A Deep Sea AUV "MR-X1" for Scientific Work

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***Abstract*- Since 2000, JAMSTEC has been developing an AUV (length: 2.5 m, weight in the air: 800 kg), MR-X1, with shape like headfish. The maximum depth of the AUV is 4,200 m and its operating time is approximately 15 hours with a Li-ion battery unit. Five thrusters are equipped for high maneuverability. A TV camera, a side scan sonar, and a manipulator are equipped for various scientific works. MR-X1 has three operation modes: an autonomous mode, an UROV mode, and a wireless (acoustic/radio) control mode. The development goal of the MR-X1 is achievement of the working robot with high intelligence for detailed ocean investigation, installation of observation equipment on the sea floor and so on.**

I. INTRODUCTION

JAMSTEC has been developing the autonomous under water vehicle, URASHIMA [1][2]. This AUV explores over a vast area of ocean. We categorize this type of AUV as cruising AUV. In contrast, an working AUV which has short-range navigational skill and robot hand work ability is needed for work in unexplored area such as the vicinity of submarine volcano or a place under the ice in Arctic, and for a simple repetitive task. We have started development of working AUV, MR-X1, since 2000.

A low cost design have been planned to save labor in launch/recover operation and in control operation. We have envisioned a design of working AUV for some functions: setting/recovery of measurement device to/from sea floor, data download from a device in deep water, simple repetitive task such as image scanning, and multiple vehicle work.

In order to achieve above plan, the body of MR-X1 must be small and lightweight. It is better for working AUV to use wireless control operation or autonomous operation. An image capturing device and a robot hand are necessary.

In this paper, we describe mainly system configurations and control system design of the working AUV.

II. SYSTEM REQUIREMENT

We have designed MR-X1 as autonomous and wireless control vehicle with small body for above purpose. Table 1 shows a target specifications of MR-X1.

Table 2 shows function differences between wireless and autonomous mode. To utilize both features by satisfying above specification, MR-X1 system must have the following functions: image recognition, wireless communication, autonomous control (motion control by scenario), environmental

Table 1: Specifications

Item	**Spec.**
Weight	800 kg (in the air)
Dimensions	2.5 (L) x 0.8(W) x 1.2(H) m
Working Depth	4,200 m
Cruising Speed	2 knot
Working time	>15 hours
Operation mode	Wireless / Autonomous
Working tools	TV camera, Side scan sonar, Robot hand, CTDO

Table 2: Function differences between wireless and autonomous

Item	Wireless	Autonomous
Object recognized by	man (sensor)	computer (sensor)
Operated by	man	computer
Judge accuracy	high	low
Response	low(in acoustic)	high
Position	rough	accurately
Computing power	low	high
Communication	need	no need
Working skill	high	low

measurement, high maneuverability, real time processing, and high performance computing.

III. CONFIGURATIONS

We describe the system configuration of MR-X1 in four parts: body, power source, propulsion and instrumental, and control system.

The body is made from aluminum frame which is covered by fiber reinforced plastic (FRP) as shown in Fig. 1. The body shape is like headfish. This shape is made available to set floating point and gravity point randomly. The Syntactic foam, specific gravity of 0.5, is attached on the frame.

The power source consists of four battery packs and a power control units. The oil-filled battery pack consists of Li-ion battery cells, a cell voltage monitor (not yet installed), and an acrylic case as shown in Fig. 2. The battery pack supplies voltage of approximately 120V and current of 16.5A. The cell voltage monitor(to be installed) transmits each cell voltage with the RS-232C interface to control system. The power control unit is used as a power hub and switch.

For high maneuverability, the robot is equipped with one main thruster (400W), two horizontal thrusters (150W), and two vertical thrusters (150W). Each rotation speed of thruster is monitored with the resolvers, respectively. For sensing, diagnostic, and observations, a lot of instruments are prepared: an inertial navigation system, a Doppler velocity log, a

Fig. 1: An overview of MR-X1.

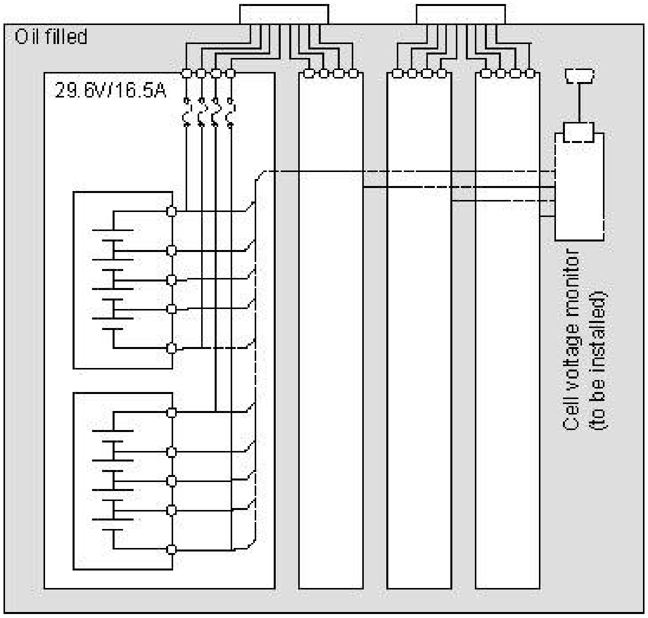


Fig. 2: a Li-ion battery pack

compass, an altimeter, a depth meter, a GPS system, an acoustic transponder, an optical communication system, an acoustic communication system, a radio communication system, a ARGOS system, and a TV camera. In the future, an obstacle avoidance sonar,

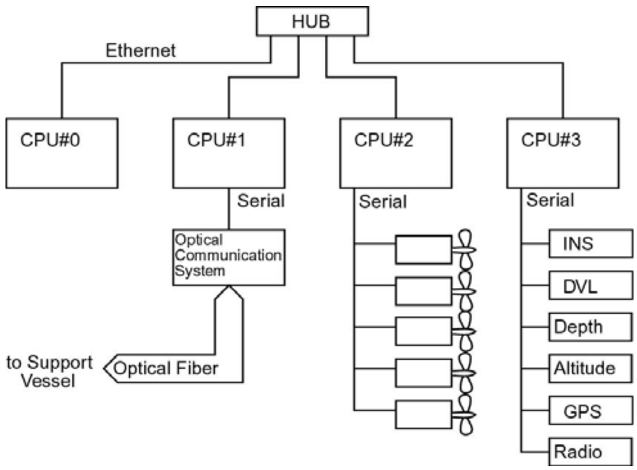


Fig. 3: A block diagram of early prototype MR-X1

a CTDO meter, a side scan sonar and a manipulator will be equipped.

In an early prototype of the MR-X1 [3], the control system had consisted of four PC-DOS boards on which Windows NT is installed as shown in Fig. 3. Each board has 4 - 12 serial interface(RS232C) ports to communicate with the instruments. In this control system configuration, we had made some inefficient choices: waste of CPU processing time that result from most processing time is assigned to communication task, no real time OS of Windows NT which does not support interrupt processing, many communication ports that result in increasing the number of connectors on the main pressure hull. Therefore we have redesigned the control system of MR-X1 as mentioned in next section.

IV. CONTROL SYSTEM DESIGN

Although JAMSTEC's ultimate goal is development of MR-X1 as well-engineered wireless and autonomous marine robot, but first we intend to make a marine robot having basic system configuration optimized for autonomous control. Therefore we solve the control system problems of identified by the prototype.

In order to improve the performance of the prototype, we have adopted a distributed processing system configuration. One chip micro-controller boards (JAMSTEC original) are developed for the cruising control, navigation, measuring, and communication equipments. A multipurpose microprocessor board is mainly used for the calculation of autonomous control and the shared memory control. Each board is connected by a serial interface.

We made comparative review of serial bus as shown in Table 3. A legacy serial interface, RS-232C, is widely used for underwater instruments, but this interface cannot connect multi-devices for a node. USB and IEEE1394 are well-known interface but their need complicate protocol stack software. I^2C is better one. It has light protocol, middle speed, and multi nodes. Some robot had used I^2C bus for control [4]. CAN-BUS which is developed by BOSCH [5] is widely used in robot application [6][7]. Consequently CAN-BUS is suitable for the marine robot so that it has enough data speed, makes branch easy, has simple protocol stack and high reliability of a connection. Table 4 shows CAN-BUS specifications. In order to reduce the total number of the main pressure hull connectors, we connect each processor by CAN-BUS as shown in Fig. 4.

The control system consists of an PC/104 computer board, which completes compatibility with standard PC Desk Top Computers, a PC/104 form factor CAN-BUS board (hereinafter collectively called "Controller"), and handmade microprocessor boards with CAN-BUS and RS-232C interface (hereinafter referred as "Target"). Each board is

Table 3: Comparison of serial interface

Standard	**Speed**	**connection**
RS-232C	~115kbps	1 : 1
USB*	10M, 480Mbps	1 : n
IEEE1394*	>400Mbps	multi-host
Ether*	10M, 100Mbps	1 : n
I^2C	400kbps	multi-host
CAN	1Mbps	multi-host

* complex protocol stack

Table 4: CAN-BUS

Item	**Spec.**	**Unit**
Speed	1	MBPS
Node	physically restricted	
Wire	2	
mode	error detection	
distance	40	m

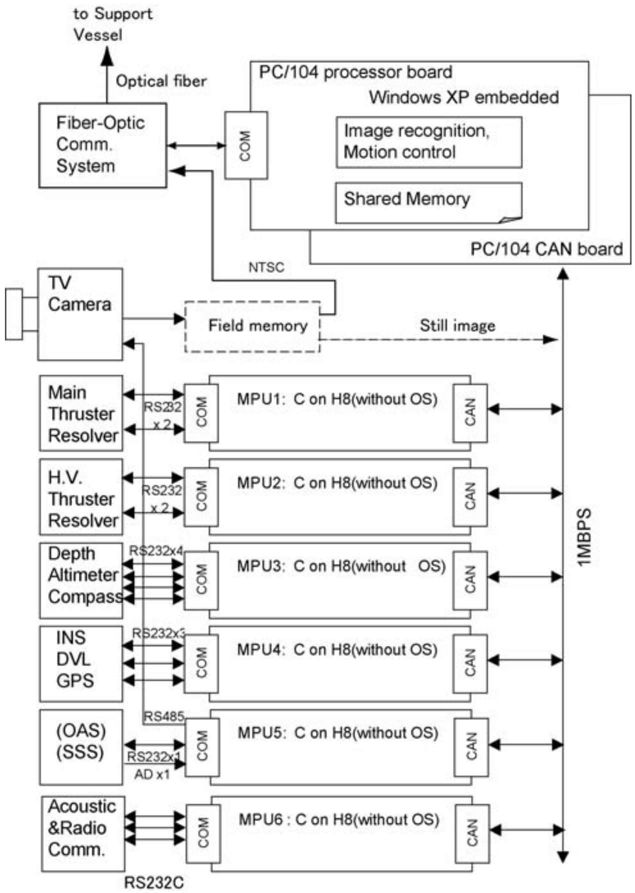


Fig. 4: A block diagram by use of CAN bus.

connected by CAN cables.

The Controller on which Windows XP Embedded is installed provides communication with a remote controller on the support vessel, communication with each Target over the CAN-BUS, shared memory management, system status management, and autonomous control of the robot.

The targets take on the function of protocol translation between CAN-BUS and RS-232C (RS-485 for TV camera) because most underwater equipments of our choice communicate with a controller over RS-232C. The target has four analog input ports for analog equipments. The target has a little intelligence that provides initialization of equipments, checking the shared memory value, and issue of commands to equipments. This processing system configuration reduces the CPU load of the Controller.

If you cannot use CAN-BUS, the same number of the connectors as of the equipments must be attached on the hull. On the other hand, this configuration needs only one connector for CAN-BUS. The CAN-BUS cable branches by a few branch-boxes outside the hull.

The features of the configuration are even distribution of the CPU load, short start-up time, boot-up from semiconductor memory device (crash proof), reducing connectors on main pressure hull, and reducing cable wiring inside the body.

V. OPERATION

As mentioned above, MR-X1 has three operation mode: UROV (optical fiber control), wireless control, and autonomous. We chose one of modes according to the type of mission.

A. UROV Mode

In the UROV mode, MR-X1 system uses a thin optical fiber cable for communication between the vehicle and the support vessel. The vehicle has no restriction by tether cable because of the optical fiber cable is very thin. By using this cable, we can remotely operate and monitor whole devices. An advantage of this mode is to get clear images obtained by TV camera. If you want to directly see and catch some materials by the manipulator, the mode would be also useful. This mode is selected mainly at the initial stage of the robot development.

B. Wireless Control Mode

In the wireless control mode, acoustic communication and radio communication are selectable. The acoustic communication is used in the deep see up to 4,000m. The radio communication is available in the case of launch/recovery operation. MR-X1 can leave a way from the support vessel in the range of radio communication available. So the robot can go to a diving point, if the vessel cannot approach the point where includes obstructions to navigation or is danger area. In recovery operation, the robot remotely approaches to the vessel by radio control.

C. Autonomous Mode

In the autonomous operation, an operator gives information of navigation to the robot before diving. The robot goes or carries a measurement device to a target point. Fig. 5 shows an image of the MR-X1 autonomous operation.

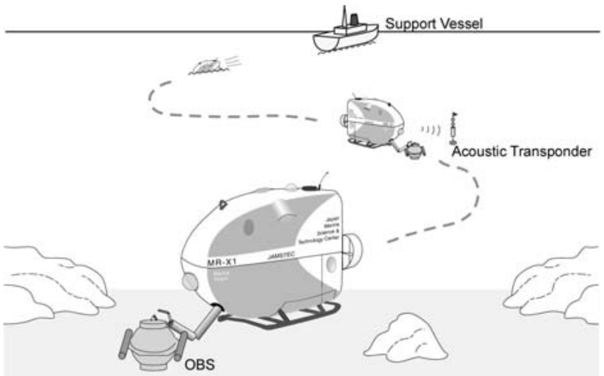
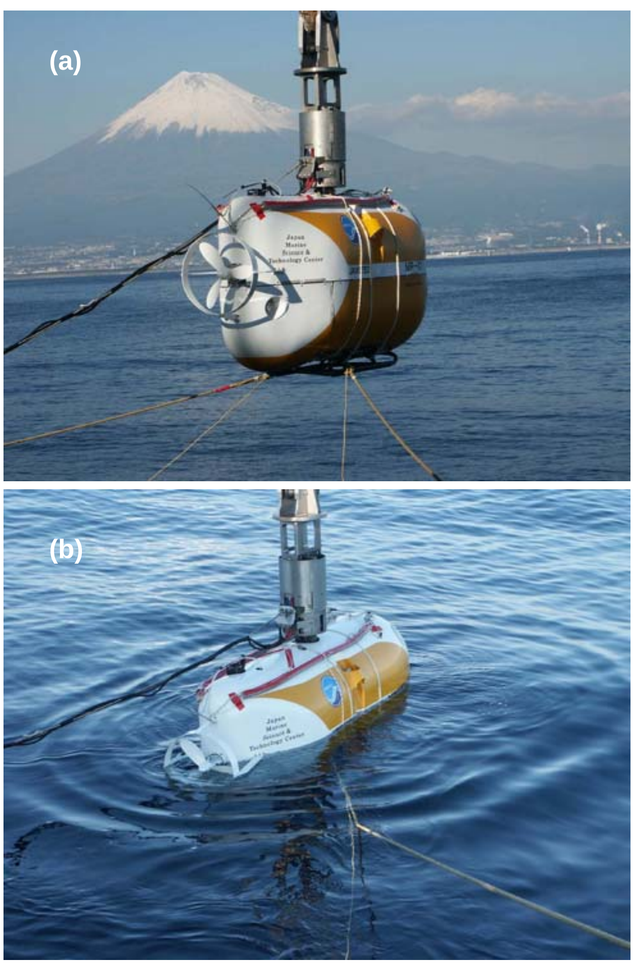


Fig. 5: An example of autonomous operation. MR-X1 installs an ocean bottom seismograph (OBS) on sea floor.

VI. TEST

A sea trial had been carried out in Suruga Bay in November 2002. We adjusted buoyant force and balance. In this trial, MR-X1 had not dived into sea. Fig.6 shows an aspect of the launch operation on the sea water.



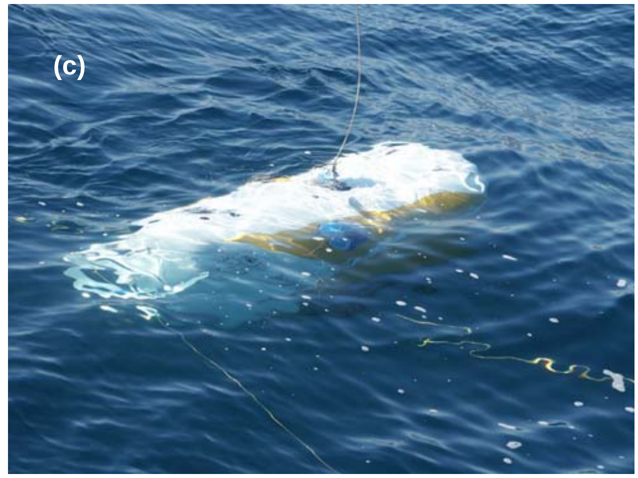


Fig. 6: A launch operation. (a) MR-X1 and Mt. Fuji. (b) On the water. (c) Immersed water.

VII. CONCLUDING REMARKS

We have been developing the small and light weight marine robot, MR-X1. The robot will be used as working AUV, for example, installing an OBS on the sea floor or collecting oceanographic data in the Arctic Ocean. The robot is small but is equipped with a lot of devices for cruising and observation. The control system is optimized to the working AUV by using multi processors which are connected with CAN-BUS mutually. As a result, we improve the efficiency of CPU utilization and reduce the number of connectors on the main pressure hull. A program for this control system has been developing. In this November, We will make sea trial without a manipulator and a side scan sonar. In the future, the AUV will control itself and recognize images of a target for various robot hand works.

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