Positioning and navigation for free-fall type underwater observation system

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In the recent years, technologies on marine development and research are strongly required and has been actively developed. However, it costs large to operate the marine apparatus, for example ROV (remote operate vehicle) or AUV (autonomous unmanned vehicle) in general. And, hence, it is difficult to increase the number of researchers or explores on the marine field. Therefore, it is necessary to develop a low cost and an easy operation system for underwater observation and exploration. In order to extend the number of which population are concerned with the underwater observation, the authors focus on the free-fall type underwater observation system(UOS) since the free-fall type UOS are realized at low cost and are easy to operate. The underwater position is required for exploration strongly although it is difficult to determine the underwater position of the free-fall type UOS due to tidal current and so on. Until now, we have developed a whole underwater circumferential observation system that is named Gyogyotto Camera. The camera system consists of the glass sphere which can be submarined at 7800m of sea depth. The observation system achieves the underwater circumferential video successfully. In this presentation, the recent free fall type UOS which recorded the world's first 3D video movie of the sea bottom at 7800m of the depth is introduced. And also the feasibility of the underwater positioning is studied using a micro electro mechanical system (MEMS) for an inertia measurement unit (IMU) inside the developed camera system.

Keywords: ocean bottom seismic observatory, underwater exploration system, inertia measurement navigation, micro-electro mechanical systems, inertia measurement sensor, whole circumferential video

1. Introduction

In the recent years, the global covering ocean observation and investigation is strongly required in order to protect sea creatures and to explore sea resource and so on.[1] A free-fall-type underwater observation systems (UOS) is often employed in order to monitor sea bed, earthquake awareness and its occurrence. Also, sea resources and creatures are often observed using the UOS. The authors are developing a low cost underwater observatory system, we call it "Gyogyotto Camera", using glass spheres like "Edokko No.1" [2-3]. The UOS we developed can monitor and record entire circumferential underwater image in real time.

For free-fall type UOS, the positioning is also required. However, a global navigation satellite system (GNSS) doesn’t work under the sea because radio wave, which is a positioning signal from the satellite, reflects at the sea surface and absorbs in the sea. Usually, inertial mass systems (IMS) or ultrasonic positioning systems like SSBL (super short baseline) are often employed. Nonetheless, SSBL takes high cost to set the ultrasonic transducer system and IMS requires a ring laser gyroscope of which cost is high and size is also large.

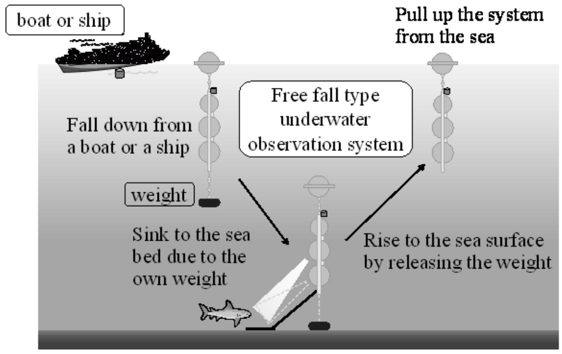

Figure 1: The operation of the free-fall type UOS.

In this presentation, the recent free fall type UOS, "Edokko No.1" which recorded the world's first 3D video movie of the sea bottom at 7800m of the depth is introduced. And also the feasibility of the underwater positioning is studied using a micro electro mechanical system (MEMS) for an inertia measurement unit (IMU) inside the developed camera system. However, high accurate positioning is not expected completely if the cost and the size of IMS sensor is limited. Therefore, most of IMS systems has another sensor to compensate the error, for example, a Doppler Velocity Logger (DVL) [5-6] or an Acoustic Doppler Current Profiler (ADCP)[7]. The authors discuss feasibility of the employment of the IMU systems in order to determine the positioning of the free fall type UOS.

2. Free-fall type UOS

Figure1 shows a schematic explanation of the operation of the free-fall type UOS which has no propulsion system like a propeller or a thruster. Therefore, the observation system sinks to the sea bed due to the weight after the system is felt down from a ship or a boat. For a while, the system measures the data, records the video or collect the soil at the sea bed. When the system rise to the sea surface, the weight is released from the observation system due to the electrolytic corrosion.

Generally, a glass sphere is employed to contain the observation apparatus for example a camera, a light and so on. The cost of the glass sphere is too low in the comparison with the material which consists of UOV or ROV. However, the strength of the glass is enough to bear 800Mpa of hydrostatic pressure at 7800m of the depth. Recently, the project "Edokko No.1" is founded in Japan in order to realize a simple, a portable and a low-cost deep sea exploration system using glass spheres. The project members are the CEOs of the small company in Tokyo downtown districts, universities, a research institute, a bank and volunteers of an electric company. The authors are also members of the Edokko No.1 project. The free-fall deep sea exploration video system, we call "Edokko No.1", recorded 3D video of deep sea creatures at 7800m of the depth, successfully. Figure 2 shows the picture of the Edokko No.1. After the success of the Edokko No.1 project, the authors have developed the deep sea exploration system in order to make the observation system, "the Edokko No.1" easy to operate. At the next section, the new observation system we called "Gyogyotto camera" is explained.[7-8]

3. Development of GYOGYOTTO CAMERA

3.1 Constitution of the Gyogyotto camera

Figure 3 shows configuration of Gyogyotto Camera. And Table1 indicates the specification of the camera. The developed camera consists of two parts. The lower part is a glass sphere and the upper is a PVC cylindrical case. The glass sphere contains batteries, a power supply board, a Wi-Fi router, four cameras (SNC-CX600, SONY), and an IMS sensor built-in smartphone (ZenFone2, ASUStek computer inc.). An angle of view of cameras is 120 degree in the air. In the water, the angle of view becomes narrower due to curvature of glass sphere and difference of index between glass and water. Then, the original camera lens changes into wider lens. And also, the four network camera are employed in order to record the entire circumferential image. The PVC cylindrical case contains batteries, a power supply board, a Wi-Fi router, a LED control board. Figure 4 describes the operation of the Gyogyotto camera. The camera connects with a buoy or a ship floating on the sea through a LAN or an optical fiber cable in order to deliver real time image of sea bed. The LED brightness controller using ethernet-serial converter is mounted on the power supply board. Due to the difficulty of the process against the glass, there is only one hole for depressurization on the glass sphere. For the glass sphere, the upper hemisphere and the lower hemisphere put together and covered the peripheral of the contact surface by butyl rubber and plastic tape in order to prevent from sinking. The LAN cable is put through the hole on the PVC cylindrical case.

Figure 5 shows the diagram for delivering path of movie and data. The four network cameras, that is SNC-CX600, are connected to the Wi-Fi router1 in the glass sphere. As mentioned above, the Wi-Fi router2 in the PVC cylindrical case is connected to the Wi-Fi router3 on the buoy in the sea surface. The connection between the

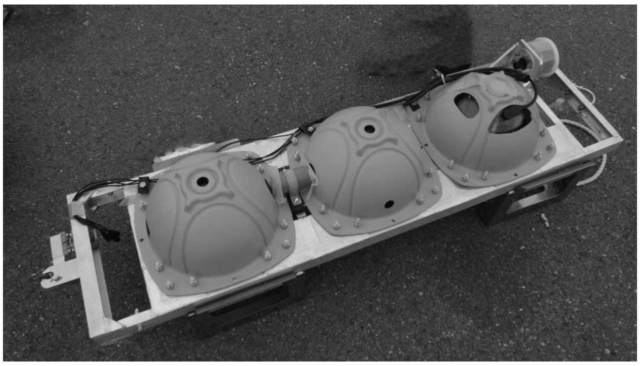

Figure 2: The whole picture of the Edokko No.1.

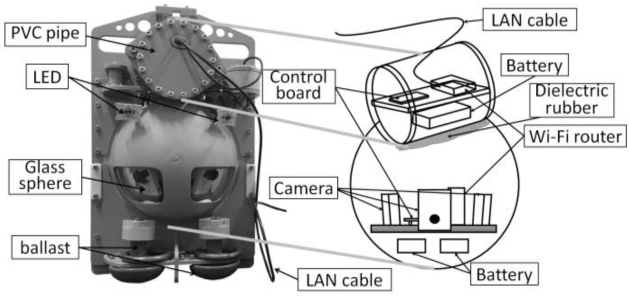

Figure 3: The configuration of Gyogyotto Camera.

Table 1: The specification of Gyogyotto Camera.

Size H × W × D [mm]	813 × 470 × 354
Weight [kg]	About 35
Drive time [hour]	About 4.4
Water depth[m]	About 300

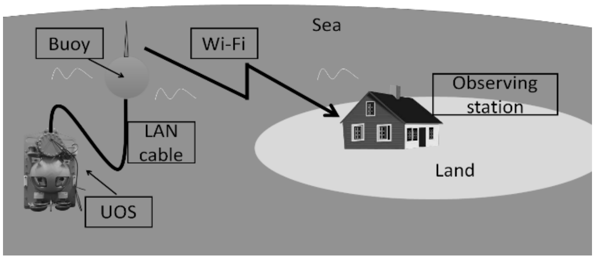

Figure 4: Schematic explanation of the operation of the Gyogyotto camera and the video delivery path.

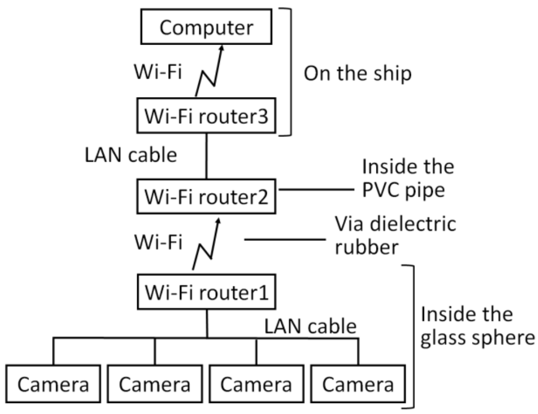

Figure 5: Diagram for delivering path of movie and data.

Fig.6 entire circumferential underwater image recorded by Gyogyotto Camera.

Wi-Fi router1 and the Wi-Fi router2 is also achieved by Wi-Fi in order to reduce the number of the process on the glass sphere and the PVC cylindrical case. As the dissipation of Wi-Fi signal becomes large, Wi-Fi is not available directly under the sea. Then, the Wi-Fi communication via dielectric rubber, which is described in [9], is employed. The dielectric rubber is installed into the contact part between the glass sphere and the PVC cylindrical case.

3.2 Underwater entire circumferential image

We conducted an experiment operation of the Gyogyotto camera at Shin-Enoshima aquarium [10]. A synthetic image from captured movie is shown in Fig.6. The images are obtained from each movie recorded by each internal camera and are stitched manually. As shown in Fig.6, the clear entire circumferential underwater image is obtained. The circumferential entire movie should help in the geomorphic investigation and creature research under the sea. For our future plan, the synthetic process is operated automatically.

4. Position estimation of the UOS

Using MEMS IMS sensor, that is accelerometer and gyroscope, built-in Zenfone2, the position of UOS is estimated. As well-known, an IMS unit produces a random walk signal. Generally, the precision of IMS sensor is characterized by the random walk signal [11]. Figure7 shows the position error by calculate the integration of the IMS sensor signal built-in the UOS when the UOS is stationary. Even if the UOS doesn't move at all, estimating position proceeds up to 800m dramatically due to the random walk signal.

The position estimation is also tried under the water. The pool as shown in Fig.8 is employed at Tokyo university of Marine Science and Technology. Figure 9 shows the estimation results. The true trajectory of the UOS measured by the laser distance measurers (DISTOTM plus, Leica Geosystems) is also indicated. On the experimentation, the UOS progress linearly by the crane in 8.1m of distance along the X direction. It took 14 seconds to progress at 0.35m/s of speed. In positon estimation of the UOS, the difference between the estimation and the measurement is severe. In Fig.9, the simulation trajectory in the consideration of the Allan variance is also indicated. According the simulation results, it is confirmed that the Allan variance causes the severe difference between the estimation and the measurement. In order to reduce the error due to the

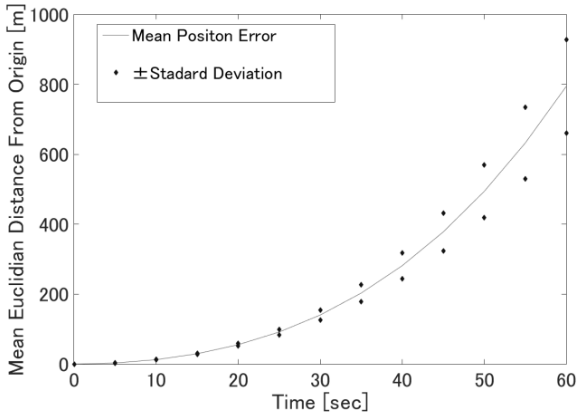

Figure 7: The UOS's stationary position error.

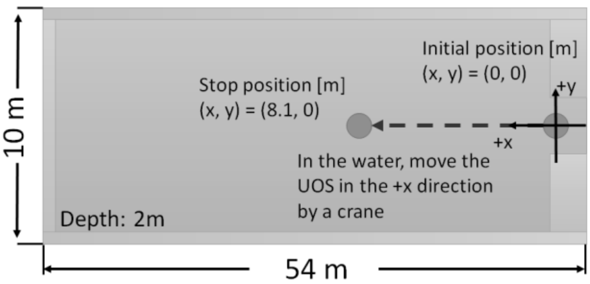

Figure 8: The setup for the position estimation experiment.

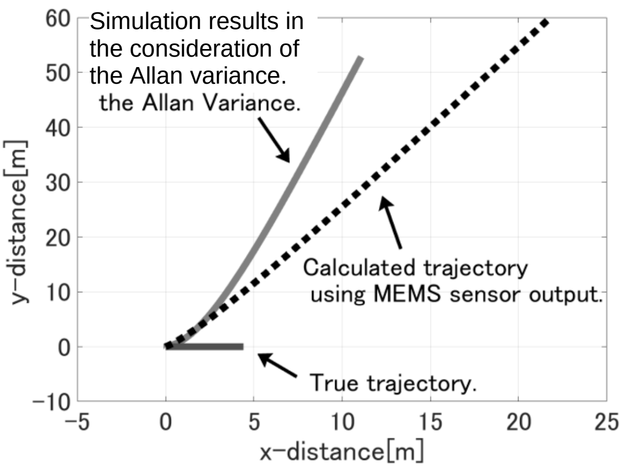

Figure 9: The UOS's trajectory under the water.

Allan variance, the filter process is generally applied. The most simple filter process is subtraction of the bias error obtained by the Allan variance from the sensor output. Figure 10 shows the results filtered by the bias error subtraction. It is confirmed to reduce the difference. However, the difference is still several meters in 14 seconds. And, hence it is difficult that only MEMS IMU sensor gives the accurate positon in the condition of low velocity speed. To increase the accuracy the position estimation, auxiliary sensors like a DVL [5,13] or an ADCP [6,12] is indispensable.

5. Summary

In this presentation, the recent free-fall type UOS project is introduce. And also the developed free-fall type UOS that are able to monitor and record entire circumferential underwater image in real time is described. The position estimation under the sea using MEMS IMU sensors is also tried. A DVL or an ADCP is indispensable in order to estimate the accurate position. The authors expecte to develope DVL or ADCP which can be operated under high hydro-static pressure.

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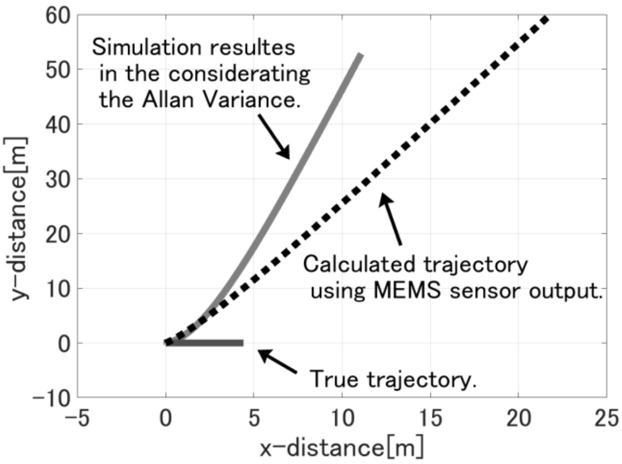

Figure 10: The UOS's trajectory under the water.

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