Development of a Marine Ecosystem and Microstructure Monitoring AUV for Plankton Environment

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***Abstract*—This paper describes a mission outline and a design concept of an Autonomous Underwater Vehicle (AUV) for monitoring marine ecosystem and physical microstructures. This vehicle is under development for a comprehensive research project "Novel technologies to evaluate multi-scale variations of pelagic marine communities and biodiversity under the influence of the Kuroshio and internal waves in coastal habitats." A cabled observatory will be deployed near the Oshima Island, which is located at the mouth of Tokyo bay, to monitor time series of multiple variables of biodiversity in marine ecosystem. The vehicle will observe plankton distribution along with the physical and microstructure measurements during deployment. The key point of this AUV development is to build a monitoring platform with low vibration at slow cruising speed, because the main target of the monitoring is the plankton environment with physical microstructures i.e. turbulences. For this need, the vehicle will be equipped with a newly developed water jet propulsion system. Acoustic communication nodes will be connected to the cabled observatory to provide a communication channel and a positioning aid.**

Keywords—AUV; Water jet propulsion; Low vibration; Plankton monitoring; Turbulence measurement

I. Introduction

Environmental change gives strong effects to marine ecosystem. To understand its mechanism and forecast the dynamics of the ecosystem is important for the future of the Earth, living things and humankind. This paper describes a mission outline and a design concept of an Autonomous Underwater Vehicle (AUV) for monitoring marine ecosystem and physical microstructures. This vehicle is under development for a comprehensive research project "Novel technologies to evaluate multi-scale variations of pelagic marine communities and biodiversity under the influence of the Kuroshio and internal waves in coastal habitats" which is funded by the CREST program of the Japan Science and Technology Agency (JST). A cabled observatory has been deployed near the Oshima Island, which is located at the mouth of Tokyo bay, to monitor time series of multiple variables of biodiversity in marine ecosystem [1]. The cabled observatory has physical/biological sensors and cameras for obtaining time series data of underwater marine environment parameters. The AUV will observe plankton distribution along with the physical microstructure measurements during deployment. The observatory will provide time-continuous data and the vehicle will provide spatial data. The observed data will be used to produce a new planktonic ecosystem model.

The key point of this AUV development is to build a monitoring platform with low vibration at slow cruising speed, because the main target of the monitoring is the plankton environment with physical microstructures. For this need, the vehicle will be equipped with a newly developed water jet propulsion system. This vehicle is designed as a cruising-type AUV and it will be operated in a shallow water coastal environment near Island facing to the Pacific Ocean. The main payload systems are turbulence measurement sensors and a digital microscope camera with a real-time image processing and archiving system [2]. Acoustic communication nodes will be connected to the cabled observatory to provide a communication channel and a positioning aid. We have named this vehicle as "MEMO-pen" which is an abbreviation of Marine Ecosystem and Microstructure mOnitoring AUV for Plankton ENvironment, since the shape of the vehicle that has a microstructure measurement pack and a microscope camera on its nose looks like a pen.

II. Mission Outline

The target environment is coastal shallow water near an Island which is assumed to be affected by Kuroshio current. The Kuroshio which means Black Stream is a strong western boundary current of the North Pacific Ocean. The change of its flow path has effects to the bio-ecosystem near the flow. A cabled observatory has been deployed in a shallow water environment at the South of the Oshima Island in the August 2014. It has various kinds of physical/biological sensors to provide real-time and continuous data. However, the spatial resolution is very limited. Therefore the AUV will be used to perform the spatial monitoring.

Since the vehicle is a moving platform, the quick response sensors are required for its payload. For the primary setup, the vehicle will be equipped with a microstructure measurement system, which is called "TurboMAP," and a plankton

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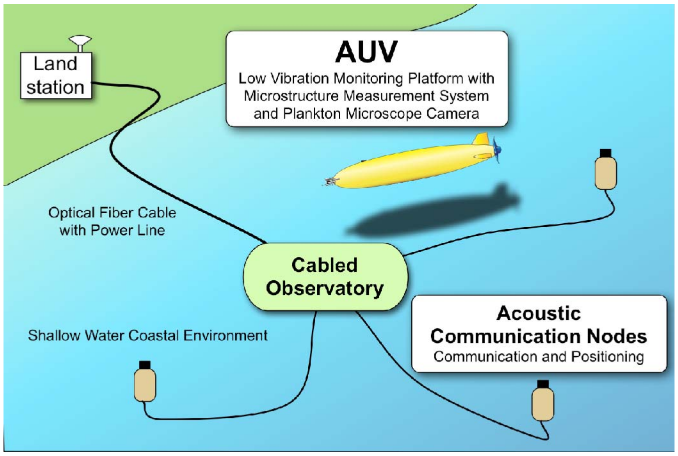


Fig. 1. Schematic drawing of the AUV working with the cabled observatory.

microscope camera with a real-time processing and archiving system. The TurboMAP measures turbulent shears, temperature, conductivity (salinity), water pressure (depth), acceleration along X/Y/Z axes, fluorescence and turbidity. To measure them clearly, the moving platform should not produce unwanted vibration, for this case the frequency band to be avoided is 1-50Hz. The observation target is microstructure, thus the vehicle's length is desirably longer than 3m.

The microscope camera for plankton measurement has a very shallow depth of field (DOF), in millimeter to centimeter scale, therefore the vehicle's cruising speed should be relatively slower (1-2knots) than the generic cruising-style AUV's speed (3-4knots).

The cabled observatory is located at about 20m depth. The vehicle also should cover around the area of the cabled observatory, and possibly it should cruise at a various depth within the 20m depth. At this shallow depth it is dangerous for cruising-style AUVs because it might collide the seabed easily.

The initial plan of the measurement area is like a cubic space for about 100m x 100m x water column depth. The vehicle should cruise at a constant velocity while maintaining its depth and avoiding the collision to the bottom and shoreline. The variety of cruising depth is programmed to the vehicle prior to the mission. Tow-yaw motion is also requested by marine scientists.

It is important for this AUV to be operated frequently at a constant time interval in the same field to provide measurement data that shows some changes affected by the Kuroshio current. Therefore, it is better to reduce the burden of AUV operators on a boat for frequent uses. Possibly, it should have a capability to be operated without any help of a support boat. For this purpose, the vehicle should have a capability to communicate with the cabled observatory to send its status and receive commands through it. AUV operators or marine scientists would have access to the AUV from a laboratory on shore. Fig. 1 shows a schematic draw of the AUV with the cabled observatory.

A docking station with a power charging and data retrieving system is an ultimate solution for long-term and boat-less operation. However, the site location for this project is close to a port where a research facility is located, and the area of water is very shallow and it is frequently attacked yearly by typhoons and storms, so we have decided not to challenge that development for this time.

III. VECHICLE DESIGN

A. *General Arrangement*

Although the vehicle's cruising speed is slow, the vehicle's size should be longer than 3 meters. The Microstructure sensors and the plankton camera should be mounted on the nose of the vehicle to measure at a point where the vehicle's wake doesn't disturb it. Thus we design this vehicle as a cruising-style vehicle. Fig. 2 shows a general arrangement of the vehicle. The vehicle has a torpedo-like shape, which diameter is 0.6m. The length is about 4.5m and it can be separated into 3 parts for easy transportation which divided into the head for payload, the middle for computer and battery systems, and tail for propulsion and motion control systems.

B. *Structure*

The AUV's structure consists of Aluminum alloy frames and rings covered by HDPE (High Density Poly Ethylene) fairings. The computer and electric systems, the battery system and some sensors are placed in pressure bottles which mostly made of hard anodized Aluminum alloys. Blocks of syntactic foams are mounted in the AUV body covered by fairings, and the other void places are free-flooded and will be filled by

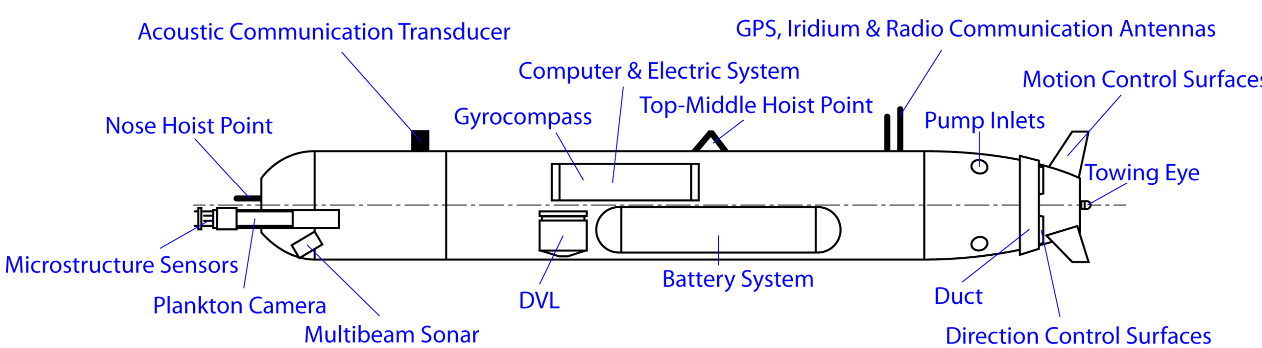


Fig. 2. General arrangement of the vehicle.

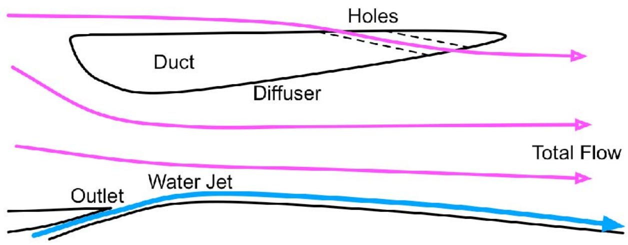


Fig. 3. Cross section of the water jet outlet.

water during the operation.

This vehicle has two hoist points, a nose point and a top-middle point. The nose hoist point has a pop-off float system with a retrieval cable.

The center of the tail end of the vehicle has a pipe with a towing eye for towing any small sensors with power and signal cable. This cable can be penetrated through the pipe and connected to the vehicle's pressure bottles. Since this vehicle has no propeller on its tail end, a towing system such as a hydrophone array can be mounted and towed easily.

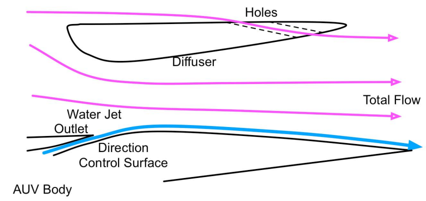
C. Propulsion System and Control Surfaces

The key development of this vehicle is the low vibration propulsion system. The shear probes, which measure turbulences, are sensitive to the frequency of vibration between 1-50 Hz. To avoid the vibration, we have decided not to use a large diameter propeller, although that is usually energy efficient. A rotating propeller also causes a spiral stream at the aft of the vehicle, which might disturb towed sensors.

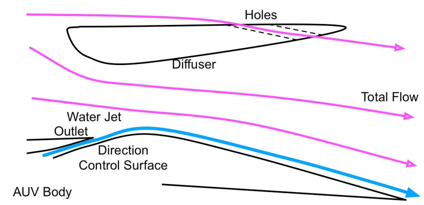
Therefore, we have proposed a kind of water pump jet propulsion system. A water pump with high rotation impeller is selected to avoid low frequency vibrations. The pumped water is pushed out through a thin and wide outlet, which is located on the surface of the aft fairing of the vehicle. Since the face of the AUV is used for mounting the microstructure sensors and the plankton camera, and also the AUV body has pressure bottles and blocks of syntactic foams filled inside the fairings, there is not enough space for waterway from the head to the aft. A centrifugal pump inlet is designed to be located on the side-surface of the aft part of the vehicle.

To increase an efficiency of the propulsion system, a duct is mounted covering the outlet of the water jet. Fig. 3 shows the cross section of the jet outlet. This arrangement is designed to have similar function to a jet pump; surrounding water is drawn by the jet flow from the outlet and increases the total flow. The duct has functionality to increase the drawn water speed near the outlet, and decrease the speed by the effect of a diffuser.

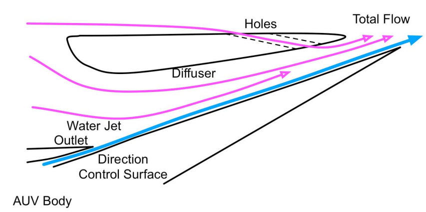
Another feature needed for this AUV is a brake or reverse propulsion system to avoid collisions with the seabed and obstacles. It is also good for the vehicle to have an ability to turn in very small radius even the has no surge velocity. For this purpose, a Direction Control Surface (DCS) is proposed as shown in Fig. 4 (a) - (d). Fig. 4 (a) shows a normal position of the DCS. The holes on the duct have two purposes, one is to increase the amount of drawn water, and another is to be used to produce reverse flow. Fig. 4 (b) and (c) show how the DCS produces a turning moment. The water jet flows following the surface by the Coanda-effect [3]. When the surface touches the edge of the duct, which is shown in Fig. 4 (d), water flow will be directed through the holes on the duct to produce a reverse jet flow.



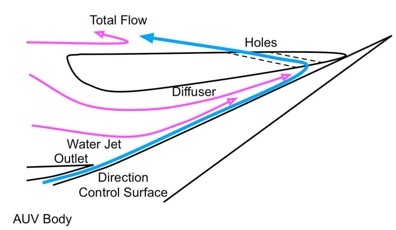
(a) Normal flow



(b) Produce minus turning moment



(c) Produce plus turning moment



(d) Reverse flow

Fig. 4. Direction Control Surface (DCS).

Cruising-style AUVs usually have streamlined narrow aft shape to decrease fluid resistance. However, the narrow shape constrains the inner space to mount any instruments. The aft shape of this AUV is streamlined but not narrow, and has sharp edge like airfoil. The DCS has an airfoil-like cross section, too. The water jet flows following the fairing shape of the aft of the vehicle by the above-mentioned Coanda-effect, and it is supposed to form stagnation of water which has shape like a virtual streamlined tail. The advantage of this design is to have large loading space without increasing the water-drag.

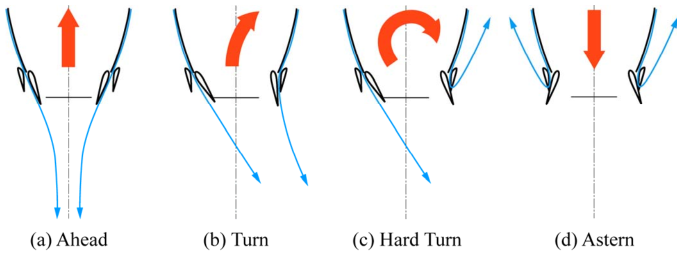


Fig. 5. Motion control by a pair of DCSs.

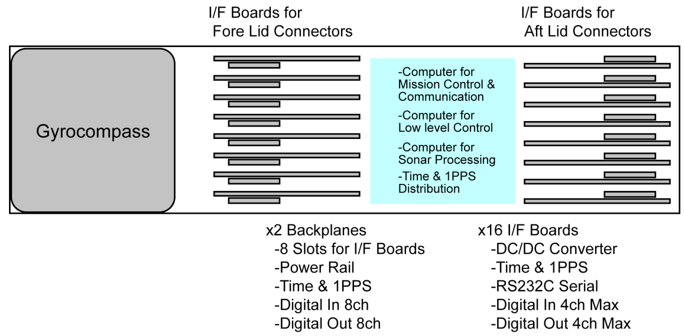


Fig. 6. Electric system in the main bottle.

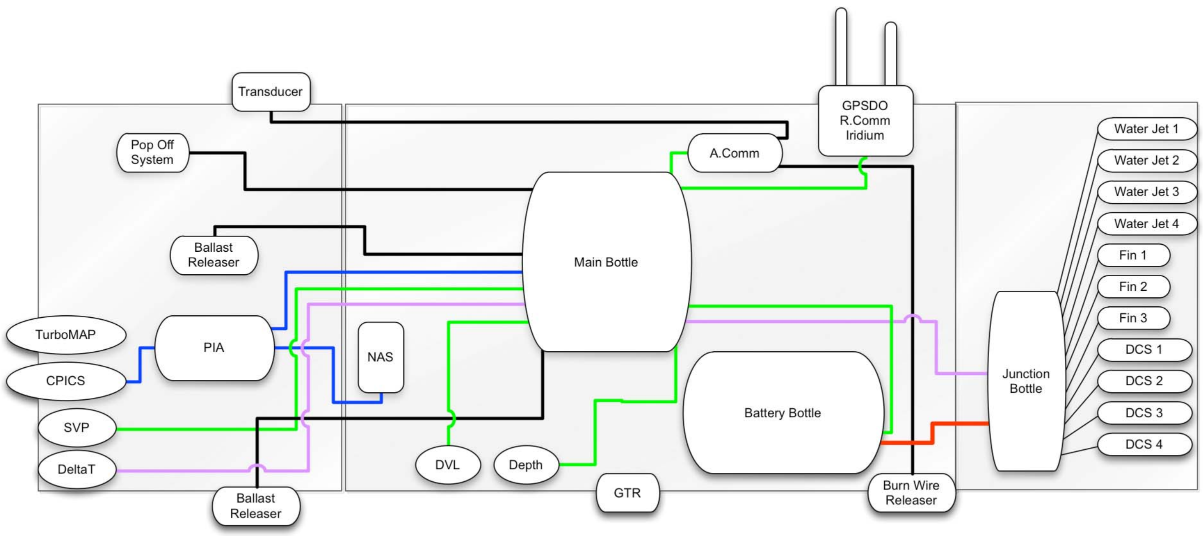


Fig. 7. Primary system configuration.

Fig. 5 (a) - (d) are the schematic drawing that how the vehicle control its motion by using a pair of the DCSs. A combination of 2 pairs of the DCSs can provide controllability in surge, pitch and yaw motions.

Basic tests for the propulsion system have been done to decide its shape. It is realized that the shape of the outlet also has significant effect to the amount of drawn water flow.

It is reasonable to locate control surfaces just behind the water jet system. This vehicle has 3 control surfaces located at the most aft of the vehicle. These 3 control surfaces provide controllability in roll, pitch and yaw motion when the vehicle cruises at relatively higher speed in surge. These motion control surfaces are necessary to control roll motion to stabilize the attitude of the vehicle.

D. Electric Systems

AUV is a platform to carry any kind of sensory systems which are always replaced for different types of missions. Electric system of the vehicle should adopt any kind of equipments which has different power requirement, different communication system, i.e. RS232C, Ethernet and etc., and different types of underwater connectors. Easy reconfigurability is quite important. As shown in the Fig. 6, we have designed the electric system in the main bottle to have easy reconfigurability. One equipment usually needs at least 1 underwater bulkhead connector on the main bottle, 1 power source and 1 communication system. When it is replaced by another equipment, the connector, the power source and the communication system usually tends to be replaced together. Therefore we have designed an I/F board and backplane system. Each I/F board has a DC/DC converter which converts the voltage from the power rail on the backplane to the required voltage for an equipment, it can be switched on and off by a signal from the low level control computer. An RS232C serial communication line, general purpose 4 digital in and 4 digital out lines, an RS232C line for time distribution, and 1PPS line for time synchronization are mounted on the I/F board. The I/F board has a connector for a harness which is connected to a bulkhead connector. Every equipment on this vehicle, which has time-synchronizing capability, can be synchronized via the RS232 time information with the 1PPS signal. These signals are provided by a GPS disciplined CSAC (Chip Scale Atomic Clock) and distributed through the backplanes and the I/F boards.

E. Primary System Configuration

Fig. 7 shows a primary system configuration of the MEMO-pen. The main bottle contains computers with the electric systems and a gyrocompass. The battery bottle encapsulates a 50.4V, 258.6Ah (13.0kWh) Lithium-ion battery pack with a protection circuit. All actuators, i.e. the water jet pumps, the motion control surfaces (fins), and DCSs are connected to a junction bottle which distributes powers and control signals.

This vehicle's navigation sensors are a gyrocompass (iXBlue, QUADRANS), a Doppler Velocity Log (DVL, Teledyne RDI, Workhorse Navigator 600kHz) and a depth sensor (Paroscientific, 8B1400-I).

A multibeam sonar (Imagenex, 837B Delta-T) and a Sound Velocity Profiler (SVP, AML Oceanographic, Micro-X SV) will be used for obstacle avoidance and rough bathymetry mapping.

The microstructure measurement pack "TurboMAP" is a stand-alone system. The plankton microscope camera (CPICS) is connected to our newly developed Plankton Image Archiver (PIA) which is a real-time processing and archiving system [2]. A Network-Attached Storage (NAS) can be connected to the PIA for large data collection.

F. Communication systems

This vehicle has an acoustic modem with a remote transducer. This modem has an ability to synchronize its clock to the reference time and 1PPS signal, so as to provide a function of "One-way ranging" through the acoustic data communication. The acoustic communication with bottom-fixed nodes assists the vechicle to estimate its position by using this functionality. These nodes are connected to the cabled observatory which is connected to a land station via an optical fiber cable. We can communicate with the vehicle from anywhere over the Internet through the land station.

Radio frequency modem with an antenna can be used when the vehicle is on the surface. Iridium satelite modem and antenna is also installed for long distance communication and emergency use.

G. Safety Systems

This AUV has 4 ballast releasers. One is to carry a descent weight, second one is to carry a ballast weight to ascent. These releasers are controled by the low level control computer. The third one is a burn wire releaser which is directly connected to the acoustic modem. This releaser can be activated through the acoustic communication even though the main computer system is down. The final one is a releaser using Galvanic Timed Release (GTR) which will be released by galvanic corrosion in salt water within a predictable time period.

IV. CONCLUSION

This paper has described the mission outline and the design concept of the novel AUV "MEMO-pen," which has unique propulsion and control surface systems. This vehicle is under construction and it is expected to be completed within the year 2014.

V. ACKNOWLEDGMENT

This study is supported by JST Crest program. We thank Prof. Hidekatsu Yamazaki who is the principal investigator of the research project.

VI. REFERENCES

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