DEVELOPMENT OF A SMALL-SIZE TESTBED AUV "TAM-EGG 1" WITH ACOUSTIC TELEOPERATION SYSTEM

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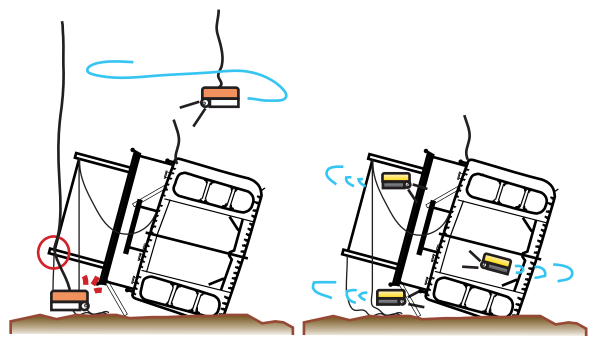
Abstract

Since Autonomous Underwater Vehicles have an advantage that they can swim freely without the restriction of a tethered cable, it is expected that the demand for the development of compact and intelligent AUV's to undertake such complicated missions that they investigate underwater structures, will increase greatly over the next few years. The small-size testbed AUV "Tam-Egg 1" and supervisory teleoperation system were developed to meet this demand. The most critical aspect of the vehicle design was to make it small and light, in order to increase its maneuverability under restricted environments. A basic performance test of the vehicle and the teleoperation system has performed in the test basin, and has proved the good maneuverability of the vehicle. This paper describes the design and a performance test of the vehicle.

1. Introduction

Since Autonomous Underwater Vehicles (AUV's) have an advantage that they can swim freely without the restriction of a tethered cable, they are very useful for ocean observation. It can be said that AUV's are increasingly finding practical applications worldwide. For investigation of underwater oilfields and resources, seabed observations are already being commercially executed by AUV's using side scan sonars, multi narrow beam sonars, sub-bottom profilers and etc.. These applications are done by cruising-type AUV's. But, applications of AUV's are not limited to wide-area survey. Hovering-type AUV's have been used to perform autonomous investigation of underwater structures both in a test tank and real sea [1][2].

Oil-tanker wrecks usually cause serious damage to natural environment. To find out the cause of such accidents, and to avoid similar accidents, immediate and detailed investigation is necessary. Periodical inspection is also necessary to protect ocean environment. Although these operations are normally carried out by Remotely Operated Vehicles (ROV's), they require specifically designed support vessels with heavy equipment. Thus, their mobility is inevitably restricted for immediate operation. As shown in the Fig. 1, ROV's also have problems of an umbilical cable that may become entangled with other structures. Therefore, it is expected that the demand for the development



(a) ROV's (b) AUV's

Fig. 1 Advantage of AUV's for Investigation of Underwater Structures

Fig. 2 The Tam-Egg 1

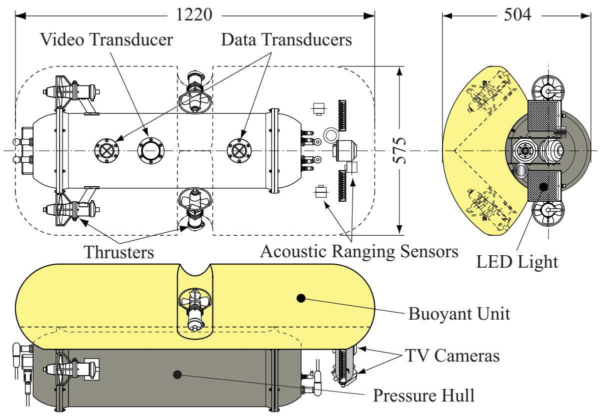


Fig. 3 General Arrangement of Tam-Egg 1

of compact and intelligent AUV's to undertake these complicated missions will increase greatly over the next few years.

The small-size testbed AUV "Tam-Egg 1"(Fig. 2) was developed to meet this demand. It can be teleoperated by human operators using a high-speed acoustic link to perform complicated maneuvers which require high intelligence. This paper describes the design and a performance test of Tam-Egg 1. Our future goals are to improve the current software system for supervised investigation of complicated structures such as wrecks and to transfer the newly developed system to ocean-going vehicles.

2. Design of Tam-Egg 1

The most critical aspect of the vehicle design was to make it small and light, in order to increase its maneuverability under restricted environments. Thus, batteries and other equipment are minimized. The vehicle has only necessary and sufficient equipment to accomplish intended investigation behavior.

The vehicle was designed as part of a larger system that utilizes a launcher, to which the vehicle shape was adjusted. This system, in turn, is part of a comprehensive research project to develop a compact deep-sea monitoring robot system [3][4].

The mission scenario of the ultimate ocean-going system is as follows;

(1)Landing: The vehicle which is mounted inside the launcher is landed from a support vessel.
(2)Descent: The launcher and the vehicle descend directing to the target using SSBL positioning system. The launcher has fins to control its direction to the target [5].
(3)Anchoring: The launcher discharges the anchor and stay at a constant height.
(4)Launching: The vehicle is launched from the launcher.
(5)Investigation: The vehicle investigates the target with assist of acoustic link.
(6)Ascent: The vehicle release the ballast and the launcher cut off the mooring cable to ascend.
(7)Raising: The support vessel will find the vehicle and the launcher using radio beacon and flashing light.

Table 1 Dimensions and Specifications of Tam-Egg 1

Length overall	1.22m
Breadth overall	0.58m
Depth	0.50m
Dry weight	131Kg
Operating depth	100m
Duration	about 3 hours
Structure	A6061-T1 TUFRAM Processed Pressure Hull
Actuators	100W Thruster x 4
Processors	NS GX-300MHz x 2
OS	VxWorks
Sensors	Magnetic Compass (TCM2)
	Fiber Optic Gyroscope
	Pressure Sensor (Depth Sensor)
	Color CCD TV Camera x 2
	Acoustic Ranging Sensor x 4
Communications	Acoustic Command Link
	Data: 125 - 250 bps
	Image: 64k - 128k bps
Lights	LED Light x 2
Battery	Ni-Cd Battery, 25.2V, 20Ah

Tam-Egg 1 is designed as a testbed vehicle which has the same size and the shape of the ocean-going vehicle. Thus only the modification of the capacity to resist pressure is necessary to build up the ocean-going vehicle. The depth rating for ocean-going vehicle is more than 3,000m and Tam-Egg 1's capacity is designed for 100m considering the experiment at the test basin and shallow water.

Figure 3 and Table 1 shows the vehicle general arrangement, dimensions and specifications. The following sections describe their detail.

2.1 Structures and General Arrangement

As shown in the Fig. 3, the vehicle consists of a cylindrical pressure hull and a buoyant unit. They both function as structural members and all pieces of the equipment are directly mounted on them. To reduce the number of thrusters and to have controllability for 4-DOF (surge, sway, heave, and yaw), 4 propeller

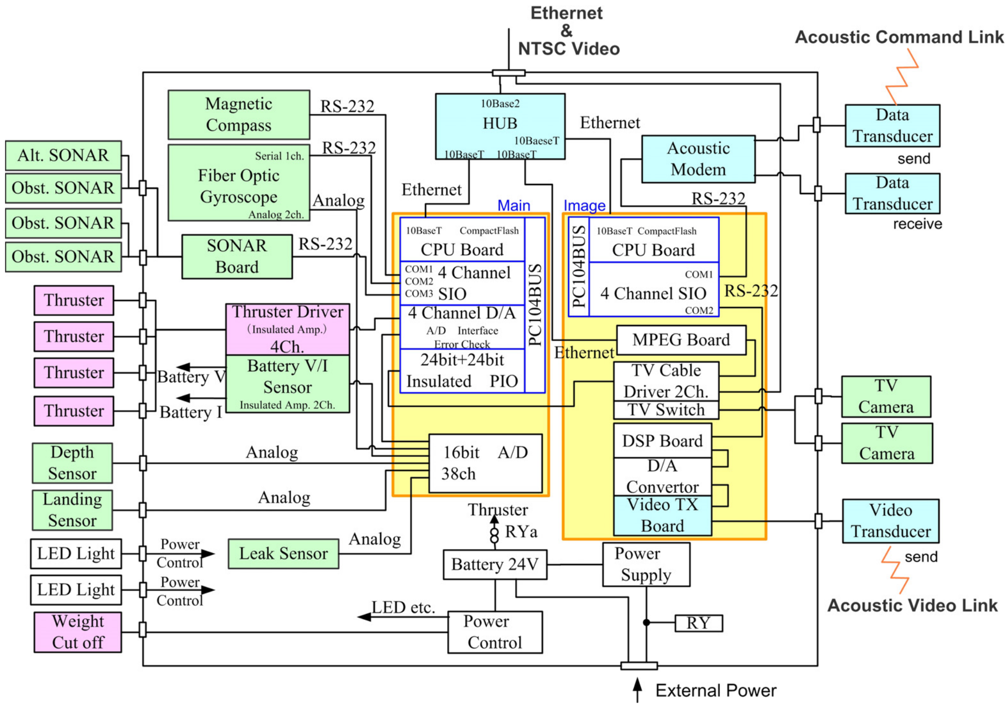


Fig. 4 System Configuration

thrusters are mounted on the vehicle as shown in Fig. 3. One pair of thrusters are fixed horizontally on both sides of the pressure hull, and another pair of thrusters are tilted vertically by 45 degrees. The horizontal thrusters are related to surge and yaw motions. The tilted vertical thrusters are related to sway and heave motions. High separation between the center of gravity and that of buoyancy provides good static stability for roll and pitch motions.

The shape of the buoyant unit is designed to fit the curvature of the ocean-going launcher. The combination of this buoyant unit and the pressure hull looks like Japanese “Tamago-Susi.” This is the origin of the vehicle’s name. The Japanese term “Tamago” means “Egg,” and “Tam-Egg” is compound word from them.

2.2 Power Systems

There are various kinds of high capacity battery cells are commercially available. However, a set of Ni-Cd battery cells are chosen for the vehicle considering its cost and easiness of maintenance. The power is provide for both electric circuits (computer and sensory systems) and thrusters. External power supply cable can be connected for long-time experiment in test tanks.

2.3 Computer and Communication Systems

As shown in the Fig. 4, two computer systems share the load of calculations. The main computer system manages sensory systems and actuators. The green-colored squares are sensory systems, and red-colored squares are actuator systems. Each sensory system transmits data through RS-232 serial or analog communication cables to the main computer system. The main computer system outputs reference analog signal to thruster driver.

The image processing computer system processes image-related information and acoustic communication data. Main roles of the image processing computer are conversion and transmitting the image data from the TV cameras to the teleoperation interface through acoustic video link. The MPEG conversion board converts the TV camera image into MPEG-format data and sends it to the image processing computer. The computer converts the MPEG-format data into special format for acoustic link and sends it to the high-speed video transmitting system [6]. The maximum transmitting speed of the video link is 128 [kbits/sec].

To avoid damage by shock, Compact Flash is used for storage for both computer systems.

Two computer systems and MPEG conversion board are connected each other via Ethernet. External computer system can be connected to the network system of the vehicle both through acoustic data link for field test and a communication cable for tank test. The communication cable contains Ethernet and NTSC video cables.

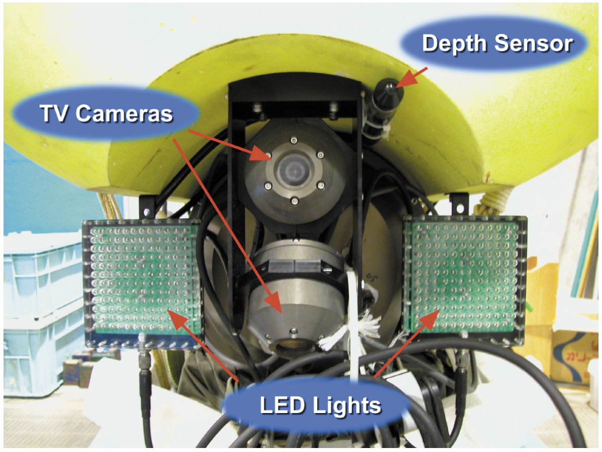


Fig. 5 The Face of Tam-Egg 1

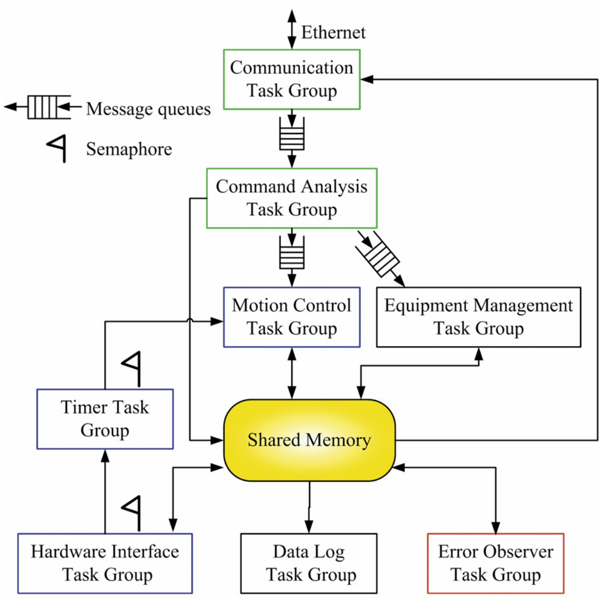


Fig. 6 Software Architecture

2.4 Sensory Systems

To perceive surroundings, the vehicle has 2 color TV cameras and 4 acoustic ranging sensors. The frequency of the ranging sensors is 175 [kHz]. Directions of the sensors are forward, downward, right and left. In order to reduce power consumption and weight, 2-TV cameras are mounted by directing forward and downward as shown in the Fig. 5, rather than pan-tilt mechanism. LED Lights are also used to reduce power consumption.

An electronic compass sensor module "TCM2," a fiber optic gyroscope (FOG) and a pressure sensor are utilized to measure the vehicle motion. The TCM2 provides roll, pitch and yaw angle data. The FOG provides high-accurate yaw angular velocity and angle data

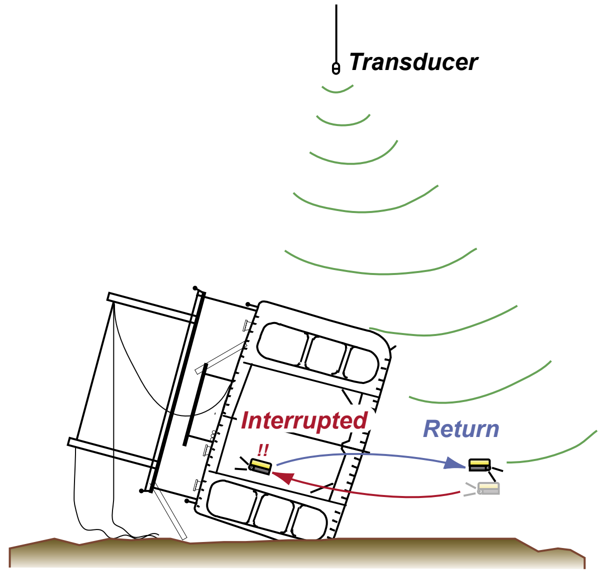


Fig. 7 Autonomous Retern Behaviour for Acoustic Interruption

by integration. The pressure sensor provides absolute pressure data to calculate depth.

To observe the vehicle internal condition, water leak sensors, a battery voltmeter, an ammeter and a thermometer are set in the pressure hull.

2.5 Software System

Software architecture of the vehicle is shown in the Fig. 6. The software system is executed on the main computer system. A operation system of the computer is the VxWorks which is a real-time and multi-tasking OS.

Each function of the task groups are as follows;

(1) Communication Task Group: It consists of acoustic and Ethernet communication tasks to maintain the communication between the vehicle and operator interface.
(2) Command Analysis Task Group: It analyzes command packets from operator interface and extracts commands and parameters.
(3) Timer Task Group: It manages the time and provides synchronization of entire tasks.
(4) Motion Control Task Group: It produces control reference values for thrusters to controls the vehicle motion in 4-DOF independently.
(5) Equipment Management Task Group: It manages equipment and power systems.
(6) Data Log Task Group: It records entire data of input and output of the main computer system.
(7) Hardware Interface Task Group: It manages I/O boards of the main computer systems.

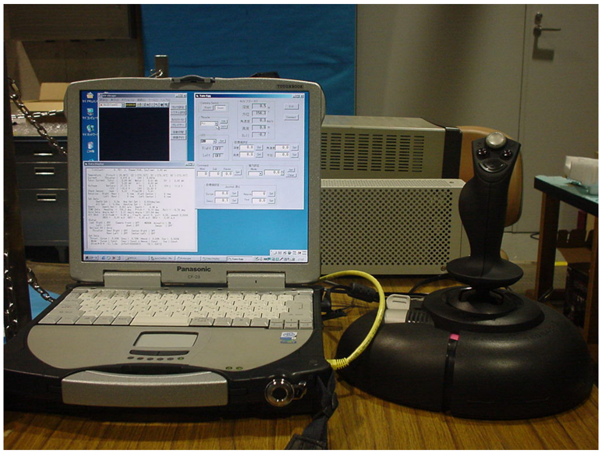


Fig. 8 Teleoperation System

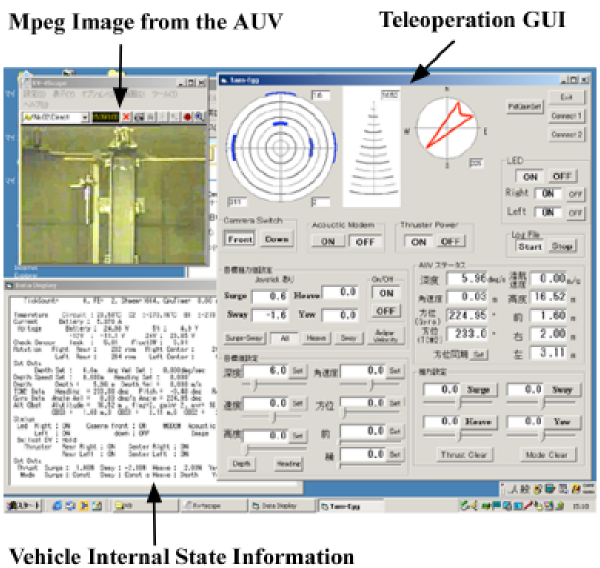


Fig. 9 Graphical User Interface

(8) Error Observer Task Group: It observes shared memory independently and manages errors.

2.6 Teleoperation System

The expected mission for the vehicle is to investigate structures under complicated environment. Although the system has high-speed acoustic link, time-delay and interruption are expected to be happened. Thus, human operator supervises the investigation behaviour, i.e., the operator send simple command to the vehicle to give directions of the investigation. The vehicle should have autonomous functions to control its motion and to make simple decision. Figure 7 shows example autonomy that the vehicle returns to the previous position when acoustic interruption happens. A study of such teleoperation system performed previously [7].

As shown in the Fig. 8, a teleoperation system consists of a laptop computer and a joystick. Figure 9 shows the graphical user interface of the teleoperation system. The operator gives commands to the vehicle using a teleoperation GUI and the joystick. The MPEG movie from the vehicle and the vehicle internal state information are provided to the operator for supervising.

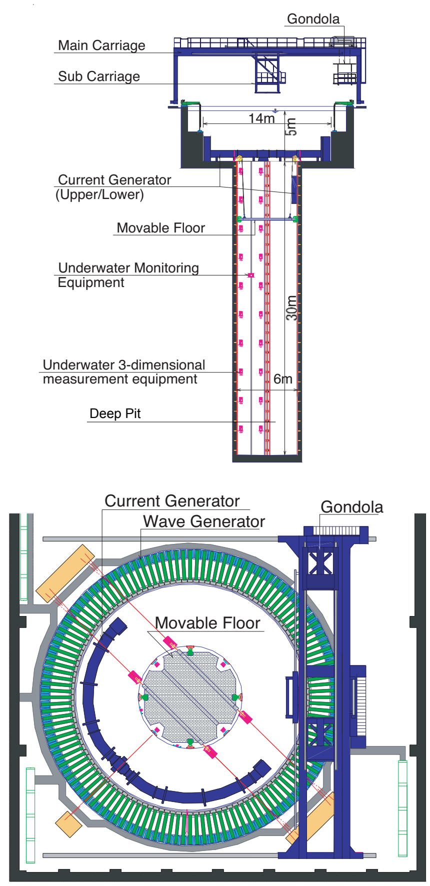


Fig. 10 Arrangement of the “Deep-sea Basin”

3. Performance Test

A basic performance test of the vehicle and the teleoperation system has performed in the “Deep-sea Basin” at the National Maritime Research Institute of Japan. As shown in the Fig. 10, it has 35 [m] deep pit that has the Guinness record. Maneuverability of the vehicle and performance of acoustic link has examined. Since the acoustic link was difficult to be used in the basin because of the multiple reflection of the sound, the communication cable was connected. Hence, without the time-delay and interruption of acoustic communication, the investigation behaviour was

Fig. 11 Performance Test in the Basin

Fig. 12 Tam-Egg 1 Descending in the Basin

Fig. 13 Tam-Egg 1 at the Bottom of the Deep Pit

performed good as shown in the Fig. 11 to Fig. 14. The operator (the first author) only watched the teleoperation interface and gave commands to the vehicle.

To examine performance of the autonomy of the vehicle, yaw angular velocity control test and depth control test was executed. PID controllers were used to perform the experiment. As shown in the Fig. 16,

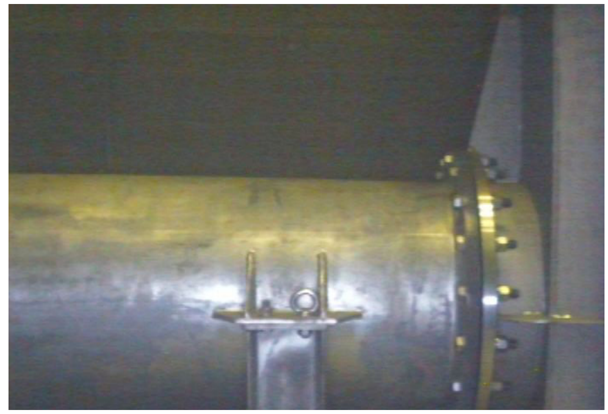


Fig. 14 TV Camaera Image of the Pipe of the Current Generator Taken by Tam-Egg 1

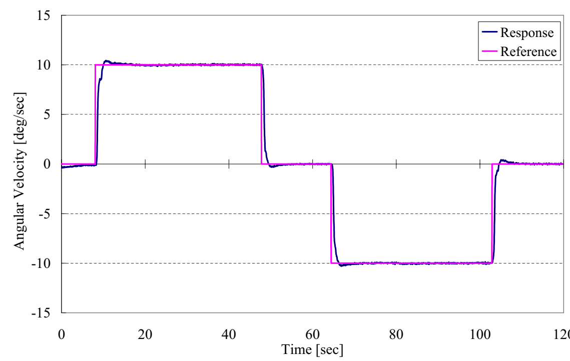


Fig. 16 A Result of Angular Velocity Control of Yaw Motion

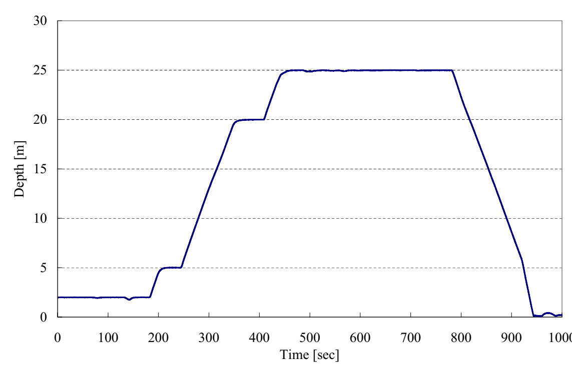


Fig. 17 A Result of Depth Control by Trajectory Control of Heave Velocity

the result of the yaw angular velocity control was very good. Based on this control, direction control also performed good result. As shown in the Fig. 17, the result of depth control by trajectory control of heave velocity was quite nice to prove the maneuverability of the vehicle.

4. Conclusions

The small-size testbed AUV “Tam-Egg 1” and supervisory teleoperation system were developed to perform complicated missions such as investigation of oil-tanker wrecks. The most critical aspect of the vehicle design was to make it small and light, in order to increase its maneuverability under restricted environments.

A basic performance test of the vehicle and the teleoperation system has performed in the test basin, and has proved the good maneuverability of the vehicle.

It is expected that the ocean-going vehicle will be constructed on the basis of knowledge obtained by using the testbed vehicle.

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References

[1] Hayato Kondo and Tamaki Ura, “Detailed Object Observation Autonomous Underwater Vehicle with Localization Involving Uncertainty of Magnetic,” Proc. of ICRA’02, 2002.05, pp.412-419.

[2] Hayato Kondo, et al., “Visual Investigation of Underwater Structures by the AUV and Sea Trials,” Proc of Oceans 2003, 2003, #451, (to be appeared.)

[3] Michio Ueno, et al., “An Analysis of Steady Descending Motion of a Launcher of a Compact Deep-sea Monitoring Robot System,” Proc. of Oceans 2002, 2002.

[4] Ueno M., et al., “Hydrodynamic Characteristics of a Launcher of a Compact Deep-sea Monitoring Robot System,” Proc. of Techno Ocean 2002, 2002.

[5] Hirotomo Ando, et al., “Model Experiment of a Launcher of a Compact Deep-Sea Monitoring Robot System,” Proc. of Oceans 2003, 2003, #127, (to be appeared.)

[6] Junichi Kojima, et al., “High-Speed Acoustic Data Link Transmitting Moving Pictures for Autonomous Underwater Vehicles,” Proc. of UT’02, 2002, pp.278-283.

[7] Takumi Imai, et al., “Semi-autonomous Touching of Underwater Object by Unmanned Untethered Vehicle,” Proc. of Oceans 2002, 2002, pp.236-241.