



R/V KAIYO Cruise Report

KY13-01

Sea-test of Advanced Measurement Technology

- Trail of a Precise Measurement using an Underwater Laser -

and

Measurement of Dynamic Characteristics of a Shuttle-robot for Virtual Mooring

Sagami Bay

Jan. 7, 2013-Jan. 12, 2013

Japan Agency for Marine-Earth Science and Technology

(JAMSTEC)

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1. Cruise Information

- (1) Cruise ID: KY13-01
- (2) Name of vessel: R/V KAIYO
- (3) Captain: Eiko Ukekura
- (4) Title of cruise / Title of proposal:
 - (a) Sea-test of Advanced Measurement Technology
 - Trail of a Precise Measurement using an Underwater Laser -
 - (b) Measurement of Dynamic Characteristics of a Shuttle-robot for Virtual Mooring
- (5) Chief researcher: Kenichi ASAKAWA (JAMSTEC)
- (6) Onboard researchers:
 - Shojiro ISHIBASHI (JAMSTEC)
 - Tadahiro Hyakudome (JAMSTEC)
 - Makoto SUGESAWA (JAMSTEC)
 - Yutaka OTA (JAMSTEC)
 - Yoshitaka WATANABE (JAMSTEC)
 - Takashi SAITO (Mitsubishi Electric Corp.)
 - Hideaki OCHIMIZU (Mitsubishi Electric Corp.)
 - Takesi KUMAGAI (sAs Corp.)
 - Susumu SATO (sAs Corp.)
 - Masahiko NAKAMURA (Kyushu Univ.)
 - Masaru INADA (Kyushu Univ.)
 - Kenichi SHIMIZU (Nagasaki Univ.)
 - Jun UCHIDA (Nagasaki Univ.)
- (7) Port of call :
 - from JAMSTEC Yokosuka
 - to JAMSTEC Yokosuka
- (8) Research area: Sagami Bay
 - The test field is within the area connecting the following points
 - (34°55.0'N, 139°13.5' E)
 - (35°00.0' N, 139°06.5'E)
 - (35°14.0' N, 139°13.0' E)
 - (35°14.0' N, 139° 25.0'E)
 - (34°55.0' N, 139°25.0' E)

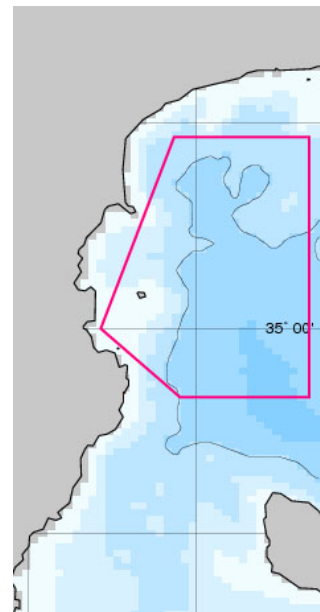


Figure 1 Research Area

(9) Cruise period: Six days, from January 8th , 2013 to January 12th

(10) Schedule:

8 th Jan.	9:00	Depart from JAMSTEC
	12:17	XBT Measurement
	13:30-15:00	Shuttle-robot Dive #1
	15:00-16:00	Otohome Launch and Recovery Test
9 th Jan.	8:00-10:00	Shuttle-robot Dive #2
	12:00-14:30	Otohome Dive #3
	15:30-16:00	Shuttle-robot Floating-test-1
10 th Jan	9:00-12:00	Otohome Dive #4
	13:00-16:00	Shuttle-robot Dive #3
11 th Jan	morning	Otohome Dive #5
	afternoon	Otohome Dive #6
12 th Jan.	9:00	Return to JAMSTEC

2. Sea-test of Advanced Measurement Technology

2.1 Outline

The acoustic wave has been applied to measure the distance in the sea until now. However there are some demerits in this method. So the new method for range finding in the sea using the laser technology has been studied and we have verified its basic utility in some sea tests. In this sea-test, the underwater laser-scan system, which was newly developed in JAMSTEC, was applied to an underwater vehicle in order to measure the distance to the seafloor. And then it cruised keeping about the constant altitude from the seafloor. As the result, the 3D seafloor topography was measured. And moreover, the 3D image created by the underwater laser-scan system was also applied as the operation-aid system for the manipulator which was equipped with the underwater vehicle.

2.2 Tests Item

In this sea test, an underwater vehicle and the underwater laser-scan system, which were newly developed in JAMSTEC, were applied. Figure 2-1 and Figure 2-2 shows the general description of each respectively. The underwater vehicle is “Otohime”. It has some types of operation modes. In this sea test, the UROV mode was applied. The underwater laser-scan

Item	Specifications		
	Contents	Unit	Remark
Dimension	2.6 x 2.1 x 1.3	m	without skid
	2.6 x 2.1 x 1.35	m	with n-skid
	2.6 x 2.1 x 1.75	m	with w-skid
Weight (in air)	842	kg	without skid
	856	kg	with n-skid
Working Depth	3,000	m	
Cruising Speed	1.5	knot	
Endurance	6	hr	
Propulsion	400W thrusters x 2 (with Tilt mechanism)		both side
Actuators	Vertical rudder		Oil filed
	Horizontal rudder		
	Tilt mechanism for thrusters		
Power	Litium Ion Batt. system 128V 30Ah		Oil filed
Operation Mode	AUVmode ROVmode		
Operation From	No-Skid		
	Normal skid equipment		
	Manipulator skid equipment		

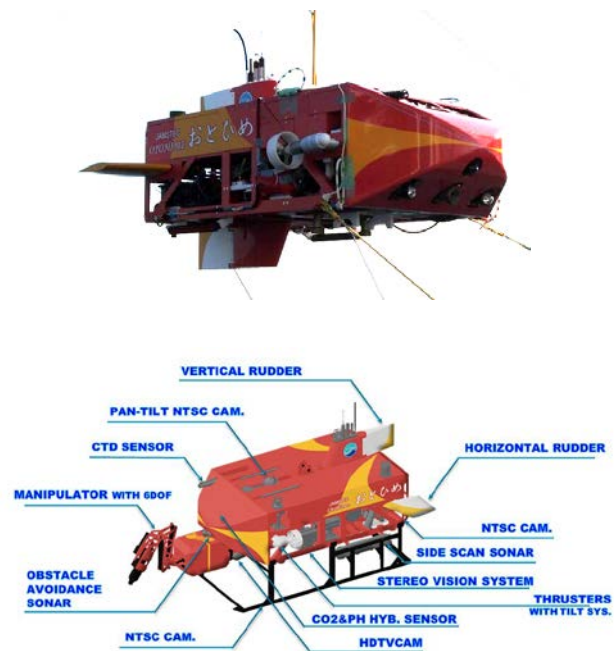
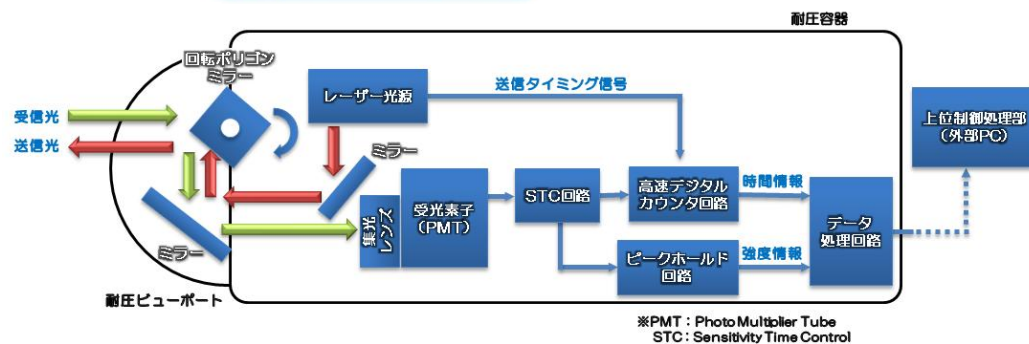


Figure 2-1 Autonomous underwater vehicle “Otohime”.

system was the world's first laser imaging device for deep-sea. The measurement range was 20 meters at the maximum.



Figure 2-2 Underwater laser-scan system.



2.3 Sea Test

Two types of sea tests were carried out. One was conducted to get the 3D image as the 3D seafloor topography. In the test, at the first, the underwater vehicle dived down near the seafloor. After that, it cruised keeping about the const altitude. And then, the laser-scan system projected the seat laser toward the seafloor. As the result, the 2D plane laser was realized, and 3D image of the seafloor topography was created by the measurement of the reflected intensity. The other was conducted that the laser-scan system was applied as the operation-aid system for the manipulator. In the test, the underwater vehicle landed on the seafloor, and then the laser-scan system projected the seat laser in front of it. As the result, the 3D image of far distance more than the range of a general underwater camera could be got. The image was useful to understand the circumference environment of the manipulator.

2.4 Test Results

As the result of the sea test, 3D image of the seafloor topography at the depth of 100 meters was created by the underwater laser-scan system. The length of it was about 150 meters

at the maximum. The resolution was about 4 centimeters. Then the underwater vehicle cruised at the speed of about 1 knot keeping the altitude of about 7 meters. Figure 2-3 shows the 3D image at the length of 20 meters.

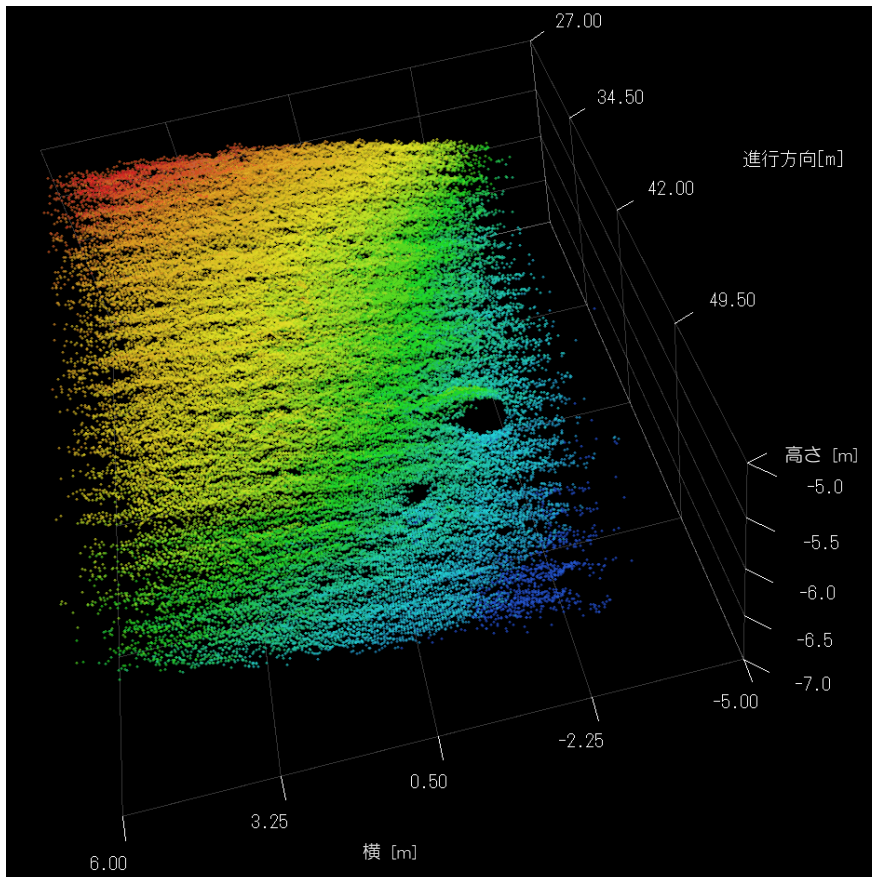


Figure 2-3 3D image of seafloor topography.

Meanwhile, the other test was also completed. In the test, the operator for the manipulator used the master arm to control it. Then the operator monitored the 3D image of the circumference environment, and the operator confirmed the work object. The operator could understand the positional relation of the circumference environment because the range of the 3D image created by the underwater laser system is farther than the range of a general underwater camera.

In these tests, the functionality of the underwater laser system were confirmed, and moreover, the utility of the application for the optical laser in the sea was shown.



Figure 2-4 A scene of the manipulator operation using 3D image of the circumference environment.

3. Measurement of Dynamic Characteristics of a Shuttle-robot for Virtual Mooring

3.1 Background

Autonomous Profiling Shuttle Development Laboratory Unit, Observing System Research and Technological Development Unit has been engaged in development of a shuttle-robot for virtual mooring since 2009.

Shuttle robots for virtual mooring will stay in designated area for a long time, while intermittently reciprocate between the sea-surface and the sea-floor and sends observed data via communication satellites in quasi-realtime. Figure 2 illustrates the image of their operations. They control its orientation and direction of movement by controlling the gravity-center controller while descending and ascending. They measure their own location with GPS or with an underwater acoustic positioning system, and compensate the drift by sea-current or tidal-current so that they can stay in designated area. They will be able to sleep on the seafloor or while floating underwater like Argo floats so that they can extend observation period. Thus, they realize a virtual mooring.

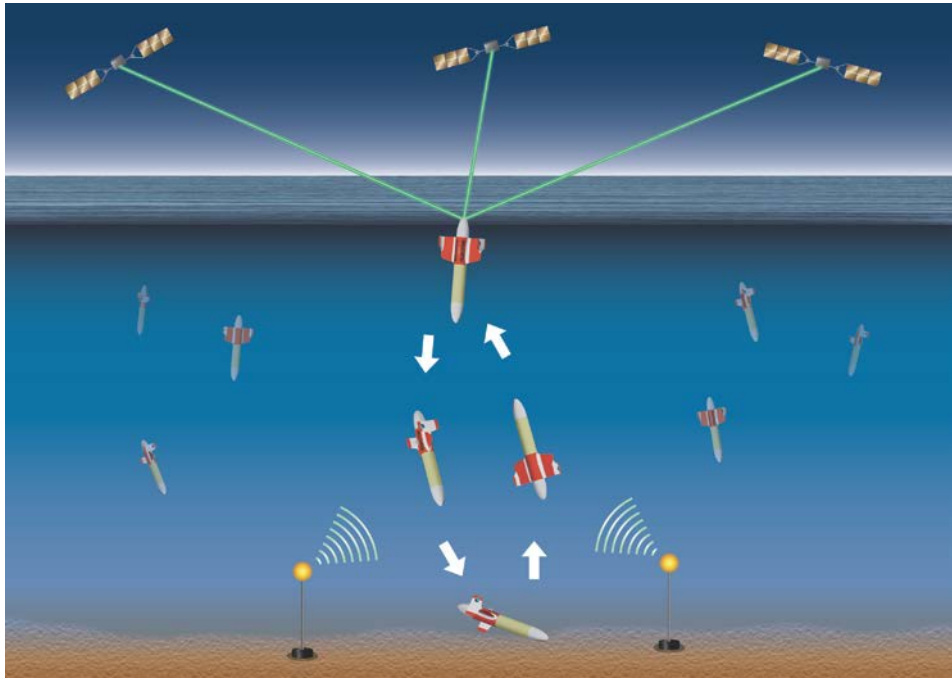


Figure 2 Operation image of shuttle-robots for virtual mooring

Up to now, the ocean environment has been monitored using many means including profiling floats, moored buoys, ships, and satellites. However, because of its vastness, it is difficult to gather sufficient data even using all of these methods.

The Argo project brought a breakthrough in oceanography. This international project, to which many countries contribute, has about 3,500 Argo floats distributed worldwide. These floats monitor the ocean environment down to 2,000m depth over four years. Nevertheless, it is difficult to increase their number to cover all oceans with adequate density because of the vastness of the world's oceans. They cannot remain in designated area where data are needed because they float with seawater. In addition, the change of seawater-temperature has been observed even in deeper waters than 2,000m. This example underscores the necessity of monitoring the ocean environment in waters that are deeper than 2,000 m.

Other methods such as artificial satellites, moored buoys, and research vessels are used. These methods have their respective limitations. Artificial satellites are suited for gathering wide-range data, but they cannot monitor the underwater environment. Moored buoys can carry out long-term monitoring at a fixed point, but they cannot monitor depths from the seabed to the ocean surface. It is also difficult to increase their number because of their costs of construction and maintenance. Research vessels can only provide a limited range of data.

Shuttle-robots have drawn attention and recently are used widely. They use wings to glide through seawater. They control their attitude and direction of movement by moving the position of their gravity center or by using rudders and elevators. They can travel autonomously over long distances gathering ocean data at a reasonable cost. They are now recognized as innovative devices that are expected to provide valuable data to oceanographers that cannot be obtained otherwise. However, their operating duration is shorter than one year. They cannot provide long-term data as Argo floats or moored buoys can.

The report by the committee in JAMSTEC for hydrographic observation of next generation pointed out that the hydrographic observation of next generation should grow out of the conventional practice deploying many devices all over the ocean, and should concentrate to observe 'key-areas' for analyzing the global climate change. These key-areas will be selected beforehand by computer simulation. Underwater gliders for virtual mooring will be the key device for the hydrographic observation of next generation.

Until now, we have made a shuttle-robot prototype 'Tsukuyomi', and evaluated its fundamental function by gliding tests in a long tank owned by Research Institute for Applied Mechanics, Kyushu University. As for the buoyancy engine, that is the key devise for shuttle-robots, we had succeeded in descending and ascending tests down to 620m in depth in the cruise of KY11-10. We also have conducted the first test in March 2012 in the cruise KY12-04 using R/V KAIYO. In that first cruise, we have confirmed the stable operation of descending down to 500 meters in depth. A safety rope that is described in 3.3.1 was used for the safety measure. We also confirmed the fundamental function and the maneuverability of

Tsukuyomi, and stable GPS-positioning and Iridium-communication while floating at sea-surface.

3.2 Outline of the shuttle-robot

Figure 3 and Figure 4 show the photo and the general arrangement of the shuttle-robot respectively. Its weight in air and the maximum descending depth are 150kg and 3,000m respectively. The pressure-tight housing is made of aluminum alloy. The shape of wings was determined after hydrodynamic tests using a small-sized model.



Figure 3 The shape and the size of the shuttle-robot (unit: mm)

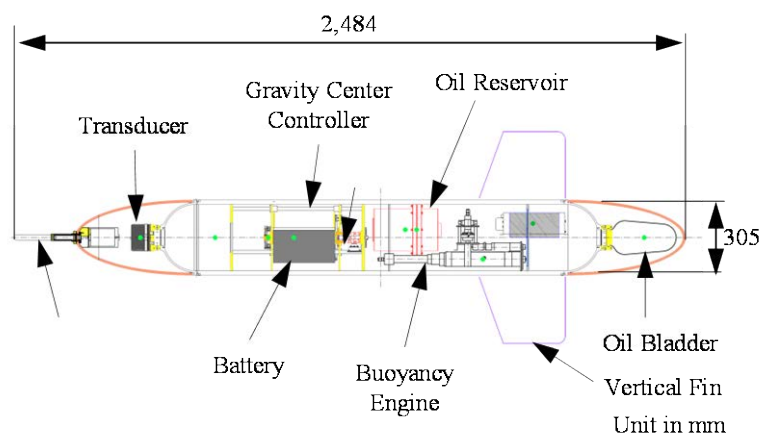


Figure 4 The general arrangement of the shuttle robot

The buoyancy engine uses a piston pump, which was based on that was developed for Deep NINJA, a new profiling float for down to 4,000m water depth. Figure 5 shows the basic hydraulic circuit of the buoyancy engine. The inside of the pressure-tight housing is

depressurized to about 0.5 atmospheric pressure. The shuttle-robot can pull in oil from the outer bladder to the inner oil reservoir through a two-port valve making use of the pressure difference between the inside and the outside of the pressure-tight housing when it is floating at sea-surface. By pulling in oil directly without using the piston pump, we can reduce the power consumption and shorten the time to reduce the buoyancy and to get enough descending velocity.

An acoustic transponder was mounted in Tsukuyomi so that we could monitor its location all the time when descending.

The shuttle-robot uses secondary Ni-H batteries. They are mounted on a moving part of the gravity-center controller. Using this gravity-center controller, we can control pitch and roll angle. The statically controllable range of pitch angle and roll angle are both within +/- 60 degrees.

3.3 Sea Tests

3.3.1 Test Items

(1) Communication between the shuttle-robot and an onboard Iridium Short Burst Data transceiver

The communication between the onboard operator and the shuttle-robot are conducted using Iridium Short Burst Data SBD Service. A SBD transceiver is mounted on the shuttle-robot. The communication to and from the SBD transceiver had been carried through Internet e-mails. That means the mother vessel needs to access to Internet. This time, we introduced another SBD transceiver for onboard operators and try to make direct communication between the two SBD transceivers. Using this method, we can operate the shuttle-robot even if the mother vessel dose not have Internet facility.

(2) Test of automatic wet-weight adjusting function when starting to descend

When start descending, the shuttle-robot draw in oil from the external oil bladder to the internal oil reservoir, and increase its wet weight. The wet-weigh when starting to descend is an important factor that control the descending velocity and its dynamic characteristics. It also affect the whole diving pattern and energy consumption. We have developed a new software

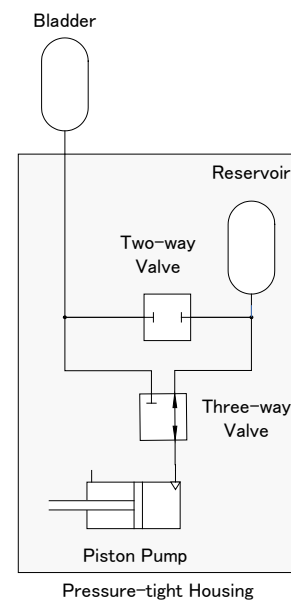


Figure 5 Basic hydraulic circuit of the buoyancy engine

which automatically can control the amount of oil to get optimum wet weight. We examined the performance of this new method.

(3) Descending/Ascending test with the safety rope

For the sake of safety, we use the safety rope which connect the shuttle-robot and a float on the sea-surface (Figure 6) until we can confirm the stable operation. A thin rope of 2.05 mm in diameter and of breaking strength of 2.3 kN is winded on a floating buoy shown in Figure 7. It is automatically pulled out while the shuttle-robot descending. Descending/Ascending tests were conducted with the safety rope to confirm the stable operation.

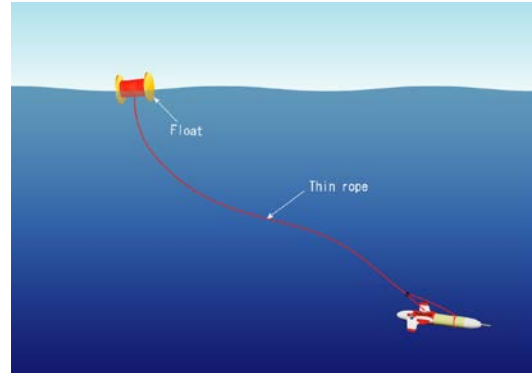


Figure 6 Configuration of the safety rope



Figure 7 Photo of the floating buoy on the sea-surface

(4) Descending/Ascending test without a safety rope

After confirming the stable operation, we tried to measure the dynamic characteristics of the shuttle-robot without the safety rope by changing the wet weight and the pitching/rolling. The pitching and rolling are controlled by moving the internal battery on the gravity-center controller.

3.3.2 Test Results

(1) Communication between the shuttle-robot and an onboard Iridium Short Burst Data transceiver

The results of this tests were fairly good. We can communicate with the shuttle-robot floating on the sea-surface every minute or every two



Figure 8 The shuttle-robot floating on the sea-surface

minutes. The communication interval was pre-programed. We could know the position of the shuttle-robot on the sea-surface which was located by GPS in real-time. We also could know the other status of the shuttle-robot. Figure 8 shows the shuttle robot while floating on the sea-surface. The GPS/Iridium antenna was mounted at the top of the shuttle robot, and stuck out of the sea-surface.

(2) Test of automatic wet-weight adjusting function when starting to descend

The inside of the pressure-tight housing of the shuttle robot are partially evacuated. Therefore when opening the two-way valve of the buoyancy engine depicted in Figure 5, the oil in the outer oil bladder is pulled into the inner oil bladder due to the pressure difference. That reduce the buoyancy of the shuttle-robot, and make it descending. When descending to the pre-programed depth, the shuttle-robot close the two-way valve, and the drawing-in of oil stops. Figure 8 shows the example of the data that illustrate the drawing-in of the oil when the shuttle-robot start to descend. In this test, the depth at which the two-way valve close was set to 8 meters.

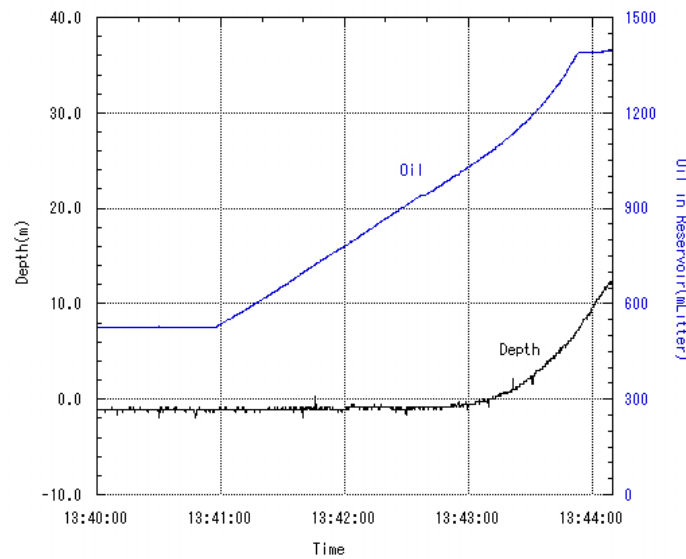


Figure 9 Test result of the automatic wet weigh adjustment

(3) Descending/Ascending test with the safety rope

Figure 10 shows the record of depth during the descending/ascending test with the safety rope of 200 m in length. The maximum depth was limited by the length of the rope. Although the dynamic characteristics of the shuttle-robot was affected by the safety rope, the stable operation of the shuttle-robot was confirmed by this test.

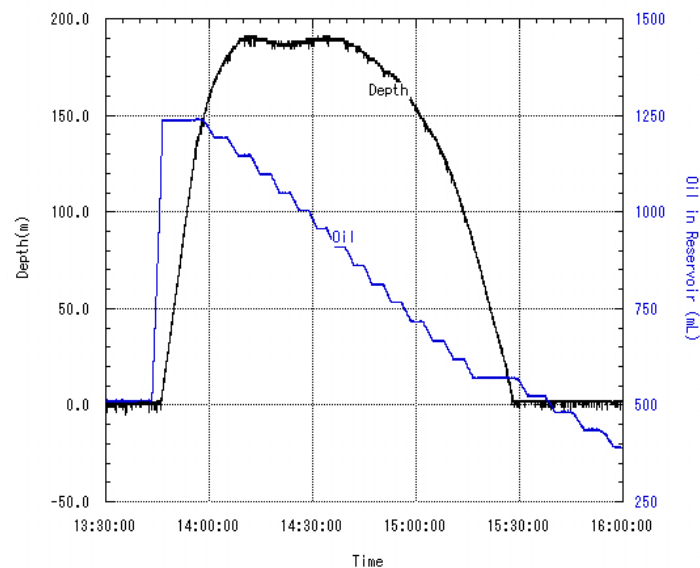


Figure 10 Record of the descending/ascending test with the safety rope

(4) Descending/Ascending test without a safety rope

Since we have confirmed the stable operation, we prepared to try the descending/ascending test without the safety rope. However during the pre-dive check in the morning, we have found serious failure of the buoyancy engine. That was the last day of the cruise, we have no choice but to cancel this test.

3.3.3 Summary

In this cruise, we could confirm the following items.

- (1) Stable communication between the shuttle-robot and an onboard Iridium Short Burst Data transceiver.

We can communicate with the shuttle-robot with a necessary interval even if the mother vessel dose not have Internet facility.

- (2) Automatic wet-weight adjusting function when starting to descend

The wet-weight when starting to descend is an important factor that affect the whole diving pattern and energy consumption. We could confirm that using the newly developed software, we could precisely control it.

- (3) Descending/Ascending with the safety rope

We could confirm the stable operation of the shuttle-robot although the movement of the shuttle-robot was restricted by the safety-rope of 200 meter in length.

3.3.4 Acknowledgements

We are grateful to the captain Hitoshi Tanaka and the all crews of the R/V KAIYO for their invaluable supports during the cruise.

4. Notice on Using

This cruise report is a preliminary documentation as of the end of the cruise and it may be changed without notice. If any data in this report is going to be used, it is required to contact with the Chief Scientist and get his acceptance.