R/V KAIYO Cruise Report

KY12-04

Measurement of Motion Characteristics of Underwater Glider for Virtual Mooring

Sagami Bay

Mar. 1, 2012-Mar. 5, 2012

Japan Agency for Marine-Earth Science and Technology

(JAMSTEC)
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1. Cruise Information

(1) Cruise ID: KY12-04

(2) Name of vessel: Kaiyo

(3) Title of cruise/Title of proposal:

Measurement of motion characteristics of underwater glider for virtual mooring

(4) Chief scientist: Kenichi ASAKAWA (JAMSTEC)

(5) Cruise period: Five days, from March 1st, 2012 to March 5th

(6) Port of call: from JAMSTEC Yokosuka to JAMSTEC Yokosuka

(7) Research area: Sagami Bay

(8) Research Map

![Research Map](image)

Figure 1  Research Map

The test field is within 34°58’N – 35°12’N and 139°12’ – 139°33’N.
2. Researchers

(1) Chief Scientist: Kenichi ASAKAWA (JAMSTEC)
(2) Scientist on board: Taiyo Kobayashi (JAMSTEC)
                          Shinpei GOTO (JAMSTEC)
(3) Scientist not on board: Takeshi KAWANO (JAMSTEC)
                             Tadahiro Hyakudome (JAMSTEC)
                             Yoshitaka WATANABE (JAMSTEC)
                             Yoshiyuki NAKANO (JAMSTEC)
(4) Chief Engineer onboard: Toru Idai (MWJ)
(5) Engineer onboard: Hiroki USHIROMURA (MWJ)

3. Purpose and Background

Autonomous Profiling Shuttle Development Laboratory Unit, Observing System Research and Technological Development Unit has been engaged in development of an underwater glider for virtual mooring since 2009.

Underwater gliders 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.
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.
Underwater gliders 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 an underwater glider 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 Tsukuyomi, we had succeeded in descending and ascending tests down to 620m in depth in the cruise of KY11-10.

In this cruise, we will evaluate the GPS-positioning and Iridium-communication while floating at sea-surface, and evaluate the fundamental function and the maneuverability of Tsukuyomi.

4. Outline of Tsukuyomi

Figure 3 and Figure 4 show the photo and the general arrangement of Tsukuyomi 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.
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. Tsukuyomi 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.
Tsukuyomi 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.

5. Sea Tests

5.1 Test Items

(1) GPS-positioning and Iridium-communication while floating at sea-surface

To confirm GPS-positioning and Iridium-communication while floating at sea-surface, and that we can control Tsukuyomi by commands sent through Iridium.
(2) Descending/Ascending Test - 1

To confirm the basic function of the hardware and the software by descending and ascending while setting the longitudinal position of the moving part of the gravity-center controller at the fore-end. We record the orientation, heading, depth and time while gliding and evaluate the maneuverability. The position of the gravity-center controller and the operation of the buoyancy engine will be pre-programmed.

(3) Descending/Ascending Test - 2

To measure the pitch angle, the roll angle, the descending velocity and the drift of heading with another longitudinal position of the moving part of the gravity-center controller.

(4) Descending/Ascending Test - 3

To measure the roll angle and the angular velocity while changing the lateral position of the moving part of the gravity-center controller.

5.2 Safety Measure

For the prevention of loss, a thin rope of 2.05 mm in diameter and of breaking strength of 2.3 kN was connected to Tsukuyomi as depicted in Figure 6. The thin rope is winded on a floating buoy, and is automatically pulled out while Tsukuyomi descending. We use this thin rope for all tests in this cruise.

Figure 7 shows the photo of the floating buoy on the sea-surface. We could confirm visually that the winded thin rope was pulled out while Tsukuyomi descending.

Another short rope for recovery was connected to Tsukuyomi as shown in Figure 8.

An acoustic transponder was mounted in Tsukuyomi so that we could monitor its location all the time.
Figure 6  Safety measure

Figure 7  Photo of the floating buoy on the sea-surface
5.3 Test Results

(1) GPS-positioning and Iridium-communication while floating at sea-surface

Tsukuyomi was launched onto the sea-surface at 13:53 on 2012/3/1, in order to evaluate GPS-positioning and Iridium-communication. Figure 9 and 10 shows the photo of the Tsukuyomi being launched from R/V Kaiyo and floating on the sea-surface respectively.

The output of the GPS receiver was recorded on a built-in hard-disk and was analyzed later. Figure 11 shows the footprint of Tsukuyomi measured with GPS while floating on the sea-surface. Tsukuyomi drifted about 710m in about 41 minutes by sea currents or tidal currents. It was confirmed that the stable GPS-positioning while floating at the sea-surface was performed. The wave height was from 1.0m to 1.5m over the cruise and the antenna was alternately floating up and sinking down at the sea-surface.

Tsukuyomi was programed to send the important data including GPS-data every minute via Iridium. We could receive the data almost real-time through Internet. Tsukuyomi succeeded sending the data in most cases when it tried (the maximum interval
between communications was three minutes). We confirmed stable GPS-positioning and Iridium-communication while floating at sea-surface.

Figure 9  Photo of Tsukuyomi being launched onto the sea-surface

Figure 10  Photo of Tsukuyomi floating on the sea-surface
The footprint of Tsukuyomi measured with GPS while floating on the sea-surface

Tsukuyomi was floating on sea-surface from 13:54 to 14:35

(2) Descending/Ascending Test - 1

The first descending/ascending test was carried out on 2\textsuperscript{nd} March. Tsukuyomi was launched at 8:15 on 2\textsuperscript{nd} March and was recovered to R/V Kaiyo at 13:25.

Tsukuyomi descended down to 470m in depth as shown in Figure 12, and ascended to sea-surface. The maximum depth was limited by the length of the thin rope. The estimated weight in water, the averaged pitch angle, the averaged descending velocity and the averaged angular velocity while descending are respectively about 0.43 kg, -56 deg., 0.28 m/s and -12 deg./s.

We confirmed that the buoyancy engine and the gravity-center controller were functioned as they were pre-programed. We also confirmed that the data were recorded as it was planed.
(3) Descending/Ascending Test - 2

The second descending/ascending test was carried out on 3rd March. We measured the pitch angle, the descending velocity and the drift on heading with another longitudinal position of the gravity-center controller. The estimated weight in water, the averaged pitch angle, the averaged descending velocity and the averaged angular velocity while descending are about 0.20 kg, -20 deg., 0.081 m/s and 10 deg./s respectively.

(4) Descending/Ascending Test -3

The third descending/ascending test was carried out on 4th March. We measured the roll angle and the angular velocity while changing the lateral position of the gravity-center controller. We could confirm that we can control the direction of rotation by changing the lateral position of the gravity-center controller as shown in Figure 13. The cause of the instability of the rotation speed seems due to the affect of the thin rope connected to
Tsukuyomi. Because Tsukuyomi was driven with small difference between the gravity and the buoyancy, the small force by the thin rope can not be neglected.

The estimated weight in water, the averaged pitch angle and the averaged descending velocity while descending are respectively about 0.30 kg, 0.42 deg. and 0.096 m/s.

![Graph showing measured data for Tsukuyomi](image)

Figure 13 Measured data when Tsukuyomi was descending while changing the lateral position of the gravity-center controller.

6. Summary

We confirmed basic function of the hardware and the software of Tsukuyomi. The buoyancy engine and the gravity-center controller functioned as they were pre-programed, and Tsukuyomi succeeded to descend and ascend by itself. We also confirmed stable GPS-positioning and Iridium-communication while floating at the sea-surface. The wave height was from 1.0m to 1.5m over the cruise. We furthermore confirmed that we can control the direction of rotation by changing the lateral position of the gravity-center controller.
We connected a thin rope to Tsukuyomi for prevention of loss. Although it was anticipated, the thin rope significantly affected the motion characteristics of Tsukuyomi. We are now planning to quantitatively evaluate its motion characteristics without the thin rope.

7. 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.

8. 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.