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System Design of an Autonomous Underwater Robot "DaryaBird"

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Abstract: Various kinds of robots have been developed parallel with the progress of computers and information processing technology, and the operations in the extreme environments, such as disaster areas, space and ocean, are getting one of the practical solutions for those hazardous missions. The underwater robots are one of the extreme environment robots and expected as one of solutions for underwater activities i.e., maintenance of underwater structures, observations, scientific research, where research area is getting wide and deep and also underwater structures are getting large-scale and deep-depth. Their efficiencies have been investigated during recent decades and are proven by ocean experiments. However, the robotic system including the support vessels is still big scale, and not so easy to handle by a few researchers. In this paper, we describe the design of an underwater robot "DaryaBird" developed aiming at handy, small underwater robots which can be operated by a few researchers. In addition, experimental results and mission strategies for AUVC 2010 are reported.

Keywords: Handy underwater robot, DaryaBird

I. INTRODUCTION

Autonomous underwater vehicles (AUVs) have great advantages for activities in deep oceans [1], and are expected as the attractive tool for the investigation of seabed resources and construction of the immersed structure and the life rescue etc. in the future. And AUVs have various issues which should be solved such as motion control, acquisition of sensor's information, decision making, navigation without collision, self-localization and so on. In order to realize the useful and practical robots which can work in the ocean, underwater vehicles should take their action by judging the changing condition from their own sensors and actuators. The large range is inquired into accurately by highly making the robot intelligence, and a lot of useful information can be obtained with the sensor equipped according to the purpose. Therefore, the AUVs should be autonomous and have 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 observation 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], and the 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 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.

II. HARDWARE DESIGN OF UNDERWATER ROBOT "DaryaBird"

A. Overview of DaryaBird

The specifications of DaryaBird are shown in Table 1. And, Fig.1 shows the overhead view in the state to install all fixtures. To enable transportation by a few people, this robot was designed aiming at 30 [kg] in dry weight. This robot is 31 [kg] in dry weight, the length is 1.044 [m], the width 0.381 [m], the height is 0.457 [m] in the state to install all fixtures. This robot can act autonomous as AUV in water by recognizing the surrounding environment and the situation. And, remote control is also possible by the connection to external PC by the optical cable as ROV. To observe a surrounding environment and an internal state, a number of sensors are installed. The flow velocity sensor that measures the speed of the robot, and the pressure sensor that measures the depth, the magnetic gyro sensor that measures attitude

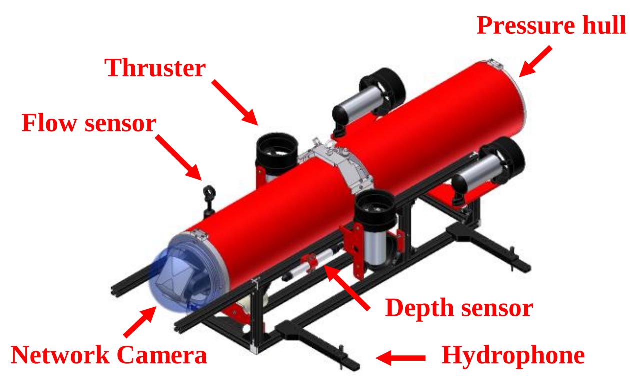


Fig. 1 Overhead view of DaryaBird

angle and azimuth angle, the current sensors as internal sensors are installed. The network camera and the sound localization device are installed as an external sensor. For the propulsion of the robot, five thrusters (BTD150: SeaBotix 24[V] DC 110[W]) are mounted on the center and the rear of the robot. The motions of surging, swaying, heaving, rolling and yawing are controlled using the five thrusters. In addition, the center of gravity- movement system is installed for controlling the motion of pitching.

Table 1 Specifications of DaryaBird

Structures	Aluminum Pressure Hulls x 2
	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 (dsPIC30F6014)
Communications	Ethernet
Sensors	Pressure Sensor (Depth Sensor)
	Hydrophone x 4 (Reson TC4013)
	Gyro Sensor x 1
	Cameras (USB:Bottom, Network:Front)
	Attitude Sensor x 1(TCM2.6)
	Flow Sensor x 1(KENEK)
Batteries	Lithium-Polymer Battery 29.6[V] 5350mAh x 1
Others	Torpedo Launcher x 2 Center of Gravity Movement System x 1 Hanger Structure

B. Sensors

(I). Internal State Sensors

Attitude sensor [PNI : TCM2.6]

As the attitude sensor, "TCM2.6" made by PNI Sensor Corporation is installed to measure attitude angle and azimuth angle. The TCM2.6 is a sensor module that integrates third-axis magnet-meter and second-axis inclination sensor. Therefore, this sensor is able to measure rolling, pitching and yawing motions.

Depth sensor [HI-NET : HAV-300KP-V]

The depth sensor is installed to measure depth. "HAV-300KP-V" made by HI-NET Corporation is an absolute pressure sensor and range of 0-300 [kPa] (19.6m in depth) can be measured pressure.

Flow sensor [KENEK : VO2000XW]

Propeller type flow velocity sensor made by KENEK Corporation is mounted on front of DaryaBird in the direction of surge to measure velocity. The direction of measurement is single-axis two-way, and the measurement range is ±3-200[cm/s], the depth pressure resistant is 200[m].

Current sensor [LEM : LTS6-NP]

Current sensors made by LEM Corporation are installed for limiter of thruster's torque. The current sensor can be measured up to ±6[A], and the output is analog voltage 2.5±0.625[V].

(II). External State Sensors

Network cameras [Canon : VB-C300]

To secure the view of forward, network camera VB-C300 made by the Canon Corporation which controls pan tilt motion was installed. This camera has a wide field angle of 65.4 degrees in water. This camera is mainly used to recognize of the obstacles and to search for the landmarks.

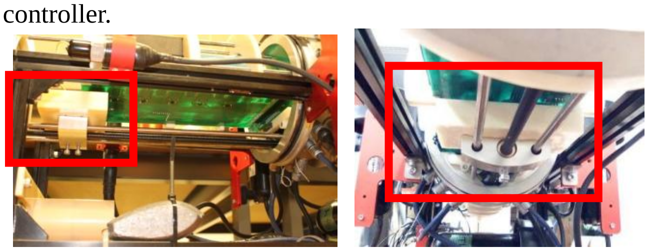
Hydrophones [Reson : TC4013]

Four Reson TC4013 miniature hydrophones are set around the robot as an underwater sound source localization system (USLS) for acoustic navigation. Each hydrophone is connected to the USLS-Hull installed the rear of DaryaBird which includes amplifier, filter and detector circuit board.

C. Other devices

Center of gravity movement system:

Fig.2 shows the Center of Gravity Movement System (CGMS) for pitching motion control of DaryaBird. CGMS is mounted in the bottom sides of the front pressure hull, and controlled by PWM commands from the main micro controller.



(a) side view (b) front view

Fig.2 Center of Gravity Movement System

Torpedo launcher:

Fig.3 shows outside view of the torpedo launcher. The material of the torpedo launcher is ABS and PVC-pipes. The diameter of the torpedo is 23[mm] and the length is 108[mm]. The launcher is mounted on the front, both sides of DaryaBird. If the targets are detected, the servo-motors rotate each stopper, and then each torpedo is launched to the targets respectively.

Hanger:

Fig.4 shows hanger for Counselor. The material of the hanger is made from ABS. The hanger is mounted in the bottom sides of DaryaBird. The hanger is folded when DaryaBird goes underwater, and the hanger that gets PVC-pipes hung up is spread when DaryaBird broaches.

Fig. 3 Torpedo launcher

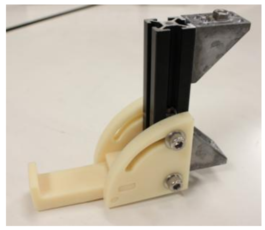


Fig. 4 Hunger structure

III. SYSTEM ARCHITECTURE OF DARYABIRD

A. System architecture

Fig.5 shows the system architecture of DaryaBird. The robot is designed for a versatile test-bed for software development, therefore a laptop computer which has high processing performance and is enough small for the pressure hull is installed. The operating system is WindowsXP with remote desktop 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.

The micro controller dsPIC(30F6014) is introduced for motion control. The measured data in the dsPIC is transmitted to the PC through a FT232: UART-USB converter connected to USB hub.

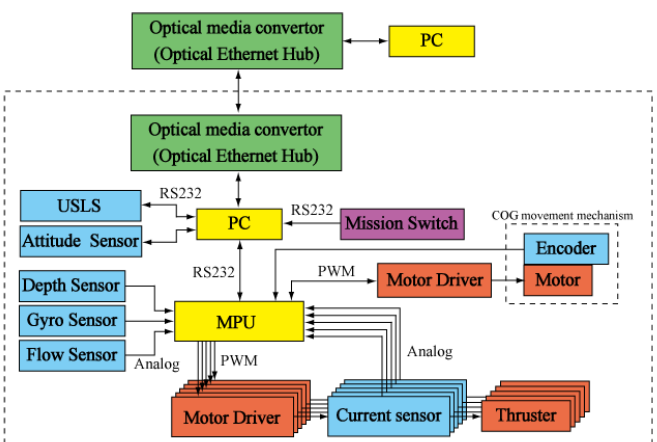


Fig. 5 System architecture of DaryaBird

IV. EXPERIMENTS

A. Strike the Life vest (Buoy)

The buoy was 0.23[m] that was the same size of AUVC's buoy. DaryaBird try to striking the buoy using the network camera, the attitude sensor, the depth sensor and the flow sensor. Figure 6-1 and Figure6-2 show image of Strike the Life vest. Next, the method of detecting the buoy is described from the image.

1. Image was performed binarization by HLS(Hue, Luminance, Saturation) color space and Laveling.
2. The label area that becomes the maximum when the area is more than the threshold, is recognized the buoy.
3. The center of gravity of the buoy $\boldsymbol{m} = (m_x, m_y)^{\mathrm{T}}$ is calculated.
4. The distance to the buoy is presumed by using width of the buoy [pixel].
5. The barycentric position of the buoy in the robot coordinate system is calculated.

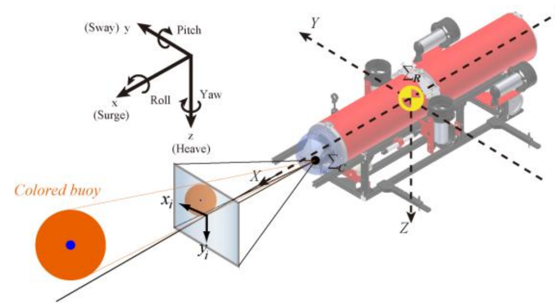


Fig. 6-1 Coordinate of striking the buoy (Bird view)

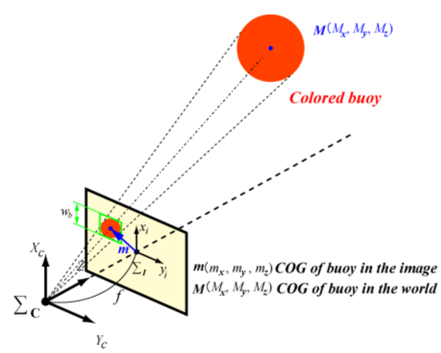


Fig. 6-2 Coordinate of striking the buoy (Camera view)

Fig.7 shows experimental result of striking the buoy. Red target was detected by the camera aimed for the buoy color. Then, estimated angle and distance from the robot to the buoy.

Fig.7-1 to 7-4 shows result data when the robot successfully adjusted and struck the buoy. Fig.7-1 shows distance between the buoy and the robot. Since the robot access to the buoy, the distance was decreased. Struck the buoy at about 21 seconds, then distance was almost 0 [m]. Fig.7-2 shows diameter of the buoy[pixel]. The diameters increased with time, and last diameter was 335[pixel] when struck the buoy. Fig.7-3 shows angle data of the target and the DaryaBird, and Fig.7-4 shows their depth data. A red line denotes target data, and blue line denotes robot data. Across the result, the exact value has been obtained. Made following the target by behavior control, and it has done a good control. Therefore, the result data was validated in real environment.

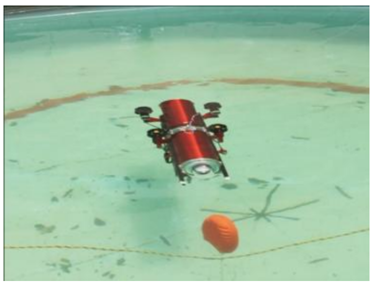


Fig. 7 Experimental scenery of Strike the Life vest

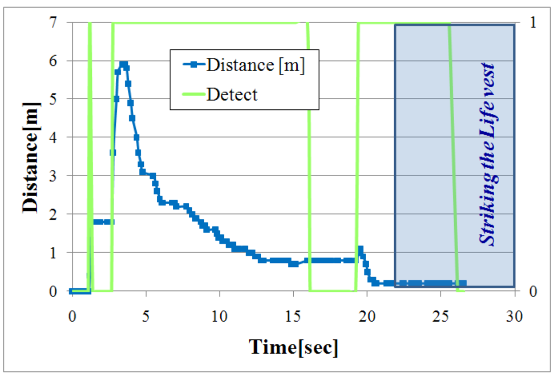


Fig. 7-1 Result of Strike the Life vest, distance to the buoy

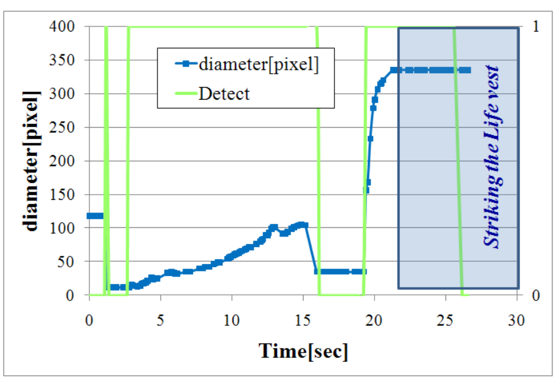


Fig. 7-2 Result of Strike the Life vest, diameter of the buoy

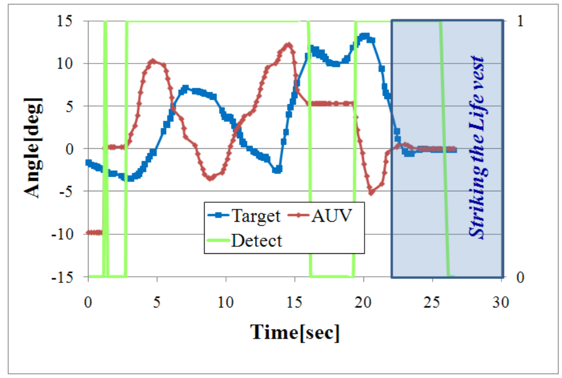


Fig. 7-3 Result of Strike the Life vest, angle data

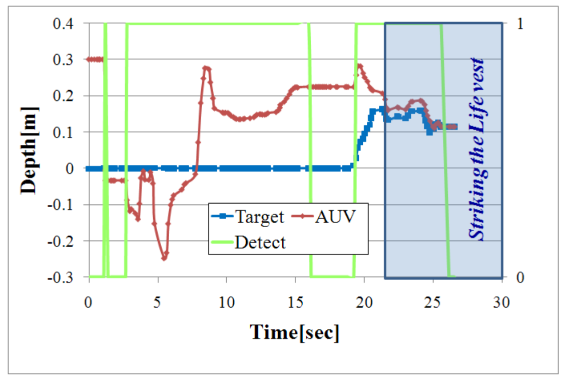


Fig. 7-4 Result of Strike the Life vest, depth data

V. MISSION STRATEGY

A. *Typical mission strategy:*

Four typical strategies to complete the mission are shown below (see Fig.8-1). In each task, a limit time is required to complete all task. Therefore a plan of "Limit time" is also used in combination.

(I) All Clear:

In this plan, "Gate", "Life Vest", "Hedge", "Window", "Hedge", "Counselor" and "Police Station" are tried to be captured in order.

(II) Fast Clear:

The fast clear plan includes "Gate", "Life Vest", "Path" and "Police Station" task. The plan is created to complete tasks at the earliest and get points from remaining time.

(III) Lost:

The lost plan is used when the AUV loses items of the tasks. The robot looks for the buoy, path, or the pinger and forwards to "Police Station" task.

(IV) Limit Time:

Limit time plan is always enabled. There is each limit time for each task respectively. The length of each limit time depends on the plans above.

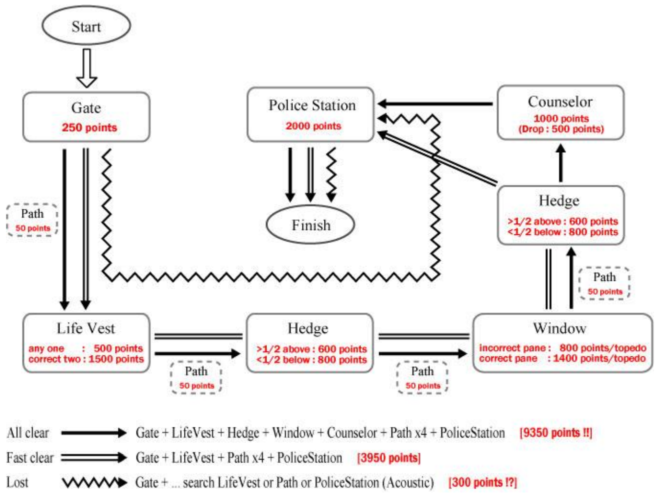


Fig.8-1 Typical mission strategies

B. Mission strategies for each task

Then, The flowchart for each task is described below and shown in Fig.8-2 through Fig.8-7.

Gate:

This task is performed as shown in fig.8-2. A starting direction of the gate is saved when the robot starts from the launcher. At first, submerging to a set depth. The central coordinate of the poles is calculated by hough transform. The actual range is set up using calibration of a known range and an acquired image on the network camera .The finish of the task is decided by the limit time or finding the path object next to the gate.

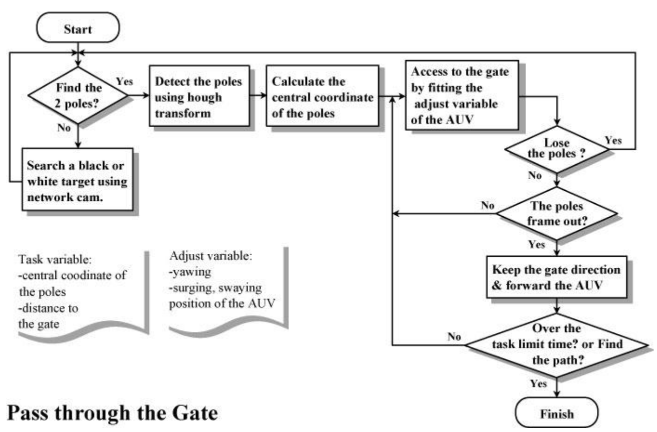


Fig.8-2 The flowchart of the "Gate" Task

Path:

This task is performed in order as shown in fig.8-3. When the AUV is in search mode, the AUV emerges a few meters for easy search. A distance and a direction between the path and the AUV are set up by the binarizatoin and Hough transform. The finish of the task is decided by the limit time or finding items of a next task.

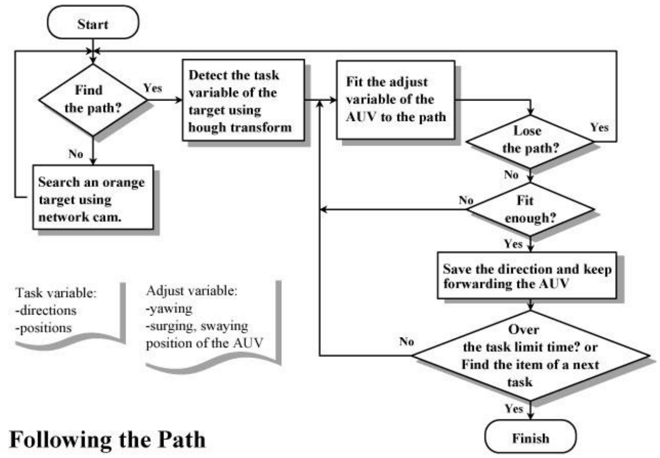


Fig.8-3 The flowchart of the "Path" Task

Life Vest:

This task is performed in order as shown in Fig.8-4. Directions and positions of the 1st buoy are calculated by the binarization and Hough transform of circle. A distance between the buoy and the AUV is estimated by the size of image of the buoy from acquired image. If 1st buoy ends, it challenges the 2nd buoy. It tries to 2nd buoy just like 1st buoy. The finish of the task is decided by the limit time or finding the next path.

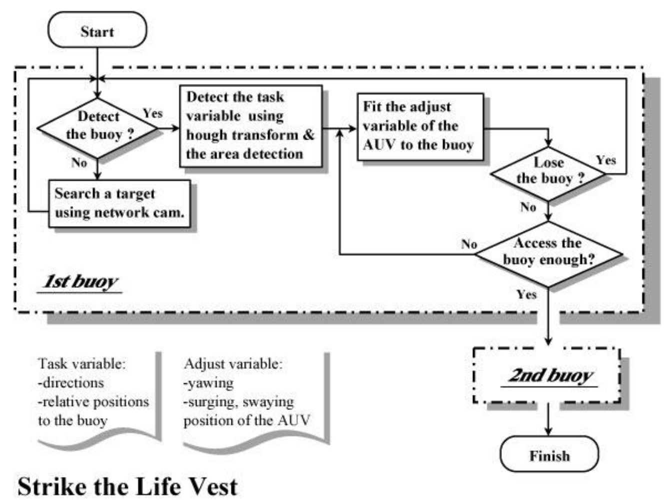


Fig.8-4 The flowchart of the "Life Vest" Task

Hedge:

This task is performed in order as shown in fig.8-5. Relative positions between the Hedge and the AUV are estimated by the binarization and hough transform of green targets from acquired image. The AUV keeps the direction, and forwarding until a finish this task. The finish of the task is decided by the limit time, or found the next path. If detecting a green target is difficult while training term, the task is excluded from our mission.

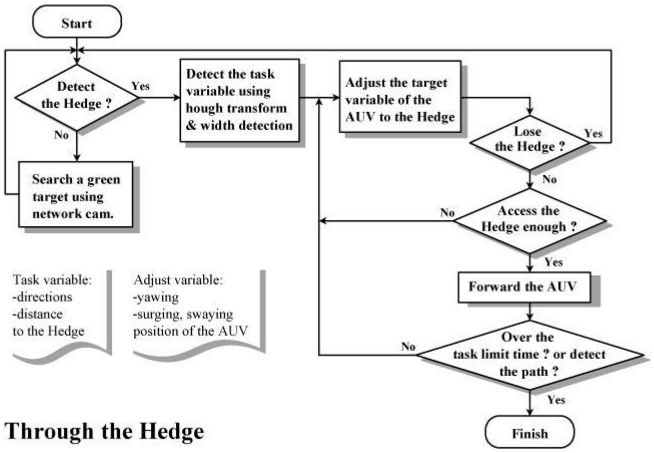


Fig.8-5 The flowchart of the "Hedge" Task

Window:

This task is performed in order as shown in fig.8-6. Directions and positions of the Window are calculated by the binarization and Hough transform of an area of the Window. A distance between the Window and the AUV is estimated by the size of image of the nest from acquired image. Two torpedoes are fired off when the AUV close enough to the Window. The finish of the task is decided by the limit time, and fire off forcibly torpedoes. If detecting a green target is difficult while training term, the task is excluded from our mission.

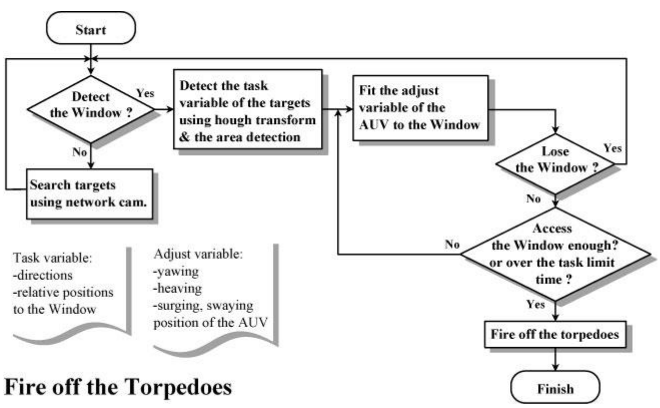


Fig.8-6 The flowchart of the "Window" Task

Police Station (Rooftop):

This task is performed in order as shown in fig.8-7. 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. The AUV starts to surface when the calculated pinger's position is within the finish threshold range e.g. (x, y) = (0.5, 0.5)[m].

The finish of the task is decided by the limit time. If the task remain time is less than the limit time, or the AUV loses the pinger over set samples, the AUV goes on to the "Counselor" task.

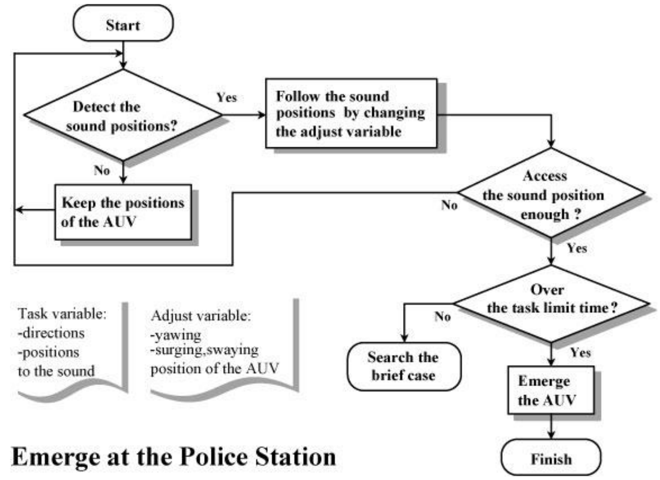


Fig.8-7 The flowchart of the "Police Station" Task

Counselor (Rooftop):

This task is performed in order as shown in fig.8-8. Directions and positions of the case are calculated by the binarization and Hough transform from an acquired orange image. The AUV starts to push down when the case is accessed enough, and hangs the case.

The finish of the task is decided by the limit time. If the limit time comes, the AUV surfaces to the floating pipe, the case is hanged or not.

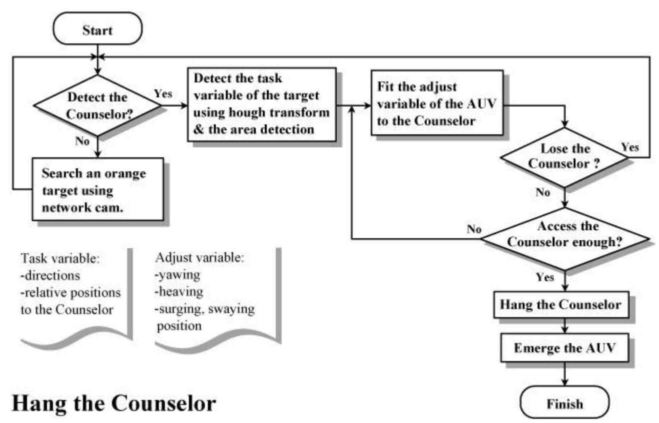


Fig.8-8 The flowchart of the "Counselor" Task

VI. CONCLUSION

We have developed the new small underwater robot "DaryaBird" for observation on shallow water. DaryaBird was confirmed to have basic performance of missions. We are going to have experiments in the ocean to observe shallow water environment and take video images for mosaicing the seafloor using DaryaBird.

In this paper, experimental results by DaryaBird for AUVC missions are described, and tasks required image processing are almost complete. Now the robot has been improved and tested iteratively. The team “KIT” look forward to demonstrate our abilities.

ACKNOWLEDGEMENTS

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