

# Heading-control Tests of an Underwater Glider for Virtual Mooring

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**Abstract**—An underwater glider we are developing for virtual mooring will be able to remain in a designated area for several years, moving between the sea surface and the seafloor up to 2,100 m deep, monitoring the sea environment. It will be able to sleep on the seafloor or while drifting in water to extend the monitoring duration. As described herein, we present results of heading-control tests conducted using a long tank. We also present results of sea tests conducted in Suruga Bay.

**Keywords**—underwater glider; virtual mooring; sea test; heading-control; long-term monitoring

## I. INTRODUCTION

The ocean is well known to play an important role in global climate stabilization. Its heat capacity is a thousand times greater than that of the atmosphere. Consequently, even a small increase in ocean temperatures can be expected to affect global climate change strongly.

Ocean environments have been monitored using many methods including profiling floats, mooring systems, ships and satellites. However, because of oceans' vast areas, gathering sufficient data is difficult even when using all of these methods.

For ocean observation systems of the next generation, key areas should be selected where environmental variation is expected to be readily apparent in its early stages. Because resources are limited, observations should be done intensively in such waters to gather ocean environment data efficiently.

Underwater gliders [1] such as Seaglider [2], Splay [3], and Slocum [4] have been used widely. They can travel autonomously over long distances, gathering ocean data at a reasonable cost. Nevertheless, their limited operating durations cannot provide long-term data as Argo floats [5] can.

We are developing a prototype of an underwater glider for longtime virtual mooring. Fig. 1 and Fig. 2 respectively present its appearance and an illustration of its operation. It can sleep for a fixed time on the seafloor or while floating in water to elongate the observation period. It can then wake up periodically to ascend and descend between the seafloor and

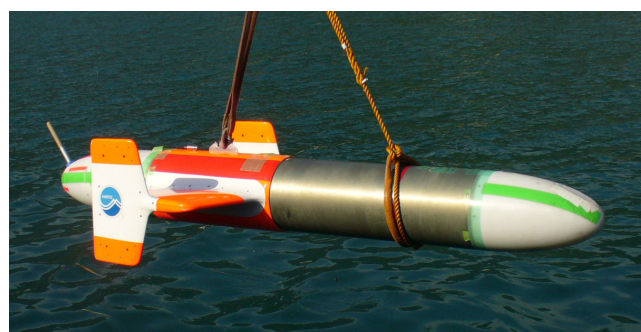


Fig. 1 Appearance of the underwater glider.

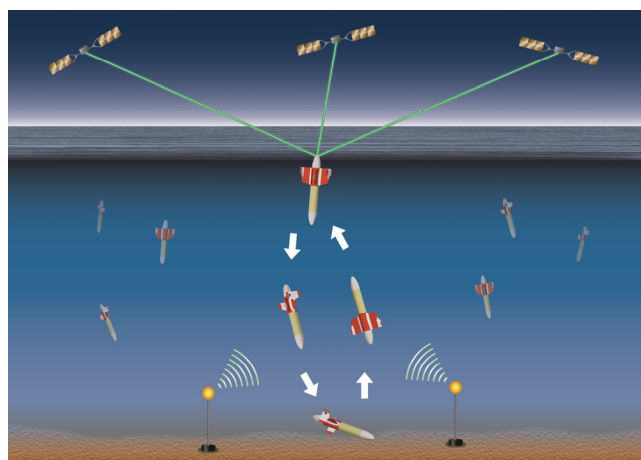


Fig. 2 Operation image of the underwater glider for virtual mooring.

the sea surface, monitoring the sea environment. It will position itself at the sea-surface using GPS, and will send data via Iridium. It can glide to a designated area if it drifts away. The glider will be able to execute long-term monitoring for several years while staying in designated waters.

Fig. 3 portrays the glider arrangement. The GPS/Iridium antenna was situated at the bow, but it has been moved to the aft portion. The underwater weight is controlled using the buoyancy engine. The pitch angle is controlled by longitudinal movement of the built-in battery and the weight mounted on

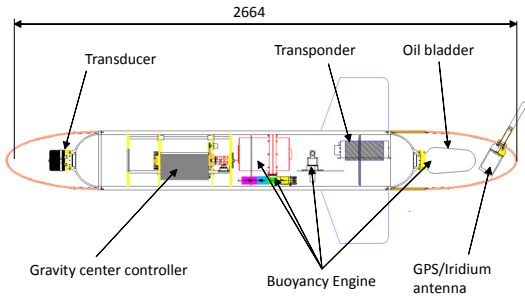


Fig. 3 General arrangement of the glider. Unit: mm

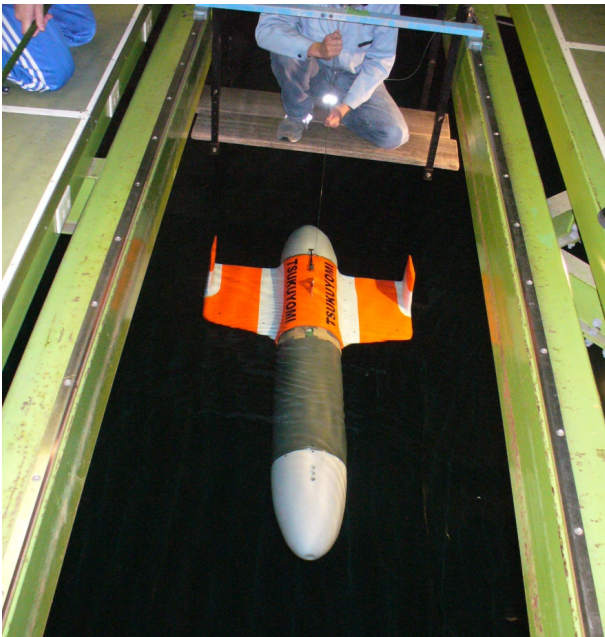


Fig. 4 Photograph of the gliding tests in the Ocean and Engineering tank.

The size of the tank is 65 m in length, 5 m in width and 7.5 m in depth. Before starting to glide, the glider was the gravity-center-controller (GCC). The roll angle is controlled by rotating them around the center axis.

The first gliding tests were conducted using the Ocean and Engineering tank at the Research Institute for Applied Mechanics (RIAM), Kyushu University (Fig. 4). Results of longitudinal motion characteristics measured during the first gliding test have already been reported [6].

The first sea test [7] was conducted in March 2012. Since then, the buoyancy engine has been replaced with a newly developed small one using an axial piston pump [8]. In December 2013, we conducted pitching control tests [8] on the coast and confirmed its stable pitch-control characteristics.

We conducted another sea test last November to evaluate the heading-control performance of the glider. In this paper, we

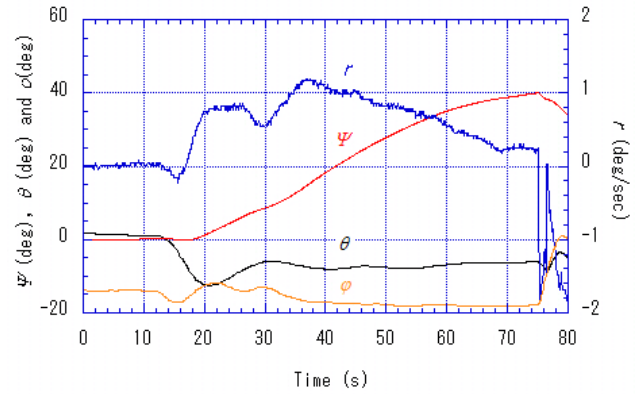


Fig. 5(a)

Underwater weight: 0.9 kg  
GCC rotation angle: 21.7 deg

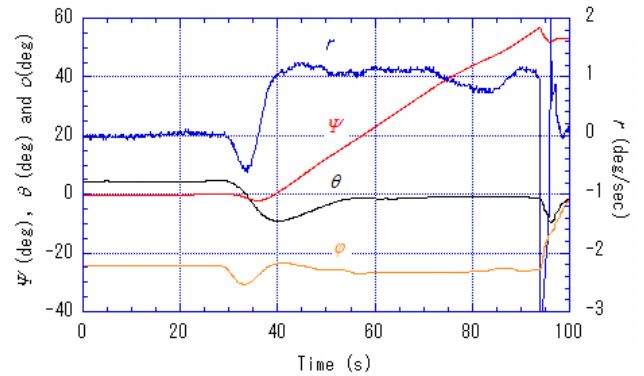


Fig. 5(b)

Underwater weight: 0.9 kg  
GCC rotation angle: 41.5 deg

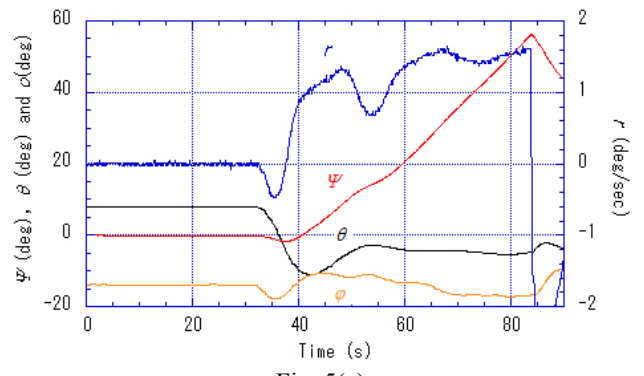


Fig. 5(c)

Underwater weight: 1.395 kg  
GCC rotation angle: 21.7 deg

Fig. 5. Examples of heading control test results of the glider measured in the Ocean and Engineering tank.

$\Psi$ ; Rotation angle around the vertical axis  
 $r$ ; angular velocity around the vertical axis

present the results of the transversal motion characteristics of the glider measured during the first gliding tests at the Ocean and Engineering tank, along with the heading control test results of a recent sea test.

## II. MEASUREMENT OF TRANSVERSAL MOTION CHARACTERISTICS

Before starting to glide in the Ocean and Engineering tank, the glider was hung with a thin nylon string, as portrayed in Fig. 4. After coming to a stop, the thin string was released; the glider then began to glide. The underwater weight, the pitch angle, and the roll angle were set before starting to glide. For this experiment, the GPS/Iridium antenna was removed because it was not needed.

The heading is usually measured using a magnetic compass (OS5000) in the ocean. However, a magnetic compass can not be used in the tank because of disturbances of the Earth's magnetic field there. Therefore, we measured the angular velocity with an attitude/angular velocity sensor (AMU Light) and integrated its output to ascertain the rotation angle. Before integrating the angular velocity, the offset should be removed from the measured data. As described above, the glider was stabilized before starting to glide. We averaged the angular velocity while the glider was halted to obtain the offset of the angular velocity. For simplicity, we did not use an Euler transformation. Although the AMU Light has an intrinsic function to calculate the rotation angle, we were unable to use them because it did not work well and showed an inappropriate value when the angular velocity is low.

Figs. 5(a), 5(b), and 5(c) present examples of the measured transversal motion characteristics of the glider. The glider was hung with a thin nylon string before starting to glide. Therefore, transient phenomena are found immediately after its release. The coordinate system was explained in an earlier report [6].

The angular velocities decrease gradually and respectively converge to constant values of about 0.24 deg/s (Fig. 5(a)), 1.0 deg/s (Fig. 5(b)), and 1.5 deg/s (Fig. 5(c)). We were able to confirm the stable rotation of the glider. We also confirmed that the angular velocity was estimated properly by integrating the angular velocity measured using the attitude/angular velocity sensor. The angular velocity increased with the increase of the GCC's rotation angle and underwater weight. The glider touched down onto the tank's floor at 75 s (Fig. 5(a)), 93 s (Fig. 5(b)), and 83 s (Fig. 5(c)).

## III. HEADING CONTROL TEST

Heading control tests were conducted on the coast last November. We use a P controller to control the heading. The maximum rotation angle of the GCC was limited to 60 deg. Before the heading control, the pitching of the glider was controlled to the target value. After the pitching control was halted, the heading control was started. When controlling the heading and pitching, the buoyancy control was halted.

The heading was measured using a magnet compass OS5000. Figs. 6(a) and 6(b) present examples of the test results while the glider was descending and ascending, respectively. The heading was controlled smoothly. However, the angular velocity in these coast tests is lower than those of the tank test.

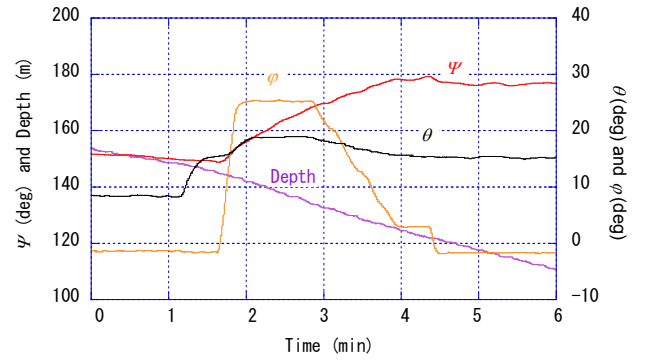


Fig. 6 (a) Heading control test results during glider ascent. Target direction was 180 deg.

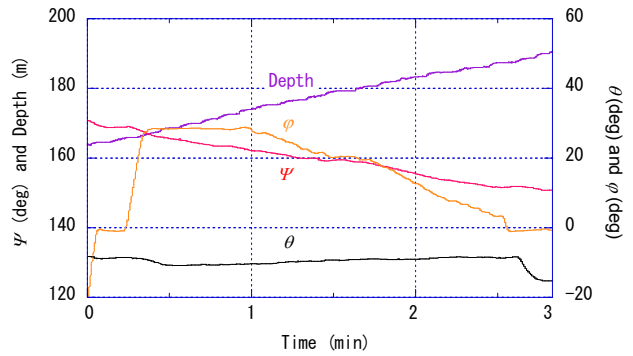


Fig. 6 (b) Heading control test results during glider descent. Target direction was 180 deg.

Moreover, a difference between descending and ascending angular velocities exists. The next sea test is being prepared to ascertain the cause of these differences and to choose better parameters for heading control.

## IV. CONCLUSION

This paper presented results of rotation tests and heading control tests. The most important of them are explained below.

Transversal motion characteristics were measured in the long Ocean and Engineering tank at RIAM, Kyushu University. The test results confirmed the stable rotation of the glider. The angular velocity increased with the increase of the GCC's rotation angle and underwater weight.

Heading control tests were conducted on the coast. We were able to confirm stable heading control using a P controller. However, the angular velocity in these coast tests is lower than those of the tank test. Moreover, a difference between descending and ascending angular velocities exists.

Before the heading control test, we conducted pitching control tests and obtained good results. Using the pitch control and heading control, we can guide the glider to the target point.

The next sea test is now being prepared to find the cause of the difference above and to choose better parameters for

heading control. The guidance performance to a target point will also be examined.

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