Working-AUV "Otohime" and its sea trials at Sagami Bay

Takeshi Nakatani, Shojiro Ishibashi, Tadahiro Hyakudome, Makoto Sugesawa, Yutaka Ota, Hiroshi Ochi, Yoshitaka Watanabe, Takao Sawa, Yoshiyuki Nakano, Takeshi Kumagai*, Susumu Sato*, and Hiroshi Yoshida

Marine Technology and Engineering Center (MARITEC)
Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
2-15 Natsushima-cho, Yokosuka 237-0061 Japan E-mail: tnakatani@jamstec.go.jp

*SAS CO., LTD
1-1-14 Taito Taito-ku Tokyo, 110-0016 Japan

***Abstract*— Since October 2010, JAMSTEC has developed two autonomous uderwater vehicles (AUVs); a cruising-AUV "Jinbei" and a working-AUV "Otohime" (Fig.1). Their major purposes are to observe underwater CO_2 distribution around carbon dioxide capture and storage field, and to explore seabed mineral resources in Japan's EEZ. The cruising-AUV performs wide area survey with sonars and chemical sensors. According to the survey results, the working-AUV "Otohime" accesses feature points and observes seafloor in detail, with its chemical sensors, cameras, and a manipulator.**

In this paper, we introduce the newly developed AUV "Otohime" and its sea trials at Sagami Bay. Through two dives at the depth of 80-120m for total 3 hours operation, we verified the performance of the overall hardware / software systems.

I. Introduction

Carbon dioxide capture and storage (CCS) is one of key technology for reducing of the total greenhouse gas. JAMSTEC has tried a feasibility study of CCS using geobiological processes in a deep subsurface [1]. For assessment of the effect on environment, it is important to survey regularly underwater CO_2 distribution and benthic environment around the field.

We have proposed to apply two types of AUVs to such surveys, as shown in Fig.3 [2]. Firstly, a cruising-AUV performs wide area survey with sonars and chemical sensors. According to the survey results, a working-AUV accesses feature points and observes seafloor in detail, with its chemical sensors, cameras, and manipulator.

For this purpose, we have developed cruising-AUV "Jinbei" [3] [4] and working-AUV "Otohime" [5]. In this paper, we introduce the working-AUV and its sea trials at Sagami-Bay, Japan.

II. The Working-AUV "Otohime"

"Otohime" is a working-AUV designed for underwater chemical observation and visual observation as well as light-duty work. The major purposes are CCS assessment and exploration of seabed mineral resources. The maximum operation depth is 3,000 meters. The AUV is equipped with following main sensors: a high-definition camera, a still camera, a stereo camera, a manipulator and a hybrid CO_2-pH sensor. The appearance, general arrangement, and specification of the "Otohime" are shown in Fig.1 and Fig.2, and Table 1, respectively.

A. Vehicle

An open frame structure was selected for robustness and ease of handing. For pitch and roll stability, the floating buoyancy material made of syntactic form is implemented in the upper part. The front part is covered with a FRP cover to reduce hydro resistance. The vehicle has two 400 watts azimuthal rotating thrusters for propulsion. The thrusters allow maximum speed of 1.5knots. The azimuth thrusters enable dynamic control when the vehicle's speed is low. At normal cruising speed, vertical rudders and horizontal rudders control the attitude and motion of the vehicle. There are one ballast releaser for diving and two ballast releasers for surfacing. The weights are 10kg each. In addition, the vehicle has a buoyancy adjustment device which can release fifty 100glums iron balls one by one. The device enables buoyancy control of the vehicle precisely. The vehicle is powered by an oil-fill lithium-ion battery. The capacity is 128V 30Ah, and the vehicle's endurance is 6 hours.

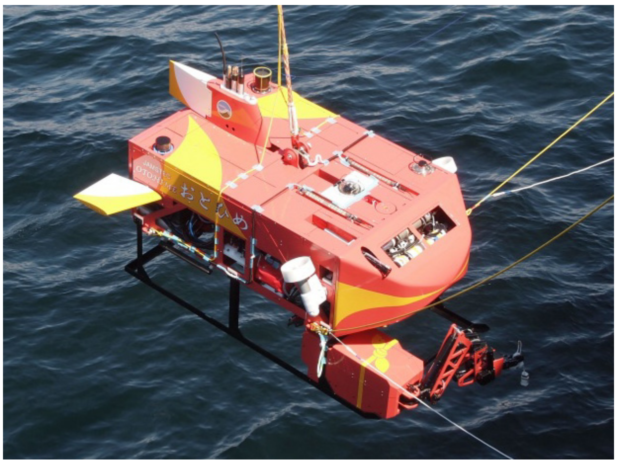

Figure 1. Autonomous Underwater Vehicle "Otohime".

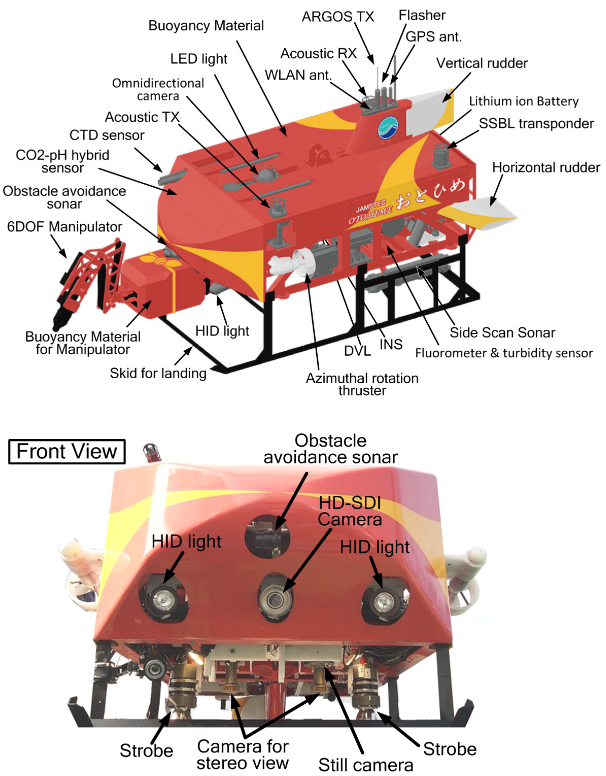

Figure 2. General arrangement of the “Otohime”.

TABLE 1 Specification of the “Otohime”.

Vehicle	
Size	2.6m(L)×2.1m(W)×1.75m(H)
Mass	842kg (935 kg with manipulator)
Max.speed	1.5 knot
Max.depth	3,000 m
Duration	6 hours
Actuators	Azimath thruster 400W × 2
	Vertical rudder× 2, Horizontal rudder× 2
Power	Li-ion Battery 128V 30Ah
OS	Linux
Communication	Wireless LAN, Acouctic comunication,
	Optical fiber comunication
Sensors	
Positoning	INS, DVL, GPS, SSBL, LBL, VLBL
Obstacle avoidance	Obstacle avoidance sonar
Scientific payloads	
Water Analyzer	CTD, pH-CO_2 hybrid,
	Fluorometer & Turbidity
Acoustic sonar	Side scan sonar
Video Camera	HDTV, Pan-tilt
Still Camera	Snap shot, Stereo
Lighting	HID x 3, LED x2
Sampling (Option)	6 DOF manipulator

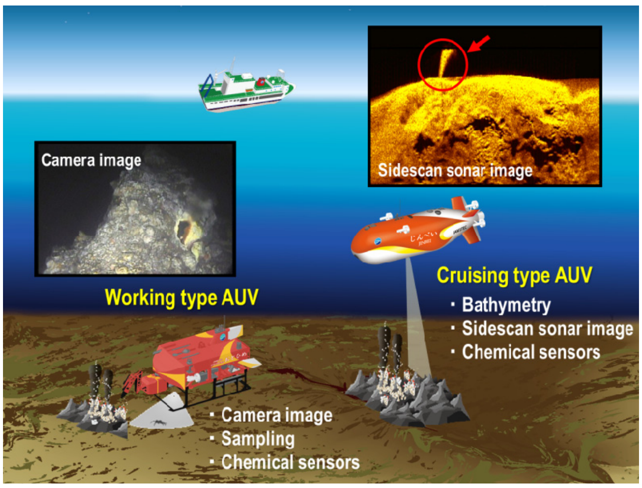

Figure 3. Oceanographic survey using AUVs.

As navigation sensor, the vehicle has a compact inertial navigation system (INS). The INS developed by JAMSTEC and JAE has ring laser gyros and enables high accuracy positioning of the vehicle [6]. It integrates information from external sensors; a 600kHz doppler velocity log (DVL), a GPS, a depth sensor, and a super short base-line acoustic system (SSBL).

A distributed CPU system controls the vehicle system [7]. CPU boards are connected via Ethernet. The OS is Linux. The system can be remotely controlled by a control equipment on board, as well as a portable tablet PC. The tablet PC; Panasonic FZ-A1 is connected to the CPU system via wireless LAN. Using the tablet, an operator near the vehicle can easily check the system information and control the equipped devices.

B. *Scientific Sensors*

The sensors for visual observation mainly consist of a high-definition camera oriented in the forward, a still camera and a stereo camera oriented in the downward. In post-processing, a 3D mosaic map of seafloor is reconstructed from images of the stereo camera.

As water analyze sensors, the vehicle is equipped a CTD sensor; SBE-49, a fluorometer & turbidity sensor; ECO FLNTU, and a hybrid CO_2-pH sensor (HCS). The HCS designed JAMSTEC is also equipped to the cruising-AUV “Jinbei” [8].

The electro-actuation manipulator has 6DOF; 4 joints, a wrist, and a claw. The maximum of gripping force is 10kg. The manipulator unit consists of the manipulator and a buoyancy material. Because the buoyancy of the unit is neutral, the unit is detachable without an adjustment of total buoyancy and attitude balance.

III. OPERATION SYESTEM

Otohime has two operation modes; AUV mode and UROV mode. In the AUV mode, the vehicle cruises autonomously according to a pre-defined mission scenario. One of its main missions is visual observation of seafloor for reconstruction of 3D image mosaic.

The vehicle can be operated as an Untethered Remotely Operated Vehicle (UROV) with a thin fiber optical cable or an acoustic communication device. In the UROV mode, an operator on support vessel can operate the vehicle watching the system information and the video images. The vehicle with the manipulator can perform light-duty work, for example, sampling or installation of a device on sea bottom.

The vehicle has a fiber cable spooler with the length of 5km.

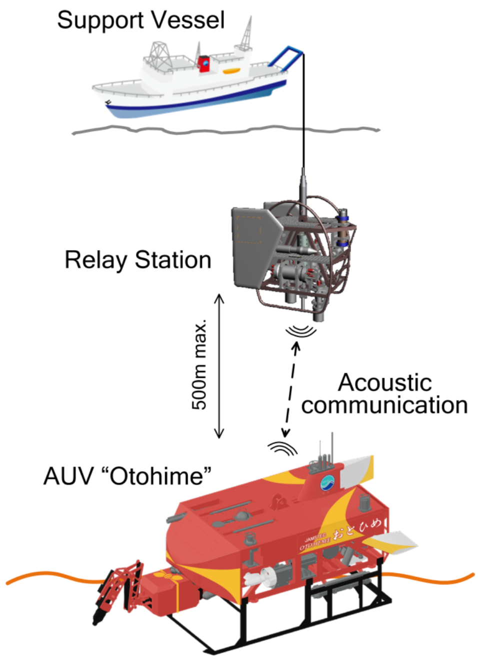

Figure 4. UROV operation based on acoustic communication using relay station.

A fiber cable is connected between the spooler and another spooler on board. The diameter is only 1 millimeter. Through the fiber, two video camera’s images are transmitted along with Ethernet LAN connection.

We have developed an acoustic high-speed communication device for UROV operation. The device can transmit video images to support vessel in semi real-time. However, the maximum transmission distance is limited to 500 meters. Therefore, we developed a communication relay station for deeper operation, shown in Fig.4. The relay station is connected to the support vessel with a metallic cable for communication and power supply. The vehicle and the relay station are communicated with the acoustic communication device.

IV. Sea Trial

In October 2012, we carried out its sea trials at Sagami Bay. Fig.5 shows the location. The vehicle was deployed as a UROV with a fiber cable. The objective of the sea trials was to perform engineering tests on the overall hardware / software systems of the vehicle.

The “Otohime” performed two dives at the depth of 80-120m during the cruise. The first dive was carried out to test cruising capability, acoustic positioning, and basic functions. The vertical profile and trajectory of the first dive are shown in Fig.6 and Fig.7, respectively. With manual operation, the vehicle cruised 300 meters maintaining an altitude 15-20m for acoustic observation. Fig.8 shows a profile of pH and pCO_2 obtained during the dive.

The second dive was carried out to test acoustic communication with the relay station and the sensors for visual observation. The vertical profile of the second dive is shown in Fig.10. Firstly, the vehicle landed on the seafloor. After that, we deployed the relay station shown in Fig.9. We succeeded in transmitting camera images in semi real-time, with

Figure 5. Map of the sea trial area. The diving point is shown as a red circle.

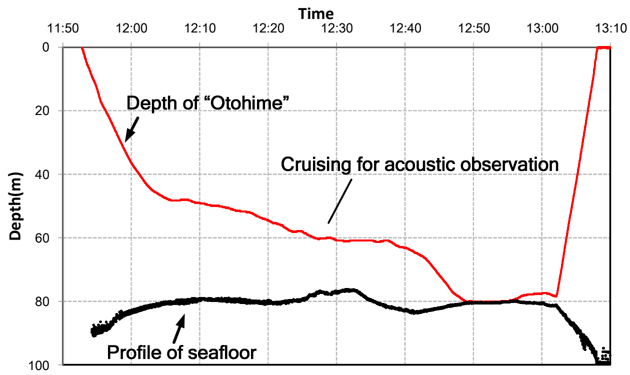

Figure 6. Vertical profile of dive#1.

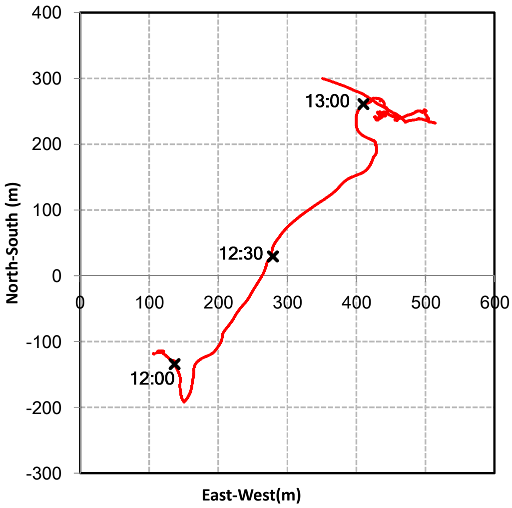

Figure 7. Trajectory of dive#1.

the acoustic visual transmission modems. Next, the vehicle cruised maintaining an altitude 1-4m for visual observation. The still camera’s images taken by the vehicle are shown in Fig. 11.

Through two dives for total 3 hours operation, we verified the performance of the overall hardware / software systems.

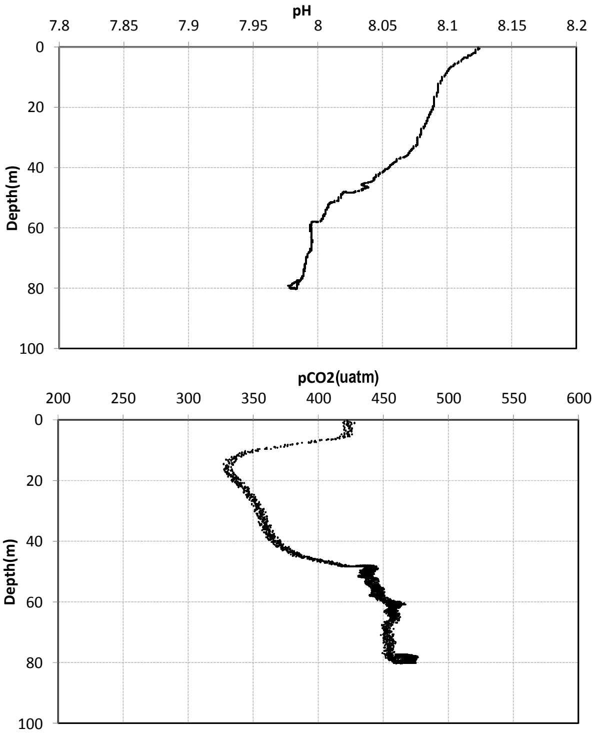

Figure 8. Profile of ph and pCO_2 measured during dive#1.

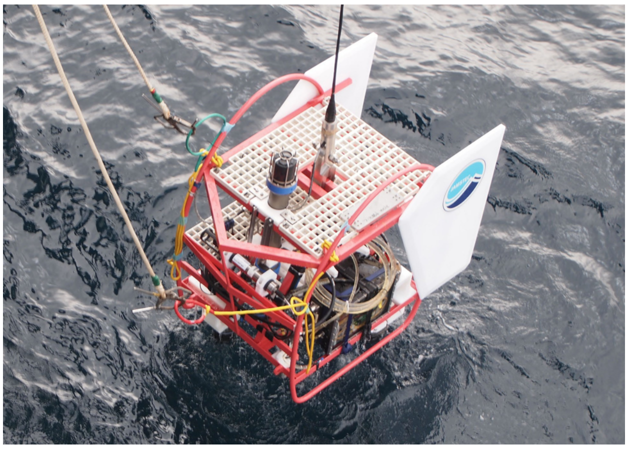

Figure 9. Deployment of the communication relay station for "Otohime".

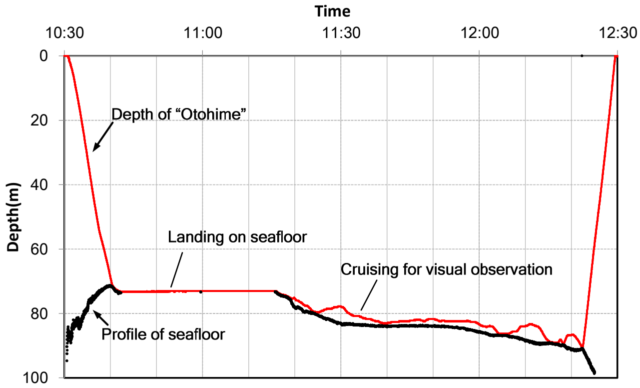

Figure 10. Vertical profile of dive#2.

Figure 11. Still camera images taken by "Otohime".

V. CONCLUSION

In this paper, we explained the AUV "Otohime" and its sea trials. The vehicle is constructed in March 2012 as a platform for underwater chemical observation, visual observation, and light-duty work.

In October 2013, the vehicle was deployed as a UROV at Sagami Bay. Through the sea trials, we verified the basic performance of the overall systems.

Based on success of the dives, we will upgrade "Otohime" as an AUV with high intelligence and high performance.

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