

Dives of Cruising-AUV "JINBEI" to Methane Hydrate area on Joetsu Knoll and Umitaka Spur

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Abstract— Autonomous Underwater Vehicle “JINBEI”, constructed in 2012, is a cruising type AUV with a weight of 2 ton and a length of 4.0m. The major purposes are observation of underwater CO₂ distribution in deep sea and exploration of seabed mineral resources. It has four rear-thrusters, two mid-ship azimuthal thrusters, and a rear X-rudder. The AUV is equipped with three main sensors; a multi-beam echo sounder, a side scan sonar, and a hybrid CO₂-pH sensor. During KY12-10 cruise in August 2012, we deployed “JINBEI” at a methane hydrate area in Joetsu knoll and Umitaka Spur, Japan Sea. The depth of the area is 850-950m. The vehicle cruised over the methane hydrate area at a speed of 2 knots. We obtained high-resolution side scan images of hydrate mounds as well as methane plumes. At same time, the CO₂-pH sensor detected the methane plumes indirectly. Through the dives, we confirmed that the cruising AUV “JINBEI” is one of powerful tool for survey of scientific observations.

Keywords—AUV; CO₂; methane hydrate

I. INTRODUCTION

Since 2010, JAMSTEC has developed two autonomous underwater vehicles (AUVs); a cruising-AUV “JINBEI” [1] and a working-AUV “Otohime” [2]. Their major purposes are to reveal CO₂ distribution in deep sea, and to explore seabed mineral resources in Japan’s EEZ.

Fig. 3 shows our concept of oceanographic survey using the two types of AUVs [3]. Firstly, a cruising-AUV performs wide area survey with sonars and chemical sensors. Then, according to the survey results, a working-AUV accesses feature points and observes seafloor in detail, with its chemical sensors, cameras, and manipulator.

In August 2012, we succeeded in operating the AUV “JINBEI” at a methane hydrate area in Joetsu knoll and Umitaka Spur, Japan Sea. This paper introduces the AUV system briefly and then describes the results of the operation.

II. THE CRUSING-AUV “JINBEI”

A. Vehicle

“JINBEI” is a compact cruising type AUV constructed by JAMSTEC in 2012. The appearance, general arrangement, specification of the vehicle are shown in Fig.1 and Fig.2, and Table 1, respectively. The maximum operation depth is 3,000 meters.

The vehicle has high motion performance. Its propulsion devices are four 400 Watts direct drive thrusters at rear and two mid-ship azimuthal rotating thrusters. The azimuth thruster enables dynamic control of the vehicle at low speed. The minimum controllable speed is 0.7 knots. Rear cross-arranged four rudders (X-rudder) control motion of the vehicle in normal cruising speed. The vehicle is capable of crash stop and astern. When the AUV is cruising at a speed of 3knots, it can stop within 30 meters.

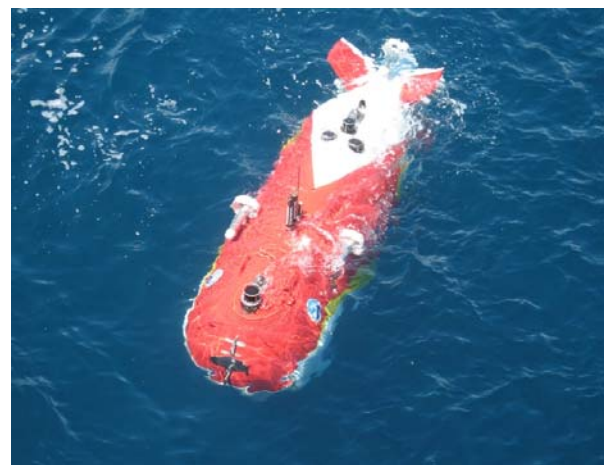


Fig. 1. Autonomous Underwater Vehicle “JINBEI”.

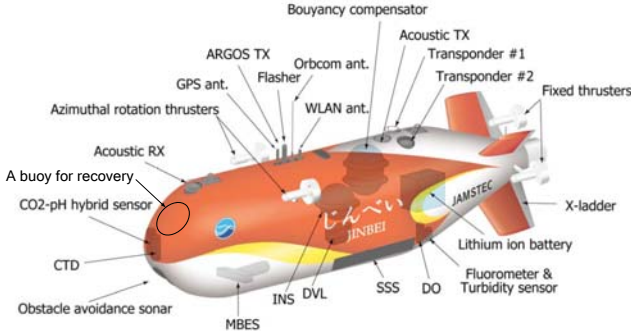


Fig. 2. General arrangement of the AUV "JINBEI".

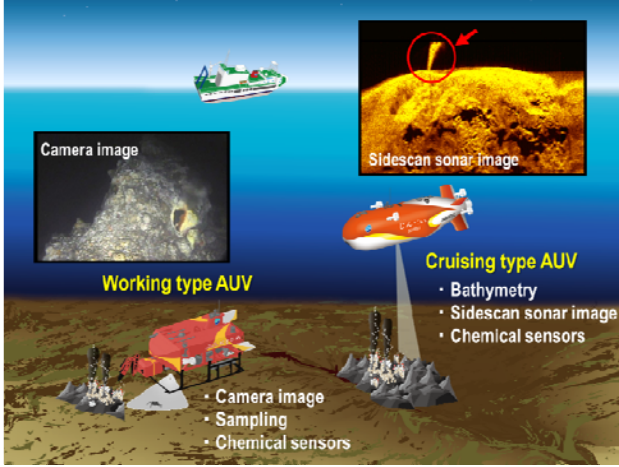


Fig. 3. Oceanographic survey using AUVs.

The vehicle has a buoyancy compensator. The compensator consists of pressure hull with capacity of 20 liters, an oil bladder, a pump and valves. It can adjust the vehicle's weight to near-neutral. The vehicle is powered by an oil-fill lithium-ion battery. The capacity is 115V 120Ah, and the vehicle's endurance is 10 hours.

As main navigation device, the vehicle has a small inertial navigation system (INS) based on ring laser gyros. The INS enables high accuracy positioning of the vehicle with a 300 kHz Doppler velocity log (DVL), a GPS, and acoustic navigation systems (ANSs). The vehicle cruises autonomously based on a navigation system according to a pre-programmed scenario.

The vehicle has an acoustic communication device for communication between the vehicle and our support ship. In operation, the communication helps safety operation of the vehicle and transmission of SSBL positioning information. For debugging of the vehicle, an optical fiber communication is also available. The vehicle has an O/E converter, a fiber spooler and a fiber cutter. A fiber cable is connected between the spooler and another spooler on board. The diameter of the cable is only 1 millimeter.

When a communication is available, we can remotely operate the vehicle system by a control equipment on board. The equipment has functions of status display, command input, as well as automatic pre-dive check. Using a portable tablet

TABLE I Specification of AUV "JINBEI"

Vehicle	
Size	4.0m(L)×1.1m(H)×1.1m(W)
Weight in the air	2 ton
Maximum depth	3,000 m
Speed	0.7 - 3 knots (2knots@cruising speed)
Minimum Altitude	30m
Duration	10 hours @cruising speed
Actuators	400W Thrusters × 4 400W Azimuth Thruster × 2 Rear X-Rudders Buoyancy Control System
Power	Lithium-ion Battery 115V, 120Ah
Communication	Wireless LAN, Acoustic comm., Optical Fiber comm., Satellite comm.
Control unit	Distributed CPU system
OS	Linux
Navigation devices	
INS, DVL, GPS, Depth meter, Altimeter, Obstacle avoidance sonar, SSBL, LBL, VLBL	
Observation payloads	
Multi beam echo sounder	Teledyne Reson SEABAT 7125
Side Scan Sonar	EdgeTech 2200-M
CTD sensor	Seabird SBE49
Dissolved oxygen sensor	JFE Advantech RINKO-III
Fluoro-Turbidimeter	WETLabs ECO FLNTU(RD)
Hybrid pH-CO2 sensor	JAMSTEC original

connected via wireless LAN, an operator near the vehicle can easily check the system information.

B. Scientific Sensors

The vehicle has three main sensors; a dual frequency side scan sonar (120 kHz and 400 kHz), a multi-beam echo sounder and a hybrid CO₂-pH sensor. In addition, the vehicle is equipped with a CTD sensor, a dissolved oxygen sensor, and a fluoro-turbidimeter as water analyzes sensors.

The hybrid CO₂-pH sensor (HCS) designed by JAMSTEC is deep-sea pCO₂ and pH sensor for AUV [4]. The principle of measurement for the pCO₂ sensor is based on spectrophotometry. Response of the pCO₂ sensor is low, and it takes a few minutes to measure pCO₂ with a high degree of accuracy. Therefore, when a priority of pCO₂ measurement is high, the vehicle cruises at a slow speed.

C. Launch and recovery system

A new launch-recovery system for "JINBEI" is shown in Fig.4. The system consists of a vehicle platform with a raising base which is rotated by oil hydraulic cylinders to 90 degrees. To uncouple the vehicle from the base, the vehicle hanger is hoisted up by a A-frame crane of R/V. Then, the A-frame crane moves outward. Finally, the vehicle is released on the sea surface by a Sea Catch release hook.

The vehicle surfaces after a mission, and then, it releases a buoy from the front part. The buoy is connected to the vehicle

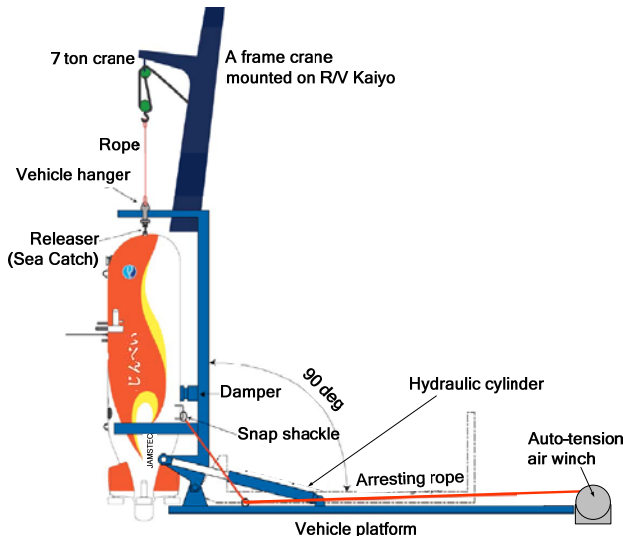


Fig. 4. A vertical hanging launcher for the AUV "JINBEI".

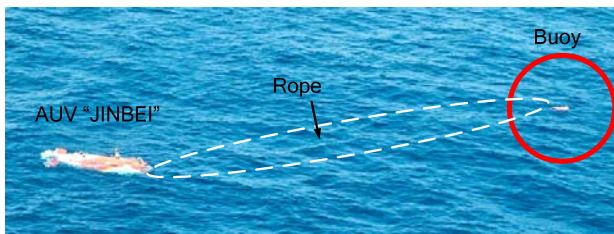


Fig. 5. A buoy released from the AUV "JINBEI".

by a rope. To extend the rope, the vehicle goes astern on the sea surface for a minute, shown in Fig.5.

Using a small workboat, R/V crews pick up the buoy. They haul the vehicle close by the rope, and then, a metallic hanger is attached to the front part of the vehicle. The vehicle is hoisted up by a A-frame crane as shown in Fig. 6. Compared to a conventional way by hanging a vehicle at two-point, the way by hanging at one-point has the following merits;

- capable of attaching a metallic hanger without a swimmer.
- capable of hoisting a vehicle from sea water with lower lifting force.
- suitable for a vehicle which has antennas and thrusters on the top.

III. SEA TRIAL

In August 2012, we had a cruise for sea trials of the AUV "JINBEI". The vehicle performed 5 dives during the cruise as shown in Table II. The first dive (#1) and second dive (#2) were carried out at Sagami Bay to have engineering tests on the overall hardware / software systems of the vehicle. The maximum depth of dive #2 was 1,015m, and we verified its performance of diving.



Fig. 6. Recovery of the AUV "JINBEI" hung and hoisted at one-point.

TABLE II THE DIVE RECORDS OF THE "JINBEI"

No.	Date	Dive Site	Duration (hh:mm)	Max. Depth (m)
1	19 Aug.,2012	Sagami Bay	1:40	63
2	21 Aug.,2012	Sagami Bay	2:10	1015
3	25 Aug.,2012	Joetsu Knoll	1:56	916
4	26 Aug.,2012	Umitaka Spur	1:56	822
5	26 Aug.,2012	Umitaka Spur	1:23	853

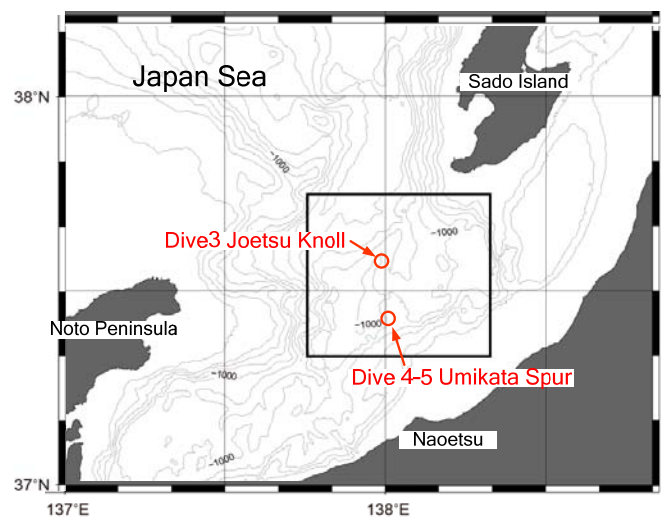


Fig. 7. Map of the sea trial area. The diving point is shown as a red circle.

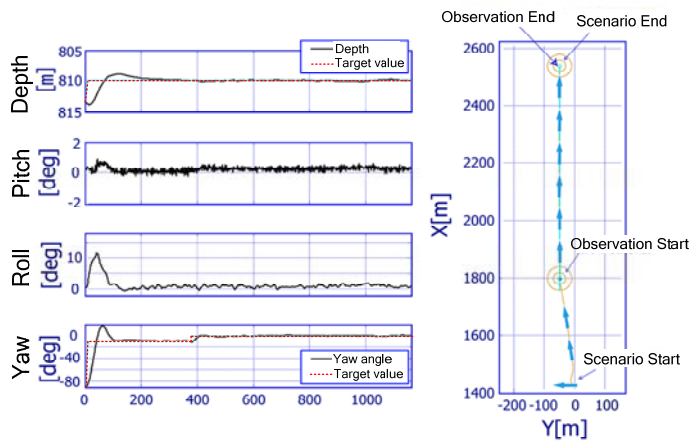


Fig. 8. Vertical profile, attitude and estimated trajectory of #4 dive.

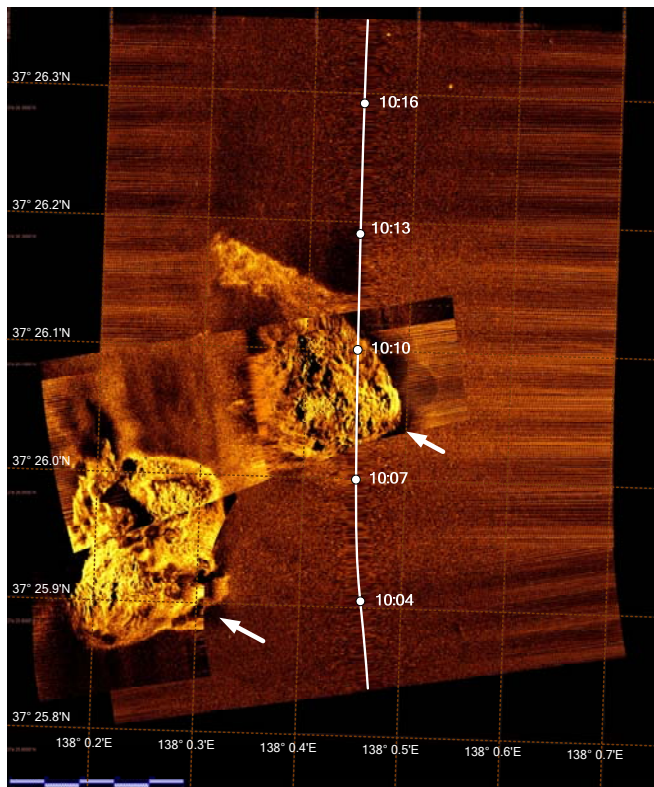


Fig. 9. Side scan sonar image taken at a methane hydrate area on Umitaka Spur during the dive #4.

Then, we had three dives (#3-#5) for observation of methane hydrate area in Joetsu Knoll and Umitaka Spur, off Naoetsu, Japan Sea. Fig.7 shows the location. The methane hydrate area has been recognized and investigated since 2004 [5] [6].

The dive #4 was a survey of methane hydrate mounts on Umitaka Spur. The vehicle was deployed as an Untethered Remotely Operated Vehicle (UROV) with semi-autonomous

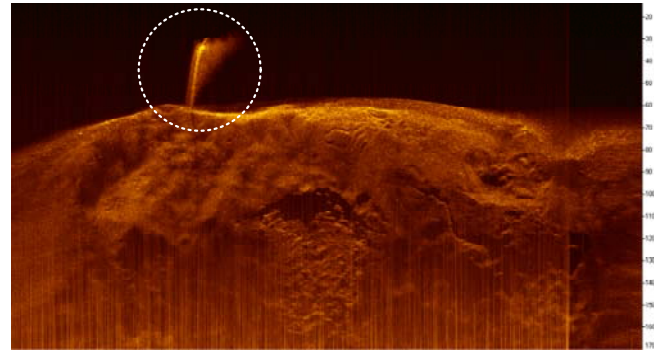


Fig. 10. A methane plume captured in row data of the side scan sonar (400 kHz).

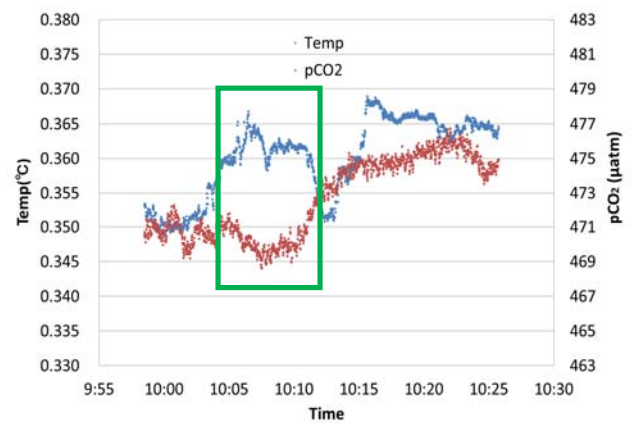


Fig. 11 Profile of temperature and pCO₂ measured during dive#4.

control. After manually operated to the bottom, the vehicle started a pre-programmed scenario, i.e., autonomous way point tracking. Because the dive was a sea trial, the scenario consisted of only one survey line. The length of the line was 0.4 miles. The target value of cursing speed and control depth was 2knot and 810m, respectively. The trajectory and depth control during the scenario was very stable as shown in Fig.8.

The vehicle succeeded in taking a clear side scan sonar image of methane hydrate mounds and plumes. Fig.9 shows the image and estimated trajectory of the vehicle. The altitude of the vehicle was 80-100m during the scenario. The two rough parts are methane hydrate mounts. The diameter of the mounts is about 200m. Fig.11 shows a row data of the side scan sonar taken on a methane hydrate mount. A methane plume was detected.

Fig.11 shows the temperature and pCO₂ measured the HCS. At the time in green frame, pCO₂ decreased 3µatm and temperature raised 0.015 deg C. At the same time, the vehicle just cruised on the methane plume. This result indicated that the methane plume was detectable with HCS indirectly. The pH value was remarkably stable at that time.

IV. CONCLUSION

In this paper, we introduced a newly developed AUV “JINBEI” and its sea trials in a methane hydrate area.

The “JINBEI” is a cruising type AUV constructed in February 2012 as a platform for observations of carbon dioxide (CO₂) in deep sea and explorations of seabed mineral resources. In August 2012, we carried out its sea trials in Joetsu knoll and Umikata spur. The vehicle succeeded in acoustic and chemical observation of the methane hydrate area.

In a few years, the vehicle will be one of major platforms for science research in JAMSTEC.

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