Key Technologies for AUV "URASHIMA"

Tadahiro Hyakudome*, Taro Aoki*, Takashi Murashima*, Satoshi Tsukioka*,
Hiroshi Yoshida*, Hidehiko Nakajoh*, Tadahiko Ida*,
Syojiro Ishibashi**, Ryoko Sasamoto**
*Japan Marine Science & Technology Center (JAMSTEC)
2-15 Natsushima Yokosuka 237-0061 JAPAN
** Tokyo University of Mercantile marine
2-1-6 Etchujima Koto-ku 135-8533 JAPAN

***Abstract*- A deep and long cruising range AUV (Autonomous Underwater Vehicle) named "URASHIMA" (AUV-EX1; development code name), has been developed by JAMSTEC since 1998. URASHIMA can cruise long distance in the sea and collect sea data and water samples automatically for offshore exploration.**

The dimensions and weight of URASHIMA are 10m(L), 1.3m(W), 1.5m(H), and about 7.5 tons in the air. There are two very important key technologies for a long cruising range autonomous underwater vehicle. One is power source. URASHIMA has two types of power sources. One is high capacity Lithium-ion rechargeable battery. The other one is solid Polymer Electrolyte Fuel Cell. With these power sources the vehicle capable of performing long ranges missions. The estimated cruising ranges are about 100km by using battery and about 300km by using fuel cell each other at three knots. The other one is navigation system. The AUV cruises independently without any communications between mother ship and vehicle. It is very important to know its present position and forward environment. URASHIMA has highly accurate navigation sensors, such that Inertial Navigation System (INS) consists of three sets of Ring Laser Gyro and accelerometers, Obstacle Avoidance Sonar (OAS), Doppler Velocity Log (DVL) and acoustic homing sonar. The AUV enable long distance cruising independently with these navigation sensors.

The sea-going tests have been started since June 2000. The equipment, hard-wear, soft-wear, and autonomous functions, will be improved gradually. In these sea trials, URASHIMA achieve to dive 3,518m depth and cruise 132.5km distance by autonomous navigation mode.

I. INTRODUCTION

Even if the global environment problem such as global warming becomes serious year by year, we cannot elucidate the mechanism of it until now. The anomaly should be caused by the unbalance of heat or the interaction among atmosphere, ocean, etc. From this point of view, we are conducting researches for the clarification of the mechanisms of circulation and perturbation of ocean. These missions require Autonomous Underwater Vehicle (AUV) that is enable to cruise long distance and collects oceanic data and water samples automatically. For this purpose, we started on the research and development project of AUV capable of performing long ranges missions since 1998.

A deep and long cruising range AUV (AUV-EX1: development code name) named "URASHIMA" was completed in 2000. The sea-going tests have been started since June 2000.

Two important key technologies need to long cruising range type AUVs. One is power source for long operational time. The other one is high accuracy navigation system because of the vehicle works without help from support vessel. It is very important for autonomous vehicle to know accurate its present position.

In this paper, we show the outline of URASHIMA, power source, navigation sensors and experimental results.

II. THE VEHICLE

A. The Construct Of The Vehicle

URASHIMA is shown in Fig.1, and specifications are listed in Table 1. The vehicle has a cylindrical shape for reducing hydrodynamic drag in order to the vehicle can cruise long range distance with limited energy.

The vehicle consists of titanium frames, some pressure hulls for protecting control system and other electrical devices from water pressure of 3,500m depth and buoyancy materials for additional buoyancy. The body is covered with Fiberglass Reinforced plastics covers.

URASHIMA has a main thruster (1.5kW power of a DC brush-less motor) for cruising, two vertical thrusters, one horizontal thruster and a pair of vertical rudders, a pair of horizontal rudders in order to control depth and heading.

Fig.1 AUV "URASHIMA"

TABLE1 Specifications of URASHIMA

		Power source:
		Fuel Cell (PEFC) and LI-ion
Length-Over-All:	9.7 m	rechargeable batteries
Width-Over-All:	2.55 m	
Height-Over-All:	2.4 m	Navigation instruments:
Width (Shell):	1.3 m	Inertial Navigation System, Acoustic
Height (Shell):	1.5 m	Doppler Current Profiler, Acoustic
Weight in the air:	7 ton	Homing Sonar, Obstacle Avoidance
Working Depth:	3,500 m	Sonar
Cruising Range:	300 km	
Speed (cruising):	3kt	Sensors instruments:
Speed (maximum):	4kt	TV camera, CTDO, Side Scan Sonar,
		Water Sampler, Digital Camera

B. Observation And Exploration Devices

URASHIMA is equipped with variety of observation instruments such as a color TV camera, a low light level snap shot digital camera, an acoustic image device and a side scan sonar. The acoustic image device has another function as the obstacle avoidance sonar. The digital camera can take seabed photos every 8 seconds from 4 to 40 meters above the seabed.

The vehicle also equips CTDO sensors and an automatic water sampler (Fig.2) as exploration devices. The CTDO can measure continuously conductivity of seawater, water temperature, depth and quantity of dissolved oxygen. The automatic water sampler system can collect 200 water samples during one cruising.

Fig.2 Automatic water sampler

C. Navigation Modes

According to mission type, we select one operational mode from three modes such as autonomous navigation mode, acoustic remote control mode and UROV mode shown in Fig.3.

In autonomous navigation mode, working scenario is preset on the onboard computer before each mission. The scenario includes the cruising course, procedure of observation and exploration devices. The mother vessel is used only at the launching and pickup, and URASHIMA cruises independently without any communication between mother vessels.

In acoustic remote control mode, the mother vessel follows the vehicle at any time, and they communicate each other during observation cruising. Though the onboard computer is preset as same as the autonomous navigation mode, new working scenario can be transmitted from the mother vessel by acoustic telemetry. The images of the acoustic picture device and the TV camera transmitted from the vehicle every a few seconds interval.

The UROV (Untethered Remotely Operated Vehicle) mode uses a thin optical fiber cable and control and return signals are sent through the fiber cable. The diameter of fiber cable is only 1mm. This mode is used at development stage for watching status of the vehicle.

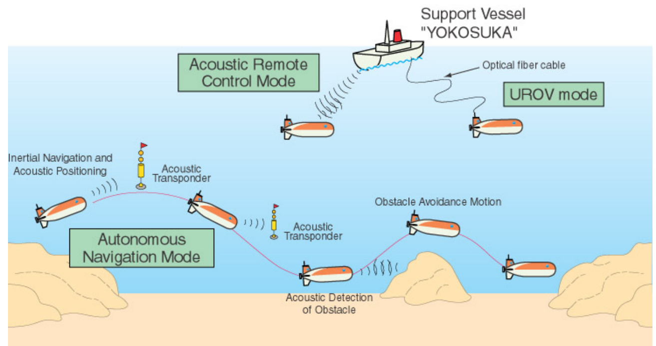

Fig.3 Three navigation modes

III. POWER SOURCES

The power source is one of the most important devices for autonomous underwater vehicle with long operational time. We develop two power sources these are Lithium-ion rechargeable battery and fuel cell for URASHIMA.

A. Lithium-ion rechargeable battery

A new Lithium-ion rechargeable battery developed for the vehicle. The general arrangement with Lithium-ion battery is shown in Fig.4. The appearance of the battery is shown in Fig.5. It is very high capacity, and it is more than 100Ah cell. The energy density is 150Wh/kg. This battery uses early stage of the vehicle development because the fuel cell is under development at same time. URASHIMA is able to cruise over 100km distance with this battery. And operational time is about 30 hours. But the aim of our AUV is 300km cruising.

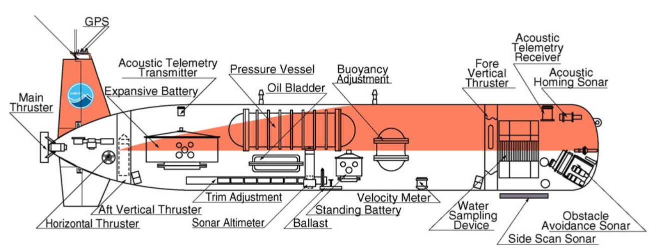

Fig.4 General arrangement with Lithium-ion battery

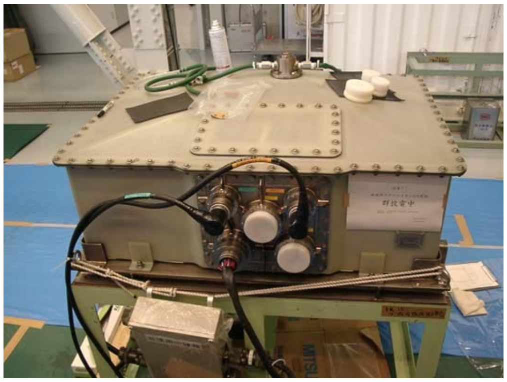

Fig.5 Lithium-ion rechargeable battery

B. Fuel Cell

The battery becomes heavier if its capacity is lager. It is too heavy and large to handle the long cruising range vehicle easily. We plane to replace with fuel cell in order to extend cruising range of URASHIMA. The fuel cell is electrochemical device with no moving parts that convert chemical energy into electrical energy and releasing only pure water. Fuel cell uses reactant of hydrogen and oxygen.

Of various fuel cell systems considered, the solid Polymer Electrolyte Fuel Cell (PEFC) seems to be most suitable for underwater vehicles. The PEFC operates at efficiencies above 50% and at low temperature about 80 degrees centigrade. It is best type for using in a closed space.

Fig.6 shows general arrangement with fuel cell system. The PEFC for URASHIMA is closed loop system (Fig.7). This system has two stacks in series. As each stack generate 2kW electricity, the output of this system is 4kW. This system is enabling the vehicle to operate at three knots for 54 hours and 300km cruise. In case of operating with fuel cell, the system is installed in pressure hull and hydrogen and oxygen tank are installed in the vehicle.

The PEFC system is under developing and testing several performances such as long time generation, stable generation under oscillated condition on the land and so on. The system will be installed in the vehicle in March 2003.

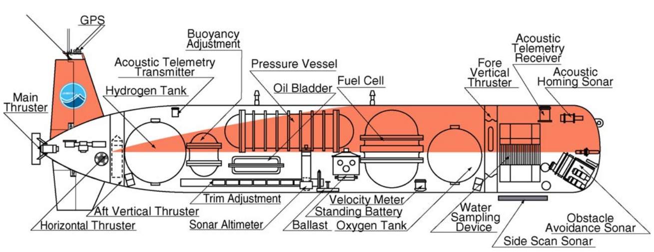

Fig.6 The general arrangement with fuel cell system

Fig.7 the solid polymer electrolyte fuel cell system

IV. NAVIGATION SYSTEM

High performance navigation system is the other most important key technology for long cruising range AUV. The vehicle required accurate cruising along the preset observation line without any reference from support vessel and GPS. The vehicle needs high accurate navigation system for finding out its position by itself.

URASHIMA has high accuracy Inertial Navigation System (INS) shown in Fig.8. This system consists of three sets of Ring Laser Gyro (RLG) and accelerometers. The error rate of RLG is in 0.2 nautical miles per hour. The vehicle also has Doppler Velocity Log (DVL) for more accurate positioning. The hybrid mode provides precise navigation by combining data from INS and ADCP. In case of long range cruising about 300km, some acoustic transponders as an acoustic lighthouse are arranged along the cruising course to make a positioning accuracy higher.

URASHIMA needs to find out any obstacles in front of it as soon as possible for safety. The vehilce has Acoustic Image device in the front shown in Fig.9. This device use obstacle avoidance sonar too. The vehicle can know about 100 meters short of the obstacles. When the vehicle notices some obstacles in front of it, it takes an avoidance action by itself.

Fig.8 Inertial Navigation System and Ring Laser Gyro

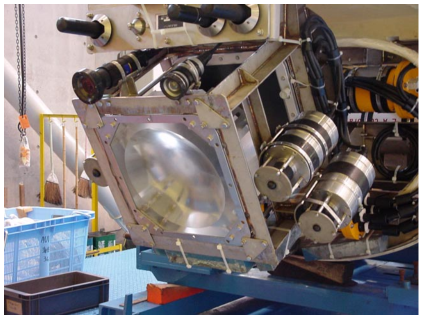

Fig.9 Acoustic image device

V. SEA TRIALS

The development project of URASHIMA has been started on 1998. The construction of the body is completed in March 2000. We carried out 9 times of sea trials until now. In 2000 sea trials, we tested control program of the system, function of observation and exploration devices and motions of the vehicle. In these sea trials, URASHIMA achieved to dive over 3,500m depth and cruise over 100km distance by autonomous navigation mode. We show some experimental results in this section.

Fig.10 shows the track of the vehicle at 3,518m diving. The diving point was Naze basin in Amami-Oshima eastward offshore. The track was taken by inertial navigation system installed in the vehicle. From surface to 300m, the vehicle was controlled by UROV mode, after over 300m, the vehicle was controlled by acoustic control mode. A picture shown in Fig.11 is transmitted from the vehicle at 3,518m depth to the support vessel by acoustic telemetry. The picture was taken by TV camera. The picture was transmitted every 8 seconds by 512 dots (horizontal resolving power) x 224 lines (vertical scanning lines).

Fig.12 shows the track of the vehicle at autonomous function test. Initial point is 5km from transponder (TP) 1. At first go to TP1, then reach in the radius 2km area from TP 1 turn to go TP2, next reach in the radius 2km area from TP 2 turn to go north. Cruising speed was 2.5 knot and depth was 800m. Indicated by blue line shows track taken by inertial navigation system. Indicated by red line shows track taken by acoustic positioning from support vessel. The blue line is good agreement with red line that shows the high accuracy of calculated position by inertial navigation system. The nonlinear part of blue line is position update point of inertial navigation system by communicate with transponder.

Fig.13 shows the track of the vehicle at long cruising trial by autonomous navigation mode. Initial point is about 30km away from TP 1, and the vehicle went to north. Cruising speed was 2.5 knot, depth and cruising time was about 28 hours. The track was taken by acoustic positioning from support vessel. At this trial, the vehicle achieved 132.5km cruising distance by autonomous navigation mode.

Fig.14 shows acoustic image of seafloor. The image was taken at 900m depths in SURUGA Basin. The vehicle closes to seafloor step by step from No.1 to No.8. The most closed area indicated by red becomes widely.

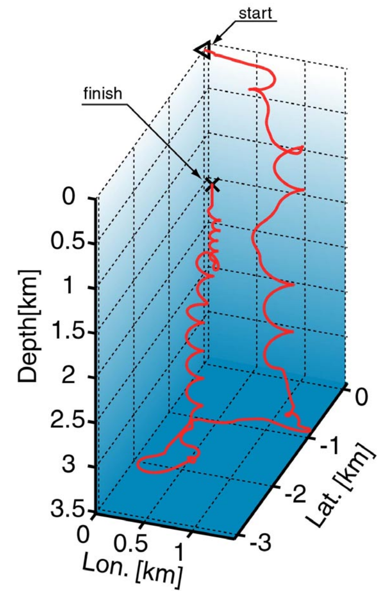

Fig.10 The track at 3500m diving

Fig.11 TV camera image transmitted by acoustic telemetly

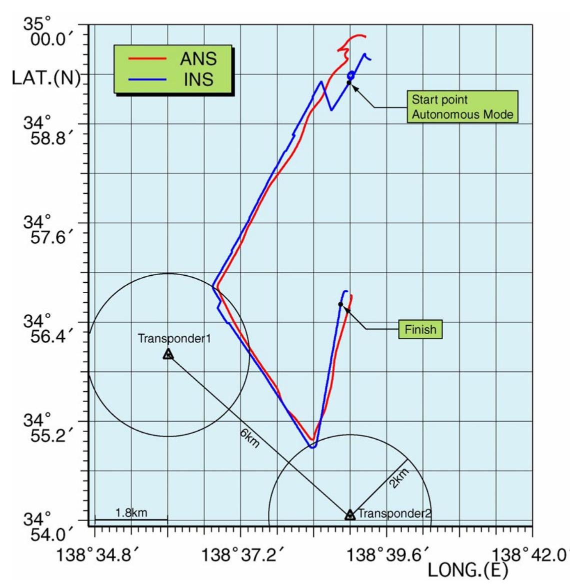

Fig.12 The track at autonomous function test

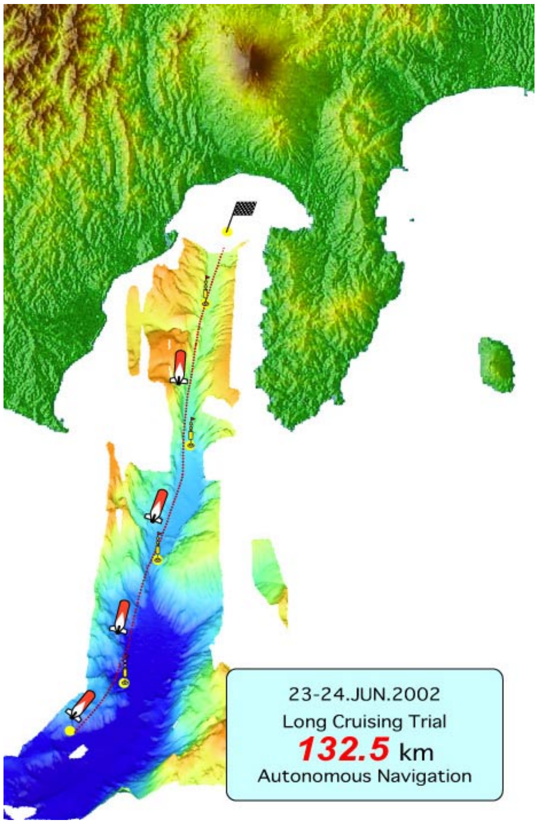

Fig.13 The track at long cruising trial

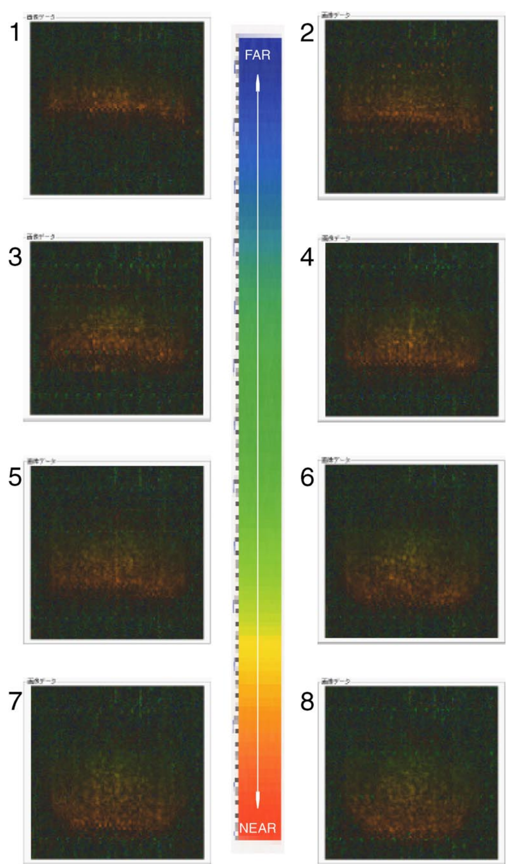

Fig.14 Acoustic image of seafloor

VI. CONCLUSIONS

JAMSTEC has planned to build deep and long range AUV since 1998. The AUV named URASHIMA was completed in March 2000. We have been carried out 9 times sea trial until now. We got some successful results shown in section V. URASHIMA will replace power source from Lithium-ion battery to fuel cell in March 2003. And the vehicle aim at 300km cruising.

The Arctic Ocean is difficult to collect oceanographic data since surface is covered with ice, but the area is very precious because of the effect of global environmental change remarkably appears. JAMSTEC is interested in the exploration and study of the Arctic Ocean, in order to the meteorological prediction on a global scale, and wants to apply AUVs to an arctic observation under ice plate. A long cruising AUV need to overcome this severe sea condition and huge range observation. URASHIMA is the first step of this aim. We need increase accuracy of positioning, long range capacity and improve service to scientists to achieve goals. Improvement of AUVs have just begun.

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