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

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Abstract:

An autonomous underwater robot named "DaryaBird" was developed as a versatile test bet to establish the techniques which realize intelligent robot behaviors.

In this paper, we have described the design development of a handy and small underwater robot "DaryaBird" which is enabled to operate by a few researchers. Hardware and software designing of the robot is explained and the mission strategies of RoboSub2012.

Keywords: Handy underwater robot, DaryaBird, RoboSub2012

1. INTRODUCTION

Autonomous underwater vehicles (AUVs) have great advantages in deep oceans activities [1]. AUVs are expected as an attractive tool for the life rescue, recovery work and investigation of seabed resources and construction of the immersed structure etc. There are various issues raised with the development of AUVs ,which should be solved, such as motion control, acquisition of sensor's information, decision making, navigation without collision, self-localization and so on. Making highly intelligent and well accurate robot is a challenge and it can be achieved with the assistance of proper sensory system. Therefore, the AUVs should be autonomous and have adaptive functions to their environment. We have investigated adaptive controller systems [2][3], a navigation system [4] and an underwater manipulator system [5].

in last couple of years, there are project reports have been published including successful underwater observation using AUVs. For example, the AUV "r2D4" dived into 2000 [m] depth and succeeded to observe active underwater volcanoes Myojin-sho and Rota located near Tokyo and Guam, respectively [6][7], and the AUV "Aqua Explorer" has proved that AUVs are useful for ocean ecologic system by tracking experiments of a Sperm [8]. However, these robotic systems including the support vessels are still big scale, and not so easy to handle by a few researchers. We have been developing underwater robots aiming at realization of handy and small underwater robots.

2. DaryaBird

The overview of the DaryaBird is shown in Fig.1 below and its technical specifications are shown in Table 1. It is very flexible in transportation by a few people even it has a weight of 31 [kg] at dry condition. The robot has the length of 1044 [mm], the width of 381 [mm] and the height of 457 [mm] in the state to install of all fixtures. This robot works autonomously in the water by recognizing the underwater environment and the situation. In addition, it can be operated as a Remote Operated Vehicle (ROV) by an external PC connected to the robot via the optical cable. To get the knowledge about the working environment and the status of the robot, speed of the robot, depth traveled orientation of the robot and other parameters should be measured. In order to do these task different kinds of sensors, current sensors, pressure sensors, tilt compensated compass sensor etc are employed in the robot. The network camera and the sound localization device are installed as external sensors.

The robot is designed for a versatile test-bed for developing the software which can be used in AUVs by carrying out research. Therefore a laptop computer which has high performance and small enough to install inside the pressure hull is employed. It consists of Windows XP operating system and with remote desktop control function. The robot is controlled by using information from cameras, hydrophones and other sensors in the autonomous mode. The controller system is made by Microsoft Visual C#. DaryaBird is also controlled by remote commands while the robot is connected with tethered cables.

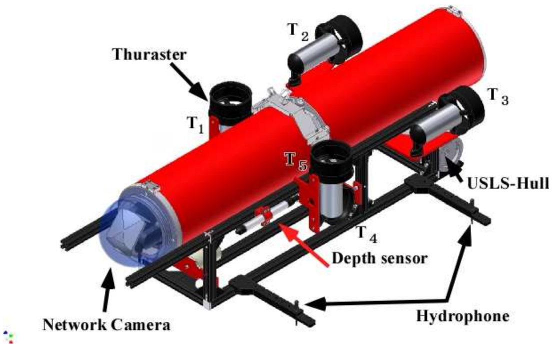


Fig.1 Overhead view of DaryaBird

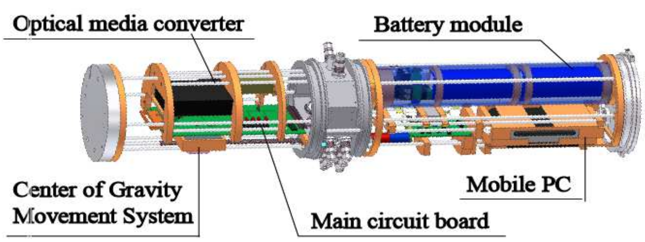


Fig.2 Inside View

Table 1: Specifications of DaryaBird

Type	Autonomous Underwater Vehicle (AUV)
Structures	Aluminum Pressure Hulls x2
	H : 457[mm] W : 381[mm] L : 1044[mm] Weight : 31[kg]
	50[m] depth pressure resistant
Actuators	110[W] Thrusters (BTD150) x 5
Computer system	Laptop PC (Intel Pentium M1.2GHz)
	Windows XP Professional
	Micro-Controller(dsPIC30F6014A)
Communication	Ethernet
Sensors	Pressure Sensor(Depth Sensor)
	Hydrophone x 4(Reson TC4013)
	Gyro Sensor x 1
	Camera(Network: Front)
	Compass Sensor x 1(TCM2.6)
Batteries	Nickel Metal Hydride battery 28.8[V]3700mAh x 1
Others	Center of Gravity Movement System x 1

3. SYSTEM ARCHITECTURE OF DARYABIRD

I. System architecture

System architecture of the DaryaBird is shown in Fig.3. It is designed with AUV and ROV mode selection feature by the external PC with the operator's requirement. The robot consists of two personal computers: the external and internal. These computers are connected together via optical media convertor. When the robot operates in ROV mode, external computer is connected to the internal computer via Ethernet TCP/IP protocol using an optical cable. As AUV mode is selected, external computer is disconnected from the internal computer system and internal computer is responsible for the behavior control of the robot, image processing, perform a best communication with main processor unit (MPU) and extracting data from attitude Sensor and Hydrophones sensor. MPU is responsible for the low-level control such as extracting depth sensor data, gyro sensor data and control thrusters and center of gravity unit.

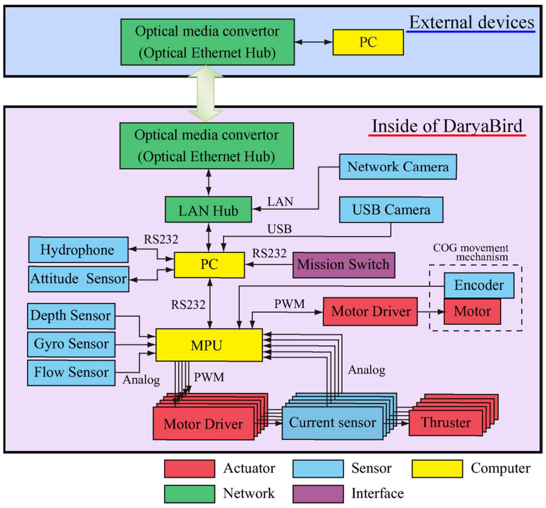


Fig.3 System architecture of DaryaBird

II. Main Circuit Board

We have developed the main circuit board shown in Fig.4 which is called as iDriver enabled to control six motors. It consists of six motor drivers together with six current sensors and communication is performed by USB1.1, RS232 and I2C. Microcontroller dsPIC30F6014A manufactured by Microchip Technology Inc* is used as the main processing unit of the iDriver. Isolation between motors and microcontroller is used to guarantee the safe of the microprocessor at any faulty condition.

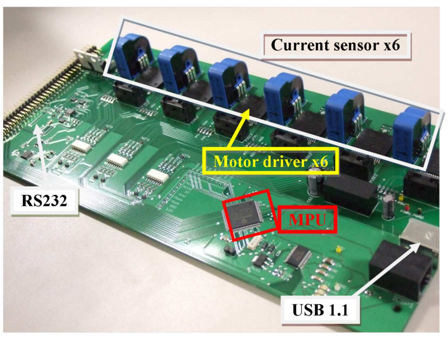


Fig.4 Overview of iDriver

Table 2: Specification of iDriver

MPU	Microchip dsPIC30F6014A, 80[MHz]
Dimensions	230 x 120 x 2 [mm] (L x W x H)
Weight	100.0 [g]
Power supply	-0.3 ~ 40 [V] for actuator control
	+5.0 [V] for MPU
	+12 [V] for OP Amp. (option)
Output current	10.0[A] (continuous)
I/O	Analog x 10, Input
	Digital x 5, Input and Output
Interface	USB 1.1 (Mini-B type)
	RS-232
	I^2C
Equipment	Current sensor x 6

III. Underwater Sound source Localization System

DaryaBird has an acoustic navigation system called Underwater Sound source Localization System (USLS) and it uses three hydrophones (Reson TC4013) installed around the vehicle as shown in Fig.1. One more hydrophone is mounted at the both sides of the robot and it is used to get the self-localization. All the hydrophones are connected to the USLS-Hull mounted at the rear of the robot. The USLS-Hull includes amplifier, filter and detector circuit board.

Arrangement of the hydrophones is shown in Fig.6. As shown in the figure, d is the baseline length and R_i (i=1, 2, 3, 4) shows a slant range between the hydrophone and the sound source. x_s, y_s, and z_s are positions of the sound source and values of x_s and y_s can be calculated using the equations (1) and(2).

$$x_s = \frac{d^2 - {\Delta R_{12}}^2 + 2R_1 \Delta R_{12}}{2d} \quad (1)$$

$$y_s = \frac{2d^2 - {\Delta R_{13}}^2 + 2R_1 \Delta R_{13}}{2d} - x_s \quad (2)$$

$$\begin{bmatrix} \Delta R_{12} = R_1 - R_2 \\ \Delta R_{13} = R_1 - R_3 \end{bmatrix}$$

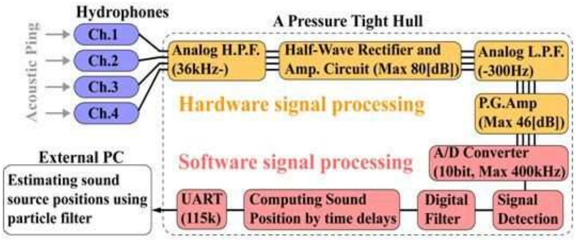


Fig.5 System architecture of USLS

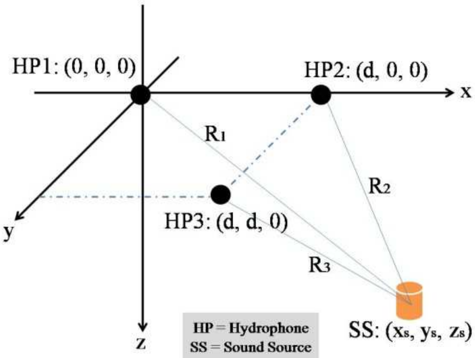


Fig.6 Arrangement of the hydrophones for 2s-D Localization

4. ACTUATORS AND SENSORS

(I) Actuators

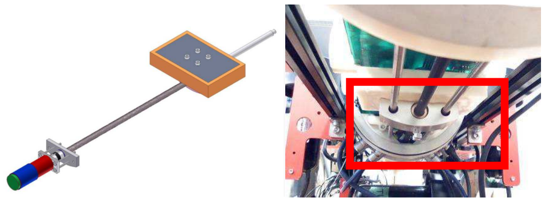
Thruster

The robot uses five thrusters, shown in Fig.7, (BTD150: SeaBotix 24[V] DC 110[W]) to control the motion of the robot. One is mounted at the bottom center of the robot and four thrusters are attached around the body of the robot as shown in Fig.1. Surging, swaying, heaving, rolling and yawing motions of the robot are controlled using the five thrusters.

Fig. 7 Thruster (SeaBotix:BTD150)

Center of gravity movement system:

Fig.8 shows the Center of Gravity Movement System (CGMS) attached to the DaryaBird for pitching motion control. CGMS is mounted at the bottom inside of the front pressure hull, and the motion of the weight is controlled by PWM commands. When the weight attached to the CGMS is moved along the slider of it, pitch motion control can be performed.



(a) over view (b) front view

Fig.8 Center of Gravity Movement System

Internal State Sensors

Tilt compensated 3-axis compass module [PNI: TCM2.6]

Tilt compensated compass module "TCM2.6" is used to measure yaw, pitch and roll motions related information. TCM2.6 uses accelerometers to measure the orientation of the compass with respect to the gravity. Since the compass also measure the complete magnetic field, the TCM2.6 can correct for the tilt of the compass to provide an accurate heading. TCM2.6 utilizes Euler angles as the method of determining accurate orientation. Since the two rotations pitch and roll are defined as axis rotation with plane body, these two rotations are independent of each other and orientation can be computed easily. It has a wide range tilt angle of ±50° and high compass heading resolution and accuracy of 0.1° and 0.8° respectively. TCM2.6 enabled with RS232 protocol to integrate with the existing system.

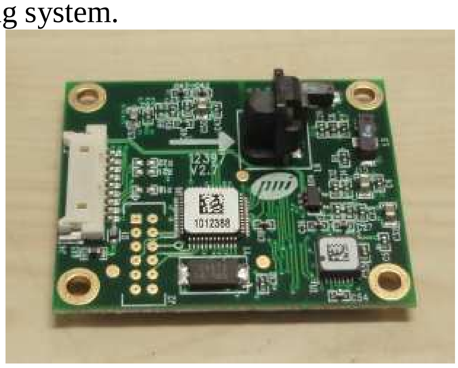


Fig.10Attitude sensor

Depth sensor [YOKOGAWA Electric Corporation:FP101 series]

The FP101 is a high accurate pressure sensor can be used to measure gauge or absolute pressure. This has the measuring range of 0 to 200kPa and corresponding maximum depth is about 10 m. The sensor outputs a voltage between 1 to 5 DC volt signal corresponding to the measured pressure. This sensor is used in our robot DaryaBird to get the knowledge the traveled depth of the robot into the water.

Fig.9 Depth sensor

Current sensor [LEM : LTS6-NP]

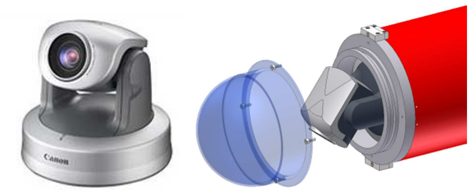
In order to provide isolated current feedback, Hall effect closed loop DC current transducer LEM LTS 6-NP device has been installed. It consists of 5V supply with 2.5[V] nominal output representing 0A. This can be used to measure the primary r.m.s. current up to 6 A and primary current in ±19.2 A. This type of sensors is installed to measure the current consumed by thrusters to limit their torques.

Fig.10 LTS 6-NP current sensor

(II) External State Sensors

Network cameras [Canon : VB-C300]

To ensure the motion of the robot without any collision, Canon VB-C300 network camera which can be controlled its pan tilt motion was installed. This camera incorporates a 70° wide angle lens capable of encompassing a fairly large area even when operated in the stationary position. This camera is mainly used to recognize the obstacles in the water and to search for the landmarks.



(a) VB-C300 (b) Mounted view

Fig.11 Camera

Table 3 Specifications of the network camera "VB-C300"

Manufacturer	Canon
Structures	Pan Tilt Mechanism
	H : 122[mm] W : 132[mm] D : 130[mm]
Power supply	DC12[V], 1.8[A] max.
Weight	780[g]
Frame Rate	Max 30[fps]
Focal Length	f = 3.0~7.2, F2.0~3.4
Output image size	160x120, 320x240, 640x480
Field Angle	H:70.8[deg], V:51.6[deg]
Pan/Tilt Drive	P:340°(±170°), T:-25°~+90°

Hydrophones [Reson : TC4013]

The TC4013 offers a usable frequency range of 1Hz to 170Hz and high sensitivity. It can operate very accurately up to the depth of 700m. Four TC4013 miniature hydrophones are connected around the robot as an underwater sound source localization system (USLS) for acoustic navigation. Each hydrophone is connected to the USLS-Hull installed at the rear of DaryaBird which includes amplifier, filter and detector circuit board.

Fig.12 Hydrophone

(III) Other devices

Nickel Metal Hydride battery

DaryaBird has one power supply unit made by battery bank. Power supply unit consists of four 7.2[V] 3700[mAh] Nickel Metal Hydride batteries (TAMIYA INC, see Fig.13).

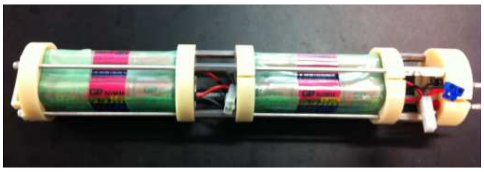


Fig.13 Nickel Metal Hydride battery bank

LED lamp [Fisheye:FIX LED500 DX]

FIX LED500 DX can be used both on land and underwater. This type of underwater video and focus light is mounted to the DaryaBird for image processing. This lamp is very bright, producing 500 lumens from high luminance 4 LEDs and it has a 120 m depth rating. We are able to adjust the brightness non-step light control up to 500 lumen.

Fig.14 LED lamp

IV. MISSION STRATEGY

Mission is performed by 5 different tasks to achieve the goal. These tasks are including of passing through the gate, Path tracking, Training (Buoy), Obstacle Course and Laurel Wreath. To focus about 5 tasks make stable complete the 4 missions and it will enhance our Team's technical skills intensively.

This chapter describes our mission strategy below (see Fig.).

Gate passing algorithm:

This algorithm is developed in order to pass the robot through the gate properly. The flowchart of this algorithm is explained in fig. 15-1. At the beginning direction of the gate is given to the robot as the initial conditions when the robot ready to launch. At first, robot is submerged in to the decided set depth. Then the coordinates of the center of the gate is calculated by Hough transformation. The actual range is set up using calibration of a known range and an acquired image on the network camera. To perform this task well and fast, robot should pass the gate and find the path object next to the gate and hence this is planned to carry out within few seconds.

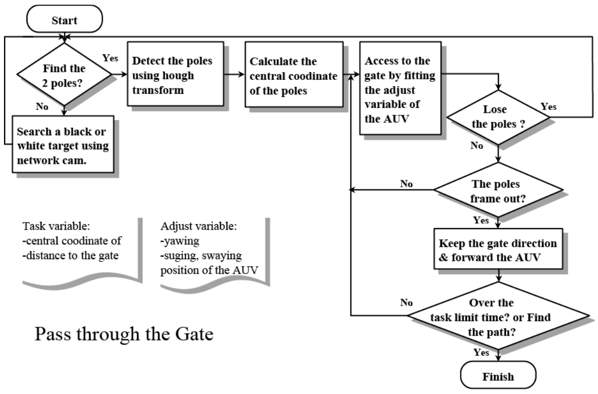


Fig.15-1The flowchart of gate passing algorithm

Path following algorithm:

Path following algorithm guides the robot reach to the buoys placed away from the gate. The flowchart of the algorithm is shown in fig.15-2. When the AUV is in search mode for the path, the AUV emerges a few meters up for easy search. A distance and a direction to the path from the AUV are computed using Hough transformation. When the robot reached to the buoy, this task is finished perfectly and robot beings to next process.

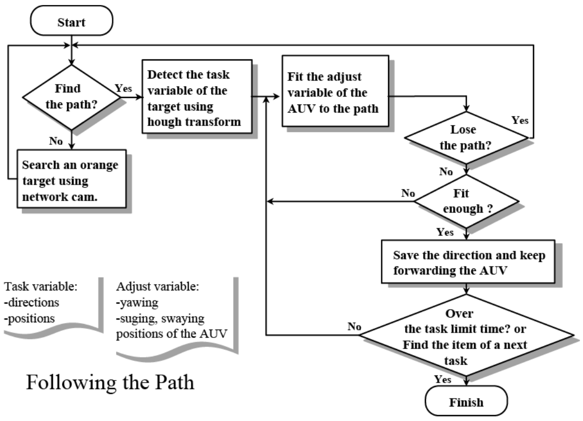


Fig.15-2The flowchart of Path task

Training algorithm:

In this task robot has to move in front to the color buoy decided by the competition organizers. Fig. 15-3 shows the flowchart of the training algorithm. Directions and positions of the 1st buoy are calculated by the computer system using the Hough transformation of circle. A distance between the buoy and the AUV is estimated by the size of image of the buoy from the acquired image. If 1st buoy detecting task is finished, robot challenges for the 2nd buoy. It tries to 2nd buoy as just like in 1st buoy. When this whole task is finished, robot will go to perform the next task of obstacle course.

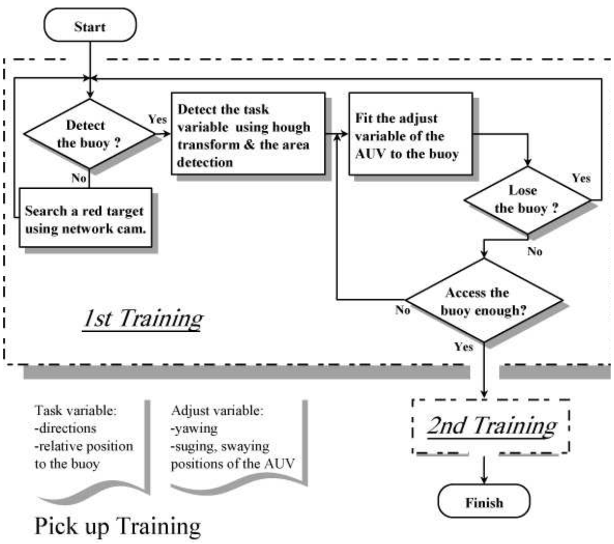


Fig.15-3The flowchart of Training task

Obstacle Course algorithm:

The flowchart of the obstacle course algorithm is shown in fig.15-4. Relative positions between the Lover Lane and the AUV are estimated using Hough transformation of the green targets from acquired image. The AUV keeps the direction fixed and move forward until finish this task without any collisions. This task is planned to finish within few second and go to the next task of Laurel wreath recover. If detecting a green target is difficult while training term, the task is excluded from our mission.

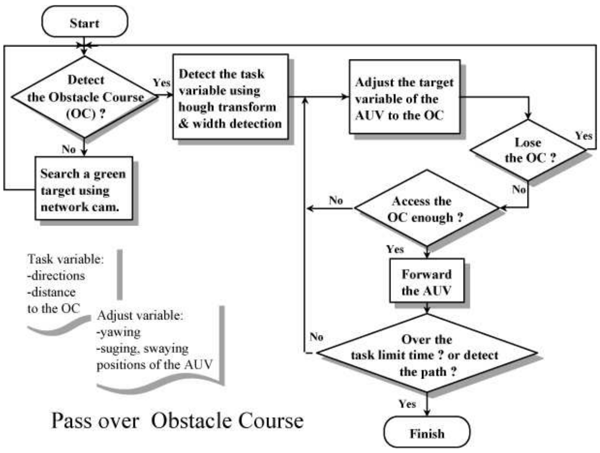


Fig.15-4The flowchart of Obstacle Course task

Laurel Wreath recovered algorithm:

This task is performed as the algorithm explained in fig.15-5. A direction and positions of the pinger are calculated by the Underwater Sound Source Localization System (USLS) installed the AUV. If each variance of the detected variable is within each threshold range, the AUV changes measurement the pinger mode to following the pinger mode. The AUV completely stops its motion while measurement mode because of eliminating the noise from thrusters and the gap of an arrival time on each hydrophone.

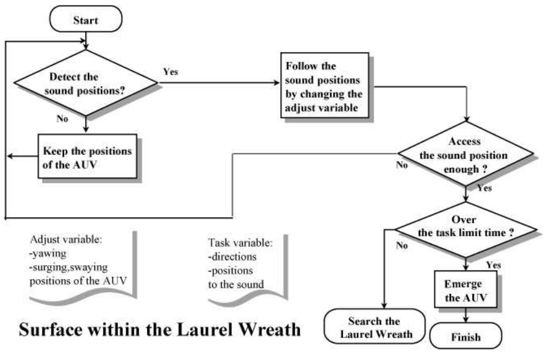


Fig.15-5The flowchart of Laurel Wreath task

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