Compact AUV platform system designed for the experiment of underwater multi-agent development

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Abstract: The underwater multi-agent technology has many potential for the various activities related to ocean development/conservation in the near future. For example, in such fields as water pollution investigation, aquaculture control, or coral reef research, we feel a growing need for a system that realizes underwater continuous monitoring in the wide range. In this case, the target monitoring area will be sliced planar hierarchically toward the depth as monitoring layers, and many AUV's arranged on each layer track the given trajectory and gather various environmental information continuously, with communicating each other in the layer or with other layers. To realize those systems we need to develop AUV multi-agent technologies. So we are now building basic systems for basin experiment for the development of AUV multi-agent behavior. We must experience many situations and problems to be solved for the development of its elemental technologies by using real systems as well as our computer simulations. In this paper we introduce our concept of the experiment in the near future and the hardware/software design of our two types of handy AUVs and ultrasound ranging/communication system for that experiment. One AUV is designed using a 17 inches-diameter glass sphere with DOS/V and RT- Linux based subsystems, which is intended to use not only in the basin but also in the calm real sea. The other AUV is designed for the basin experiment using a 7 inches-diameter acrylic sphere with low-cost embedded system with SH-2 based subsystems. The basin experiment to verify the basic AUV facilities and ultrasound ranging for position detection was carried out.

Keywords: AUV multi agent, underwater continuous monitoring, underwater cooperation, basin experiment

1. INTRODUCTION

The underwater multi-agent technology has great potential for the various activities in the near future ocean development or investigation. Figure 1 illustrates an imaginary picture of deep ocean construction as one example of those activities. Because we can utilize buoyancy force actively to reduce the self-weight of the structural members in the water and the external force is relatively small compared with near free surface in the deep water, there is a new possibility of underwater structure to be developed if only we can develop the method of automated underwater construction using many autonomous underwater robots[1,2].

Figure 2 shows the schematic view of underwater monitoring system now we are planning to develop as another possibility of underwater multi-agent. We are aiming to realize the continuous monitoring system in time and space where many compact AUV groups distributed in target coastal sea area from the surface to the bottom. The target monitoring area is sliced planar hierarchically toward the depth as monitoring layers, and a group of AUV arranged on each layer tracks the given trajectory and gathers various environmental information continuously communicating each other in the layer or between other layers. There are also autonomous moving buoys on the surface that have the role not only of the observation around surface environment but also of the communication interfaces between underwater groups and facilities on land, satellites etc. The target area also marked off one lot from another and each division has an AUV group communicating other groups to organize information networks from land base through free surface to the bottom of the sea. We call this system as PADOMS abbreviating Portable and Autonomous Distributed Ocean Monitoring System[3].

Although the underwater multi-agent system will include not only the AUVs but also other non-vehicle type robotic agents, in this research we restricted our experimental task using AUV only. More complicated task that needs non-vehicle type underwater robot is the next step of this research.

To extract and solve the problems in the development of
AUV multi-agent technologies, we should build up a series of basin experiment system which we can experience various problems arising from the real system to verify the result of simulated algorithms. The essential parts of the experimental system are AUV platforms, ultrasound ranging system and ultrasound data communication system. In this paper I will introduce each system mainly two types (large one and small one) of AUV platforms just we have built.

2. ULTRASOUND RANGING SYSTEM

We made an ultrasound ranging system that is used to avoid obstacle collision in the AUV path and to calculate the underwater coordinate by LBL as shown in Fig.3 with reference to the basin fixed coordinate system. The LBL is constituted by 3 transponders. Each transponder has 10ms delay time in responding to the calling from the AUV. The ultrasound transmitter/receiver circuit diagram is shown in Fig.4. The microprocessor PIC16F873 with 20MHz clock is the controller of the total ranging system. This PIC is linked via RS232(COM2) with the main PC in the main pressure hull. Corresponding the activate signal from the main PC within the control interval time, it transmits carrier signal for the LBL position detection or the measurement of distance from the basin walls in 3 directions. The corresponding transmitter and receiver channel is selected by a multiplexer with the 3 bit signal from the PIC. The ultrasound frequency here is 40kHz. The 40kHz 10 pulse transmit carrier signal is generated by the PIC software with TTL level and each transducer has a transformer which boosts the drive voltage from 10V to 30V amplitude. When the receiver detected the returned signal, the signal voltage is boosted by a transformer and amplified 50dB by operational amplifier with BPF. There is a hysteresis comparator which determine the minimum sensitivity threshold of the received signal. The received signal through the comparator stops the timer of the PIC. The timing pulse is 200kHz and this signal is supplied to the timer counter of the PIC. The every successive transmit signal has 10ms intervals to attenuate the multi-pass signals. The transformer is also used for the impedance matching of the ultrasound oscillators and circuits. All ranged data like coordinate and distance are calculated in the PIC using ultrasound velocity 1445m/s and also transmitted via RS232 to the main PC.

Figure 5 shows the calibration results of this ranging system in our 3m(W) × 3m(D) × 6m(L) basin. The x-axis shows the real distance between transmitter and receiver facing each other and the y-axis shows the ranged distance which is the average of 100 times measurement by our system. The standard deviation was about 10mm. There existed about 30mm offset in each data caused by the threshold voltage of the comparator but they were cancelled in the software calculation. As we developed these system from scratch, the cost is not so expensive and we can easily set up many different frequency sets of transponders to avoid multi pass fading in the basin when we will execute the multi-agent experiment in the next step of this research.

3. LARGE AUV PLATFORM SYSTEM

3.1 Hardware Configuration

We made two types of AUV platform. The one platform is designed so as to be able to use not only in the basin but also in the calm sea. We decided to develop the platform as reduced in size and weight as possible because on the field experiment, we experienced the handling of the AUV is very hard if the AUV is massive. From the aspect of cost reduction in both fabrication and operation, we aimed that we can handle
the platform by two men at shore and we can put it into the water or out from the water using a general fishing boat with no extra facilities. So we selected BENTHOS 17inch pressure tight sphere glass which is widely used for underwater measurement instrumentation. Figure 6 shows the hardware system of the large AUV. Table 1 shows the weights and displacements of principal parts of the AUV. The total weight in air is about 45kgf. It seemed the limit that we can handle it by two men in land and put it into or pull it up from our basin by hand. We will need small winch when we make an experiment in the real sea using a fishing boat. Although the glass pressure hull is not so expensive and widely used for ocean research, the 6500m depth spec is too high for our purpose and it is not necessarily convenient for the non-professional users like students to handle it, from the view point of the brittleness of the glass, wide dead space due to its shape. And the open/close operation is really troublesome because the crude rubber tape is used for water tight sealing. So we are now planning to develop the pressure hull for our convenience in the next step of this research. Figure 7 shows the appearance of the large AUV.

A thruster has a 70W motor with tacho-generator for the local feedback control of the thruster revolution speed. We prepared 2 propellers for basin experiment and calm sea field experiment whose diameters are 9cm, 15cm respectively. Figure 8 shows the bollard force calibration results. The 15cm diameter propeller’s bollard maximum thrust is about 2kgf. Each motor has a motor driver which generates PWM power signal with tacho-generator local feedback. The thrust signal is fed from D/A card to the driver. An AUV may have 4 thrusters for planar and vertical motion control, but this time we equipped only 2 thrusters for horizontal motion direction. The total battery power inside is 700Wh in this case and we can put 4 more batteries so the maximum power capacity is 1100Wh in this system. The calculated maximum speed with 15cm propeller is about 0.8kt.

We selected the PC104 computer system and the main CPU is NSGeode300MHz with 64M RAM and a 20G HDD. The PCMCIA card for wireless LAN and A/D, D/A cards are equipped. The wireless LAN is used for the remote login access from an external computer for program download or sensor data acquisition. One of the important functions of the large AUV is the interface function between the land based computer and the underwater multi-agents so the wireless LAN is important as the communication device. The attitude sensor is TCM2 which senses the heading, pitch, roll angles and the sensing data is collected by RS232(COM1). The power consumption of PC system is less than 25W, and we estimate each 4 thrusters’ averaged power consumption is about 30W without disturbance like current, so that we can continue one experiment about 4 to 6 hours. It may be enough at this stage, but we need further good ideas to realize longer navigation time.

The ultrasound ranging/LBL module is separated from the main pressure hull to avoid PWM noise generated by the motor drivers inside. Because the glass pressure hull is transparent, we used a set of an infrared LED and a phototransistor for the infrared serial data communication between main PC in the main hull and PICs for ultrasound ranging module outside. Generally speaking, the underwater electrical connector cost is very high, so we designed to limit the use of the connector only for the power transmission. We reduced the use of underwater connector by using the infrared data communication. Once the watertight seal is equipped we don’t want to open the hull easily so the main power switch is controlled externally using photo sensors because the magnet switch could not work because the glass wall was too thick.

<table>
<thead>
<tr>
<th>Specification</th>
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<tr>
<td>Length (mm)</td>
<td>680.00</td>
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<tr>
<td>Beam (mm)</td>
<td>870.00</td>
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<tr>
<td>Height (mm)</td>
<td>450.00</td>
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<tr>
<td>Weight in Air (kg)</td>
<td>42.21</td>
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</table>

3.2 Software Configuration

We selected RT-Linux V3.1pre2 as the operating system of the main computer PC104 because it is free and is possible to get hard real-time operation. The VxWorks is widely used as the operating system of many AUV platforms. But in our experiment RT-Linux is enough. Figure 9 shows the software constitution of this AUV. Each operations such as D/A for thruster drive or RS232 for ultrasound ranging control is executed by the periodic thread whose period and priority can be varied independently arranging each operation’s necessity. The lower level time consuming tasks such as ultrasound ranging or sensor data acquisition are executed separately from the main thread and processed by PIC programs so the corresponding thread is a kind of a watchdog of the PIC to synchronize the whole threads within the desired sampling time. Because these threads are implemented as the kernel module it is not easy for a user to control the threads externally, so we used a user process to activate or stop the kernel module through RT-FIFO as commonly used. The wireless LAN process to communicate the external PC is also
the user process. The acquired data is also transmitted through RT-FIFO and the user process handles all time
consumptive file accesses such as acquired data recording to
the HDD.

3.3 System check experiment
To verify the basic function of the assembled hardware and
software system, we executed the basin experiment using the
large AUV and ultrasound ranging, LBL system. Fig.10 shows
the schematic view of this experiment. The thrusters and
ultrasound transducers are attached to the vinyl chloride frame
around the hard hat. The inner structure of the glass pressure
hull has four stories floor as shown in Fig.7. The batteries are
sited at the bottom of the layer. On the second floor, there
exist motor drivers and DC-DC converters. The main CPU
modules are sited on the third floor and TCM2 is on the top
floor. We used two thrusters limiting the experiment in plain
motions. Figure 11-12 show the ultrasound ranging data
while the AUV moves in the basin. The AUV moves toward
from its initial point and it moves backward after 12.5sec from
the start. The thrust forces are fixed about 0.2N output.
Figure 11 shows the ranged distance from the front sonar to
the transponders A,B as shown in Fig.10 on the basin wall.
Figure 12 is the result of the distance ranging to the right side
wall, backside wall and basement of the basin. The front sonar
ranging result by LBL transponders and back sonar ranging
result show good accordance each other, which indicates the
ultrasound ranging system worked well. Because the robot is
floating on the calm surface, the ranging data to the basement
is constantly about 2.4m, which indicates good accordance
with the real value from the robot to the basement. Although
we did not use any control algorithm in this experiment the
AUV swam straight, so we could confirm the good accordance
of the thruster outputs attached on both sides as the right hand
side ranging result shows. In the next experiment we will try
various control algorithms to achieve the group navigation
correctly. We used infrared photo sensors for the power
switches of thrusters and the ultrasound ranging module,
which worked well but it was time consuming to adjust the
best position where the LED and the phototransistor was
correctly face to face because it is difficult to attach them to
the glass pressure hull. It is difficult for us to process the glass
pressure hull so we will develop more convenient pressure
hull. Through this experiment we confirmed the function of
what we built up such as ultrasound ranging system, TCM2,
thruster system, wireless LAN system, infrared serial
communication system and RT-Linux based software device
drivers for above systems.

4. SMALL AUV PLATFORM SYSTEM
We also made a small AUV platform. We are planning to
execute many AUVs cooperative work experiment in our
basin as illustrated in Fig.13. The large AUV mentioned in
the previous section is too large for us to distribute in the basin.
On the near future experiment, the large AUV is used for the
floating communication interface system between the underwater agents and land base or agents. So we need much
smaller agent for the handling and mobility in the basin
experiment. The production cost must be suppressed while it
has enough equipment for our purpose. We designed and
produced small AUV with that concept. The pressure hull is
composed of two 7 inches diameter acrylic semi-spheres
which are connected by an O-ring seal. Figure 14 shows the
appearance of the AUV. The hull is transparent so we can
implement optical communication like a set of infrared LED
and phototransistor without using any penetrate connectors for

![Fig.9 Software configuration of the large AUV](image1)

![Fig.10 Basic function check experimental view](image2)

![Fig.11 Ranged distance data between AUV and the LBL](image3)

![Fig.12 Ranged distance data up to each basin wall](image4)
the data communication between the inside equipment and outside equipment like a land PC. The thruster is composed of a 2W geared motor and a five-blades propeller. We designed and fabricated the magnet coupling for watertight seal of the thruster to reduce the production cost. The principal dimension of the small AUV is listed in the Table 2. The total weight in air is about 2.8kgf. As the total size is small we can handle it easily and many of them can swim in our basin. The hull is designed to bear the pressure at least 10m water depth. We selected Lithium ion battery for power supply and the total capacity is 450Wh. By power consumption calculation we may use it about 6 hours with one full charge of the batteries. The main MPU is SH-2(SH7045) as shown in Fig.15. It controls the total system and generates maximum 4 PWM signals for the propeller speed control. The RS-232 serial communication is used for gaining the ranged distance from the ultrasound controller of which MPU is PIC16F873. This RS-232 signal is also transmitted from the inside MPU to the outside PC by infrared data communication. So we can monitor the information inside the pressure hull without opening it. The frequency of the sensing and actuation is 1Hz, this time, the timing is controlled by the interrupt of interval timer generated by a compare match timer module of SH-2. An electric compass is used to detect the heading angle. Each device like electric compass has its own PIC and all serial communication line is multi-dropped through the communication interface PIC to the SH2. The 6 underwater connector are attached for ultrasound transducers and thrusters in each direction. The magnet switch is used for power on and off and a relay is used for thruster power line with it. As we mounted a wireless CCD camera inside, we can see the underwater image as far as the robot is near water surface. We have just finished the basic function test in the basin by free swimming. We have not implemented modern controller, we will try path tracking experiment in the next step.

5. ULTRASOUND COMMUNICATION SYSTEM

Ultrasound communication system is essential for our basin experiment. We made a binary FSK serial data communication system. It is desirable for multi-agent communication that the ultrasound oscillators are non-directive. But in the narrow basin the multi path fading occurs so in this step of the experiment we used the oscillator which has 30 degrees directivity to avoid the multi path fading. Figure 16 shows the test condition of this FSK development. The protocol which we are planning now is as follows.

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ah mt x10 y20 z30..... yn
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The first character means the communication starter’s ID in this case the AUV is “a”. And the next character is the destination AUV’s ID in this case “b”. A space is used to separate the meaning block. The next block is an action command or a message from the starter to the destination. In this case “mt” means “move to”. The command or message word must be listed in each AUV’s database. The meaning of the following block depends on the command or message which we must build up the details. In this example, “mt” follows the coordinate (10,20,30) where “b” should go. The end of the communication is “yn”.

In this binary FSK system, the signal 0 corresponds to the carrier 35kHz and the signal 1 corresponds to the carrier 38kHz. We selected each carrier frequency closely so as to use one transducer and receiver. A character data is translated to 8 bits binary code in the PIC program and integer data is translated to 16 bits binary code. Figure 17 shows the received binary signals. The received binary signals are reprocessed by the PIC and reconstructed into the characters or integers.
Figure 18 shows the reconstructed received data. In this experiment we transmitted “abx10” as 40bits binary code. Although the basin in this experiment is a kind of storage tank so it is very narrow as shown in Fig.16, we can communicate with no multi path fading. As it is inevitable for underwater robots that the communication rate is very low so we must develop the efficient communication protocol and well balanced autonomy/cooperation algorithm using these real systems.

6. SUMMARY

Underwater multi-agent technology is expected to broaden the chance of underwater activities such as underwater construction, resource development or ocean environment monitoring. We must experience many situations and problems to be solved for the development of its elemental technologies by using real systems as well as our computer simulations. In this paper we introduced our concept of the experiment in the near future and the hardware/software design of our two types of handy AUVs and ultrasound ranging/communication system for that experiment. One AUV is designed using a 17inch-diameter glass sphere with DOS/V and RT-Linux based computer systems, which is intended to use not only in the basin but also in the calm real sea. The other AUV is designed for the basin experiment using a 7inch-diameter acrylic sphere with low-cost embedded system with SH-2 and PIC based multi CPU subsystems. We also made an ultrasound ranging system and LBL for coordinate detection, and a binary FSK ultrasound data communication system which we succeeded to transfer 3 characters and 1 integer successive data. The basin experiment to verify the basic AUV facilities and ultrasound ranging for position detection was successfully carried out. As the basic component of the basin experiment was developed, we must assemble the total system and the execution of group behavior experiment is our next step of this research.

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