as the autonomous navigation mode, the new working schedule can be transmitted from the mother ship by acoustic telemetry. The images of the acoustic picture device and the TV camera transmitted from the AUV can be observed on board at few-minute intervals.

4.3 UROV Mode

The UROV mode uses a thin optical fiber cable, 1 mm in diameter, and control and return signals are sent through the fiber. The cable is expendable and reeled out freely both from the vehicle and on board fiber reel during the operation. After each operation, the cable that was reeled out is cut and spliced again for the next operation. The UROV technology was developed for eliminating the thick and heavy cable from deep diving ROVs [2]. This mode is selected at the technically feasible stage for the AUV.

5. NAVIGATION ASSISTANT DEVICES

Performing long-range missions requires an accurate inertial navigation system (INS) and a hybrid system have been developed. Three sets of ring laser gyros (RLGs) and accelerometers are installed in the INS, used in the pure inertial navigation mode. The RLG developed for H-II rocket has the high resolving power, under 0.025˚. The hybrid mode provides precise navigation by combining data from gyros and Doppler sonar. The Doppler sonar can choose automatically the velocity against the seabed and the water according to circumstances.

Fig. 6 Photograph of Water Sampler System

The global positioning system (GPS) can be also used on the sea. When the AUV finishes the mission and surfaces, he checks his position by GPS and reports it through the satellite communication. This system defuses an accidental loss of the AUV.

The acoustic homing sonar and the obstacle avoidance sonar are also used as navigation assistant devices.

6. OBSERVATION AND EXPLORATION DEVICES

A variety of observation instruments, the color TV camera, the snap shot digital camera, the acoustic image device and the side scan sonar, are installed in the AUV.

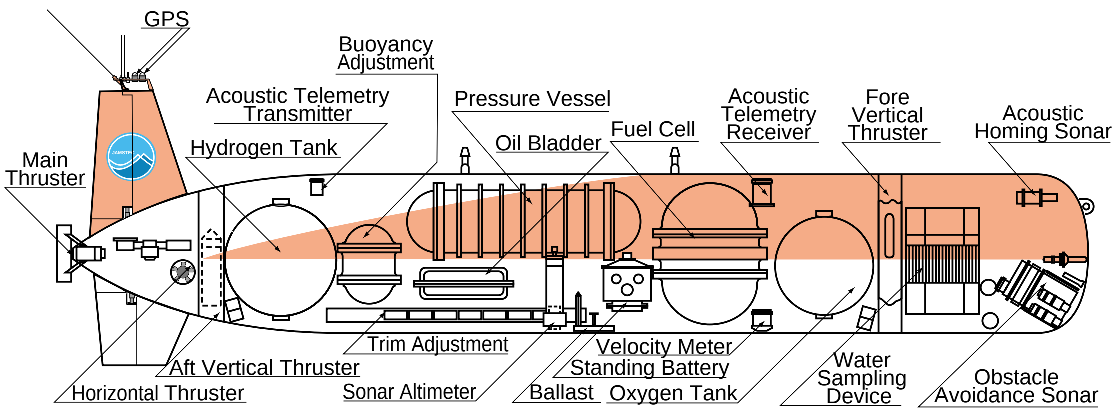

Fig. 7 General Arrangement of Urashima (Fuel Cell)

The snap shot digital camera, which is the 16 bits cooling type supersensitive CCD camera, can take landscape photos every 8 seconds from 8 - 40 meter above the bottom. The acoustic image device does double duty as an obstacle avoidance sonar. It can visualize the two-dimensional and quasi-three-dimensional landscapes from reflect signal and delay time of super sonic. The AUV navigates maintaining a certain depth, from 100 to 200 meters, getting topography and earthiness by the side scan sonar.

The AUV is also equipped with many exploration devices. The CTDO can measure contiguously conductivity of seawater, water temperature, depth and quantity of dissolved oxygen. The automatic water sampler system (Figure 6) can collect 200 water samples in navigation. The collected water samples are analyzed content of $_{14}C$, which indicates the dissolved carbon dioxide by the Tandetron type accelerator mass spectrometer. The AUV can be equipped alternatively with the automatic water sampler system or the side scan sonar.

7. CONCLUSIONS

From 2000 fiscal year, the trials of Urashima are scheduled to start. After the fundamental performance test at the quay, trials using the UROV mode will be conducted in the sea to confirm the reliability. The trials of the fuel cell, mean while, will be performed on the ground. The fuel cell will be tested with rolling and pitching to probe the durability against oscillation. It will be installed in the AUV from 2002 fiscal year. Figure 7 shows a general arrangement of the AUV with the fuel cell.

JAMSTEC is interested in the exploration and study of the Arctic Circle, in order to the meteorological prediction on a global scale, and wants to apply AUVs to an arctic observation under ice plate. AUVs need to overcome this severe condition and the wall of distance. Urashima is the first step of this target. To achieve goals such as increased accuracy, long-range capacity and improved service to scientists, improvement of Urashima has just begun.

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