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System Design and Hardware Development of Autonomous Underwater Robot "DaryaBird"

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Abstract: Various kinds of robots have been developed as computers and information processing technology advance. Operations in extreme environments such as disaster areas, space and ocean are getting one of the practical solutions for hazardous missions. The underwater robots are one of the extreme environment robots that are expected as one of solutions for underwater activities; maintenance of underwater structures, observations, scientific research. These activities require robots that can cover large area deep under ocean water. Their efficiencies have been investigated during recent decades and are proven by ocean experiments. However, the robotic system including the support vessels is still large in scale, and is not so easy to handle without number of researchers. In this paper, we describe the design of "DaryaBird" developed to be easy to handle, small-scaled underwater robots that can operate only with two researchers. In addition, mission strategies for Robosub2015 are reported.

Keywords: Autonomous underwater vehicle, MATLAB/Simulink, Modular architecture, Robosub2015

1. INTRODUCTION

Autonomous underwater vehicles (AUVs) have great advantages for activities in deep oceans [1] and are expected as the attractive tool for underwater development or investigation near future. AUVs have various issues to should be solved motion control, acquisition of sensors' information, decision making, navigation without collision, self-localization. A machine should be able to make monitor the changing conditions from their own sensors and actuators, then change their behaviors without much of efforts from the operators. Limited amount of operation control is necessary because of the features caused by the working environment. Therefore, the AUVs should be autonomous with adaptive function to their environment. We have been investigating adaptive controller systems [2][3], a navigation system [4] and an underwater manipulator system [5].

Recently, there are reports of successful underwater observations using AUVs, for examples, the AUV" r2D4 " dived into 2000 [m] depth and succeeded to observe active underwater volcanos Myojin-sho and Rota located near Tokyo and Guam respectively [6][7]. An AUV" Aqua Explorer "has proved that AUVs are useful for ocean ecologic system by tracking experiments of a Sperm Whale using AquaExplorer[8]. However, these robotic systems including the support vessels are still large in scale, and are not easy to handle by a few researchers. We have been developing underwater robots and these technical issues in Kyushu Institute of technology (KIT).

AUV "DaryaBird" have been developed by KIT Underwater robot team aiming for easy-to-handle module contracture. The main concepts of DaryaBird is:

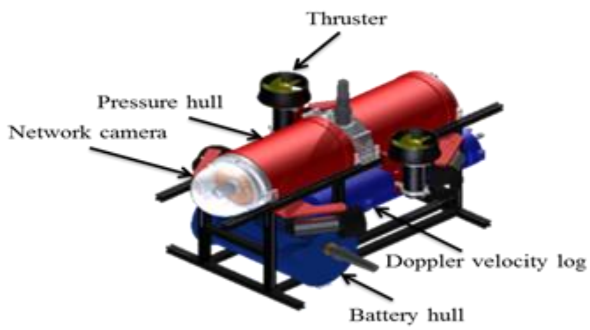

Fig.1 Exterior view of DryaBird

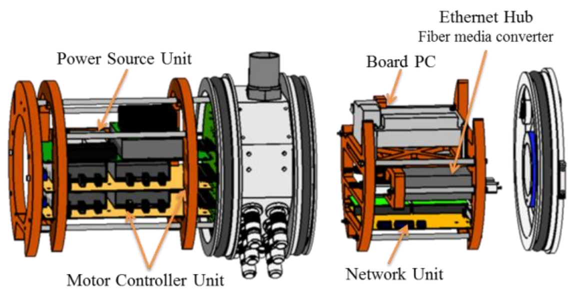

Fig. 2 Interior view of DaryaBird

1.small and handy enough to complete mission by a few operators without support vessels.

2. Frame structure for adding various options.

3.The operation mode, AUV or ROV mode, is selectable depending on mission.

4. Module system for easy maintenance.

These robots are being developed to overcome cooperative tasks. In this paper, we describe the hardware and software design of the DaryaBird and simulation system for Robosub2015.

2. OVERVIEW OF AUV “DARYABIRD”

DaryaBird means “gull” in Persian. The specification of DaryaBird is shown in Table 1.This robot can function as AUV by recognizing the surrounding environment and the situation. In addition, this robot can also function as ROV using remote control system by connecting to external PC with optical cable. To observe a surrounding environment and internal state, this robot is equipped with number of sensors, a pressure sensor that measures the depth, a magnetic gyro sensor that measures attitude angle and azimuth angle. A network camera and sound localization device are installed as external sensors. For propulsion, six thrusters (BTD150: SeaBotix 24[V] DC 110[W],HIBIKINO thruster: ROBOPLUS HIBIKINO 24[V] DC 90[W]) are mounted on the center and the rear. Motions such as surging, swaying, heaving, rolling and yawing are controlled using these six thrusters.Fig.3 shows the system architecture of DaryaBird. The robot is designed for a versatile test bed and software development. Therefore, a small computer with high processing performance that is enough small enough for the pressure hull is installed. The operating system is Windows 7 with remote desktop function. Robot is controlled by using information from cameras, hydrophones and other sensors in autonomous mode. Mathworks MATLAB/Simulink is used as controlling system. DaryaBird is able to be controlled by remote commands while it is connected with tethered cables. A micro controller is introduced for motion control. Sensor information such as pressure, attitude angle is transmitted to the PC through RS232C-USB converter connected to USB hub.

Table 1 Specifications of DaryaBird

Structures	Aluminum pressure hulls ×2 Aluminum T-sloted frame 50[m] depth pressure resistant
Dimensions	H413×W506×L830 [mm]
Weight	32[kg]
Thrusters	110[W] (BTD150) ×4 90[W](HIBIKINO Thruster)×2
Controller	Board PC (Intel Core-i7) Windows 7
Communication	Ethernet and Optic LAN
Sensors	Pressure sensor (Depth sensor) Doppler velocity log Camera (Ethernet and USB) Attitude sensor Hydrophone
Batteries	LiFePO4 12[V], 9[Ah] ×3

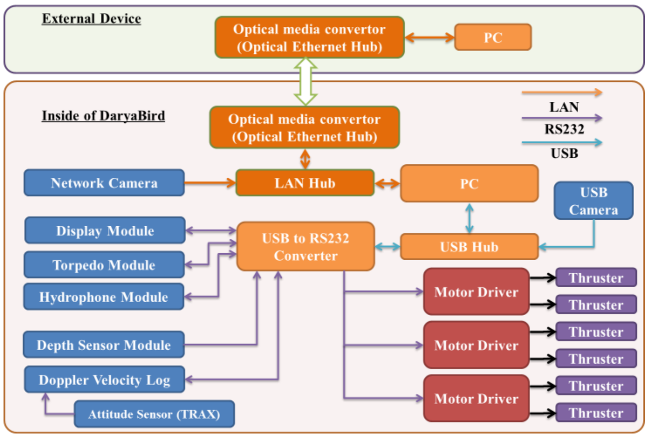

Fig.3 System architecture of DaryaBird


Fig.4 Thruster (SeaBotix:BTD150)


Fig.5 Thruster(ROBOPLUS HIBIKINO:HIBIKINO Thruster)

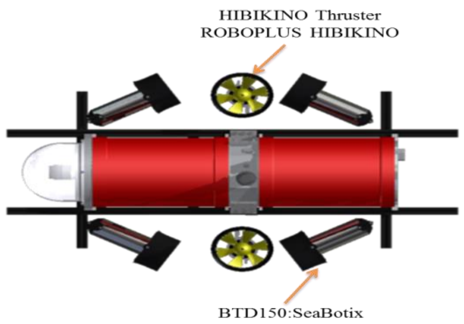

Fig.6 Arrangement of thrusters

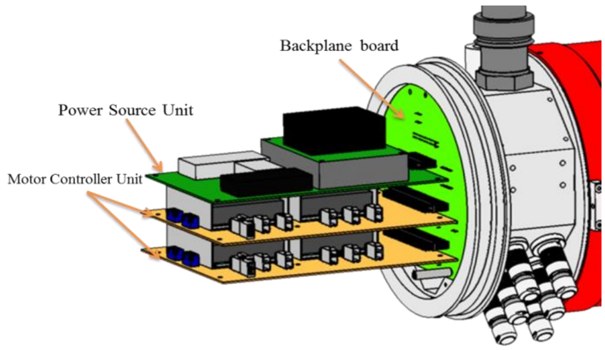

Fig.7 Motor Controller Unit

3. HARDWARE AND SOFTWARE

This section deals with hardware and software architecture of DaryaBird

3.1 Pressure hulls and frame

Fig.2 shows inside of pressure hulls. Pressure hull is joined to center part. Center part holds electrical parts such as connectors and circuit boards for thrusters, sensors and motor drivers. The center part is designed for less connector trouble. Connectors are normally mounted on the outer side of the hulls. When robot needs maintenance, all the connectors must be carefully removed one by one wihch require extra caution and time. Center part system allows these connectors to be centred in the middle of the robot, resulting easier access to the internal parts. Moreover, these pressure hulls are designed to hold the pressure up to 50 meters of depth. These two pressure hulls are supported by aluminum T-slotted frame. External devices can be attached or detached on any place on the frame by using T-slot.

3.2 Actuators

The six thrusters shown in Fig.4, Fig5, (BTD150: SeaBotix 24[V] DC 110[W], HIBIKINO thruster: ROBOPLUS HIBIKINO 24[V] 90[W]) control the motion of the robot.

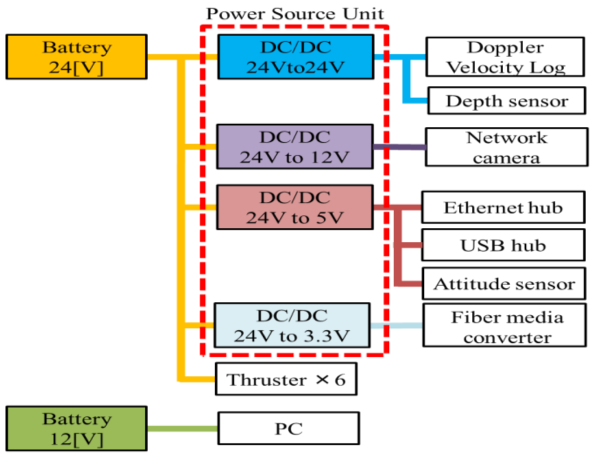

Fig.8 Power supply system

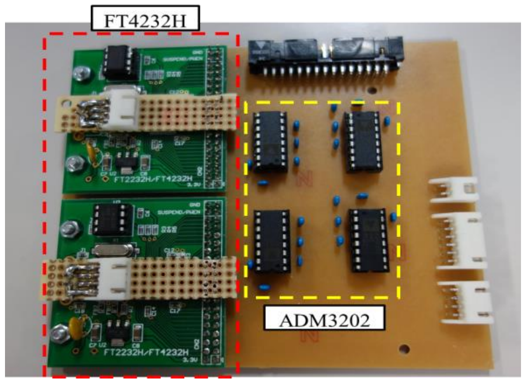

Fig.9 Communication Unit

Fig.6 shows the arrangement of thrusters. Four thrusters (BTD150) are attached in front and in the rear. These thrusters control surging, swaying, yawing motions of the robot. Two thrusters (HIBIKINO Thruster) are attached at the center. These thrusters control heaving, rolling motions of the robot.

3.3 Main Circuit board

The main circuit board consists of three units. As shown in Fig.7, Motor Controller Unit and Power Source Unit are connected with the backplane board. Motor Controller Unit signal line is sent to the communication Unit.

Motor Controller Unit consists of two boards. Two motor drivers are mounted on each board. The Sabertooth2×25V2 can supply two motors with up to 25A each. Communication is performed by RS232. Isolation between motors and other device is used to guarantee the safety of the other components.

Fig.8 shows the power supply system of DaryaBird. Power Source Unit convert voltage level.

As shown in Fig.3, sensor and motor driver communication

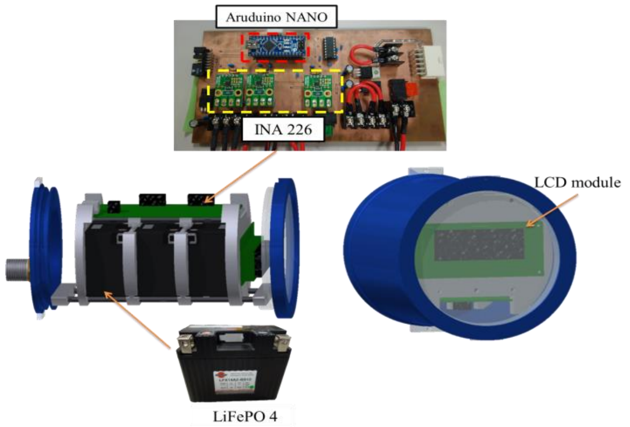

Fig.10 Battery module

Fig. 11 Pressure sensor (YOKOGAWA Electric Corporation: FP101A)

standard is unified by RS232. Communication Unit has two functions. First, the level conversion module (ADM3202) convert RS232 to TTL level. Second, FT4232H is a USB 2.0 to UART. The device features 4 UARTs.

3.4Batteries

DaryaBird has LiFePO 4 batteries shown in Fig. 10. LiFePO 4 is a relatively safe type of Lithium battery due to its good energy density (available power per weight). DaryaBird is attached with battery hull maintenance improvement. Inside of this hull is mounted on current sensor and voltage sensor. (INA 226) These sensor values are transmitted to communication unit using arduino nano. The battery hull has transparent acrylic cap and LCD module. Therefore the battery can be always monitored.

3.5 Sensors

3.5.1 Pressure sensor

The FP101 is a high accuracy pressure sensor that can be used to measure gauge or absolute pressure as shown in Fig. 11. It has measuring range of 0kPa to 300kPa, and its corresponding maximum depth is about 20m. The sensor outputs a voltage between 1 to 5 DC volts signal corresponding to the measured pressure. This sensor is used in DaryaBird to monitor the depth where the robot is operating.

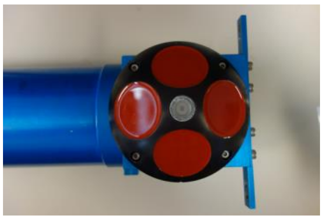

Fig. 12 Doppler Velocity Log (Teledyne RD Instruments: Explorer DVL)

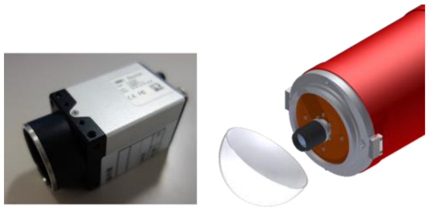

Fig. 13 Network camera(Baumer: VLG-22C)

Fig. 15 Attitude sensor (PNI Sensor Corporation: TRAX)

3.5.2 Doppler Velocity Log (DVL)

The Doppler sends out a 4-beam ’Pings’ and measures the resulting response in terms of frequency shift. This translates to a Velocity relative to the reflection point. Thus, DaryaBird is able to monitor how fast it travels.

3.5.3 Camera

To ensure robot control without any collision, Baumer VLG-22C GigaE camera is used which has a resolution of 2040 by 1084 and lightweight and compact. This camera is mainly used to recognize the obstacles under water and to search for the landmarks.

3.5.4 Attitude sensor

As attitude sensor, ’TRAX (see Fig. 14)’ made by PNI Sensor Corporation is installed for the control of motion in DVL hull. The TRAX is able to measure rolling, pitching and yawing motions. Acquisitioned data are transmitted through RS 232.

3.6 Passive SONAR System

Super-short-baseline is adopted for underwater acoustic detection device. This scheme is intended to use a hydrophone array with the hydrophones in small distance. The arrival

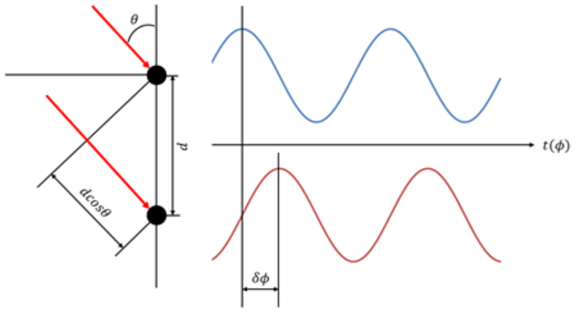

Fig.16 Sound source localization based on SSBL

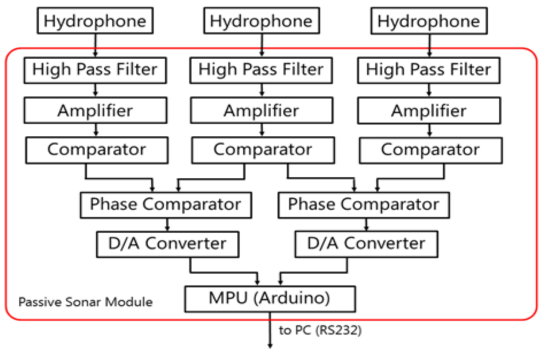

Fig.17 Passive Sonar System

angle of the sound source is predicted from calculation of the phase difference between the hydrophones.

Team Kyutech's Passive Sonar System uses electronic circuits for signal amplification, phase comparison and D/A conversion. The signals are inputted to Arduino which sends serial (RS232) to PC which configures the information.

4. Software

4.1 Framework

Darya Bird's software consists of three main layers as shown in Fig.18. Decision making happens in the upper layer based on information from each sensors. Motor control command values are outputted from here down to the middle layer. For example, this layer is responsible for image processing during buoy-touch and the behavioral transition from searching to approaching. The middle layer calculates thrusters' power output based on the command values from mission control output. Surge and Sway movement is performed by speed control using PID and FF control as shown in Fig.19. As for Heave and Yaw, P-PI control is used to control depth and heading angle. The lower layer takes care of the communication between each devices mounted on the

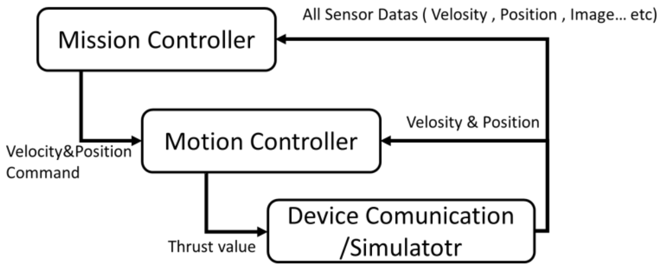

Fig.18 Frame Work

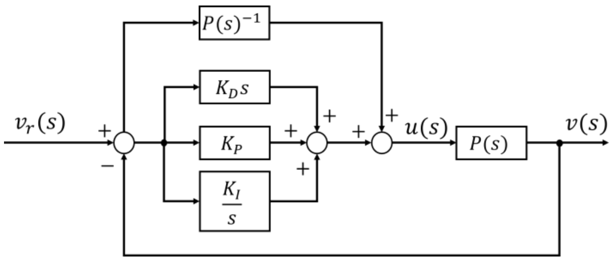

Fig.19 Velocity Control system (Surge&Sway)

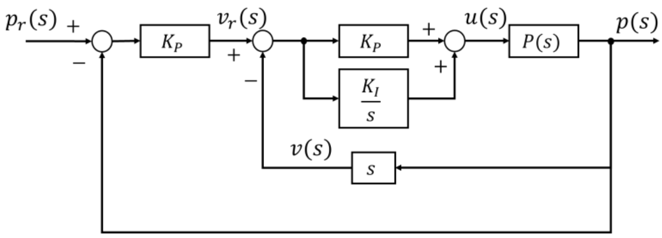

Fig.20 Positon/Angle Control system (Heave&Yaw)

AUV. Serial communication devices such as motor drivers and DVL and image acquisition device such as GigE camera communication is made in this layer. The software configuration can be switched for simulation.

MATLAB/Simulink is adopted for its excellent legibility to speed up the development efficiency.

4.2 Simulator

Following are Darya Bird's motion equation and the 6 vector format.

$$(\mathbf{M} + \boldsymbol{M_a})\dot{\boldsymbol{v}} + \boldsymbol{c}|\boldsymbol{v}|\boldsymbol{v} = \boldsymbol{F_G} + \boldsymbol{F_B} + \boldsymbol{F_T}$$

$\mathbf{M}\dot{\boldsymbol{v}}$: inertial force

$\mathbf{M}$: inertia matrix

$\boldsymbol{M_a}$: inertia load matrix

$\mathbf{c}$: fluid drag coefficient matrix

$\boldsymbol{F_G}$: gravity

$\boldsymbol{F_B}$: buoyancy

$\boldsymbol{F_T}$: thrust

This formula is used to perform the motion simulation of

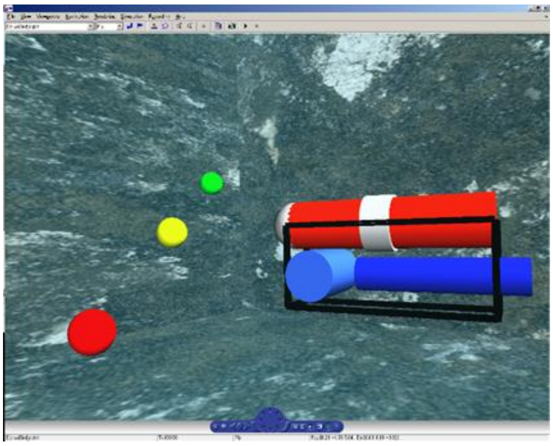

Fig.21 Simulator

DaryaBird. Limit cycle test is performed for least squares estimation.

The “Simulink 3D Animation” toolbox is used to for virtual simulation. The environment is constructed with vrml file. Blocks are placed on Simulink to call the vrml file then position and orientation information of object corresponding to the AUV is inputted. Fig.21 shows the virtual animation. By specifying the viewpoint coordination on vrml, different point of view from different camera mounting position can be shown.

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