Design and Implementation of Zeabus AUV for Robosub 2018

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***Abstract*—Kasetsart University has participated in Robosub since 2014. In 2017, our AUV called Zeabus has been redesigned in a single hull with a truss structure and acrylic covers to reduce weight. More advanced equipment such as imaging sonar and new cameras are added. More features of software parts are also improved such as auto exposure and new object detection algorithms in order to perform tasks more efficiently. Devices, computers, and main circuits have been installed in a single hull. Circuit boards are redesigned to reduce the size and weight. Zeabus AUV is still operated on *ROS (Robot Operating System)* like in the previous version.**

I. Introduction

Robosub is an international AUV competition organized by AUVSI (Association for Unmanned Vehicle System International) foundation and is co-sponsored by ONR (Office of Naval Research). The competition is annually held at TRANSDEC facility, part of SPAWAR Systems Center Pacific in San Diego, California. The competition is designed to challenge student-built AUVs with tasks that simulate real-world missions.

The Faculty of Engineering, Kasetsart University, has participated in Robosub since 2014. Our team continue to improve the team AUV every year. As a result, the ranking of our team named as Zeabus has kept improving from 18th in 2014, 10th in 2015, and 5th in the final round of 2016. The name of our AUV is Zeabus, which is the same as our team's name. In 2018, our team has significantly redesigned Zeabus to improve the overall performance and aimed for a better result in the competition.

II. Competition Strategy

Overall of our team is probably good because of highly efficient team workers and helpful supporters including of professors, Zeabus alumni and so on. Based on our experience in the former competition, we have found many problems, so we plan to overcome the obstacles of competition in this year. In this year, there are not enough team members, but our team members actually use most of the time in Zeabus laboratory. According to the course, we all think we have time to get things done in many tasks. We can separate our plans into two parts, including the major plan and minor plan

The major plan is under the responsibility of Mechanic and Electronic parts. The major plan is focused on the overview of how to accomplish the competition. From a previous AUV which was built by a former team, apparently something is quite weird was found, namely it has over volume that is not suitable with its weight, causing more masses were added. Hence, a new AUV was designed and built for this Robosub so that to adjust proper volume and mass. Moreover, a mechanism as a gripper and torpedo launchers was assembled which are specific for the tasks. Hence, the mechanic team was separated to two sub-team which are a main team and a gripper team. Mechanic members have done in the part of finding the most appropriate platform, gripper, hulls. The main flame structure of Zeabus platform is quite good for positioning all of the gadgets. Mechanic members have also designed torpedo launcher and tested pneumatic system to drive the gripper.

The minor plan is under the responsibility of software part which includes AI, Control, Vision, Imaging Sonar, Hydrophone and Sensor parts. From the major plan, the minor plan is developed to focus on how to accomplish the tasks. In casino gate task, it does not have hydrophone to locate the source of the sound. Actually, we have the least of time to accomplish this task because we use the most of time in qualification task. At first, we had already designed the new Zeabus AUV platform, but it will be too late to integrate all of the gadget and rehearse the tasks so we have changed the plan to use the old one. The strategies in this plan are to use all of gadgets efficiently. Vision part will find and detect the gate due to AI part requesting. Control part will move in the direction that AI requests. Control part hopes AUV stable the most to make the best result from Vision part and Imaging Sonar part. Vision part and Imaging Sonar part will receive the position from Sensor part which used to be prepared it for a long time and also develop it periodically. In the previous year, imaging sonar had developed and was installed in front of the AUV in order to be used along with cameras for underwater detection. In this year, we have planned to develop the performance of our imaging sonar system by using new technique of image processing algorithms. AI part plans to make AUV rotate itself. AI part also requests data from Vision and Imaging Sonar parts to analyze the task spot periodically. After that AI part will send the data to Control part which will command the AUV to the accurate position.

III. Design Creativity

A. Mechanical System Module

As Fluid mechanic and Submarine Structure which are main issues to design AUV, in addition previous AUVs was used be prototype to design the new AUV, it was mixed each good point and also added other creativity as well.

Thereby, the AUV has 8 thrusters which produce force and toque as 6 degrees of freedom and we seek for the best performance AUV shape which concern on both pressure drag and viscous drag, it has small diameter and long length so that to minimize the drag. Furthermore, its hull material is aluminum 6063 that was anodized which prevent corrosion and is specific for underwater vehicle. However, heavy battery has been a problem, in this case a problem was solved by choose AUV frame is aluminum profile which make our new AUV can be adjust weight along longitudinal and also is constructed easily. Especially, to complete the tasks, we choose pneumatic system to run the moving mechanism parts which compressed CO2 is utilized a gas within the system. The new Zeabus platform is shown in Fig. 1.

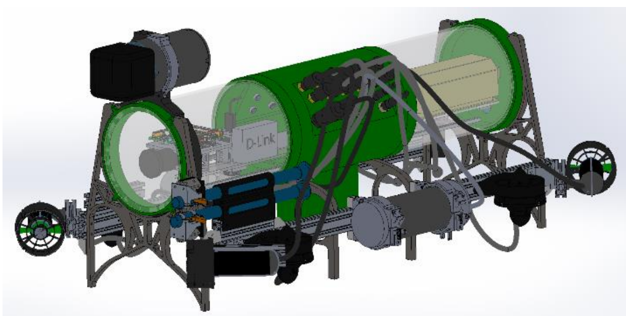

Fig. 1. Zeabus platform

As the task called "play slots", the torpedo launcher was design following torpedo length which was precisely calculated to has its density lower than water as 0.98 gram per cubic centimeter and also was coated by epoxy resin so that to has enough strength. The torpedo is launched by spring which was calculated sufficient k to produce an enough force that fire torpedo toward more than 1 meter under 5 meters in water. By this mechanism comprised of a latch and a pneumatic valve which move the latch out then torpedo will be released. The new torpedo design is shown in Fig. 2.

Fig. 2. torpedo

Fort the 3 tasks, including Buy a gold ship, Roulette, and Cash in, the gripper was specifically designed, namely it can move in yaw-axis so that to griping the ball on the tray in the task called "Buy a gold chip" to drop on the tasks called "Roulette" and "Cash in", in this case 2 servos and 3 pneumatic cylinders is utilized to be moving mechanism in order to minimize carried torque on the gripper and operate in underwater and on surface as well. Moreover, the Zeabus gripper, of which its material are ABS, PETG, PLA, Flex, and PC, was manufactured by 3D-printer. This gripper shown in Fig. 3 is installed at the front of the AUV.

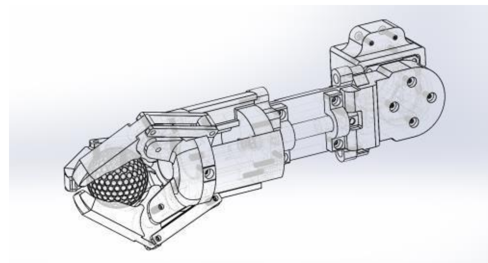

Fig. 3. Gripper

B. Electrical System Module

Electrical parts of Zeabus AUV are divided into several modules so that they can be manufactured, tested, maintained, or upgraded separately without affecting other subsystems. With this design concept, the system up-time can be maximized. Main design concerns of these modules are safety, ease of uses, low energy consumption, low weight, and high reliability. Also, the sizes of these modules must be fitted in limited installation areas. Electrical modules implemented on Zeabus are shown in Fig. 4 and listed as follows.

1) Power distribution modules

This module mainly transfers the power from batteries to all other modules. The module is able to protect the overall system when an overcurrent is drawn. The module will shut down the whole system if the emergency switch is activated. The power distribution module also includes many isolated voltage regulators to supply power to sensors, computers, and other modules that require a stable power source.

2) Thruster controller module

This module controls all 8 thrusters by receiving commands from an on-board computer and generates control signals to Electronics Speed Controllers (ESC).

3) Communication bridge module

This module converts signals from serial ports to USB in order to connect serial communication to an on-board computer. This module also provides signal isolation on transmitted and received signals to reduce communication noises.

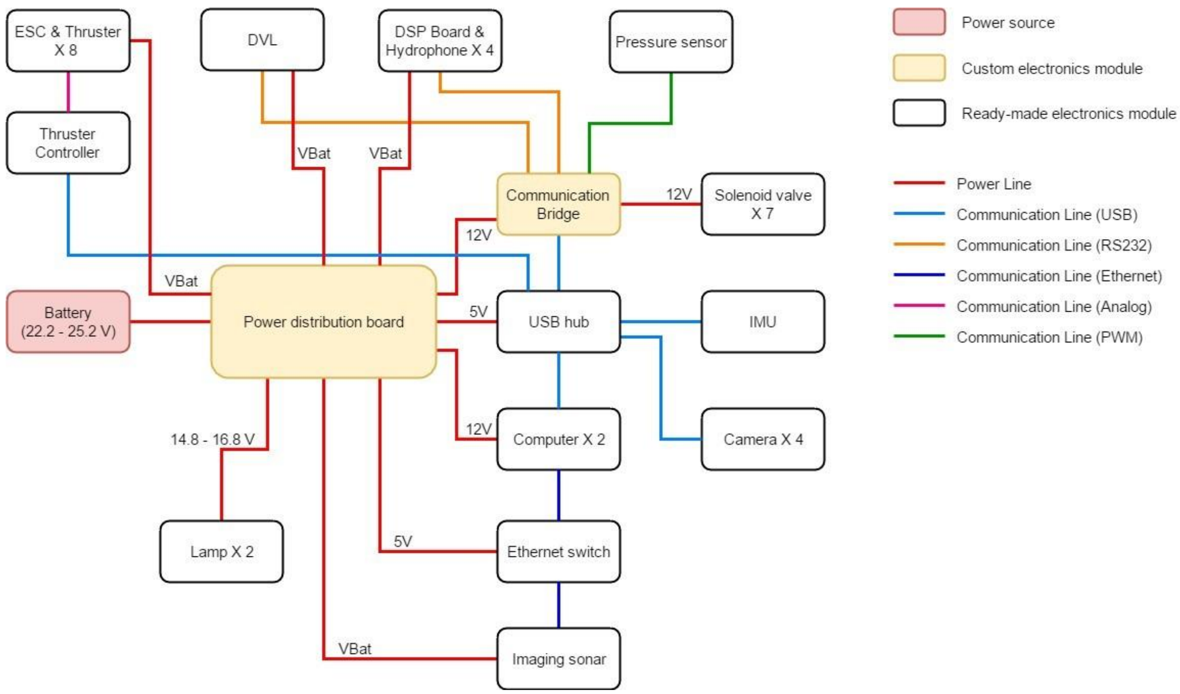

Fig. 4. Electrical modules and connections

C. Software overview

The Zeabus software system is composed of:

1) Mission planner group module

This part decides a plan, a path, and a direction of the AUV.

2) Control system module

The control system module is used to control thrusters. The main control algorithm used on this module is the PID.

3) Vision system module

The vision system module is used when the AUV has to navigate by using visual data from cameras or imaging sonar.

4) Imaging Sonar System Module

The imaging sonar system module is used when the AUV has to navigate by using visual data from sonar

5) Hydrophone Processing Module

The hydrophone processing module is used when the AUV has to navigate by listening the pinger

In mission planner group module shown in Fig. 5, there are several submodules including sensor fusion, mission planner, path planner, and trajectory generator. Sensors, such as IMU, cameras, and hydrophones, send data through communication channels, and then the sensor fusion software module fuses all data together in order to process in the next step. This module also checks the power for operations. The mission planner module uses the fused data to select a strategy to perform tasks based on different criteria. Once the strategy is decided, the path planner module generates the robot path according to the strategy. The trajectory generator then generates actuator trajectories such that the robot will follow the generated path. These trajectories are used as control goals for actuators such as thrusters. Other peripheral devices such as grippers, torpedo launchers, and lamps will be activated based on trajectories generated according to the strategy chosen.

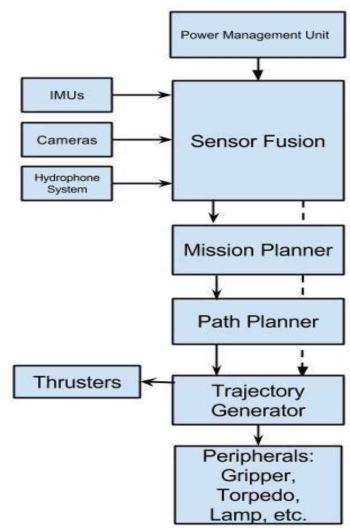

Fig. 5. Mission planner group module.

Our mission planner module is written by Python. Mission planner connects with other systems by ROS (Robot Operating System). When an AUV is performing a task, mission planner acquires and processes data from nodes. After processing, mission planner commands each node to perform the task. This process is repeated until the AUV finishes a task.

In control system module we use offset for tuning PID to make it easier and make AUV more stable. In a part of PID control concept shown in fig. 17 is used to stabilize the depth and handing of our vehicle. The controller receives data from sensor (IMU, DVL, and pressure sensor) and uses fusion framework from ROS, of which Unscented Kalman Filter (UKF) [2] is utilized in order to combine all measured data, that estimates orientation, position, velocity and attitude of the AUV under the linear system, including outputs of quaternion called "Euler angle" is utilized to be angle estimates. Our robot self-stabilizing algorithm utilizes the estimated angle and the rate of change in angle. Eight thrusters, of which their outputs are precisely calibrated to make the vehicle move in the correct path in order to control the robot stability, are controlled in this process using the pulse width modulation (PWM).

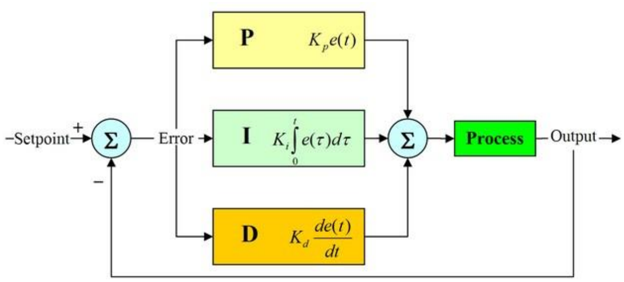

Fig. 6. Block diagram of PID control algorithm

D. Vision system module

In vision system module IDS Ueye camera UI-3260CP-C-HQ Rev. 2 is used in Robosub competition this year. Our vision system is written by using OpenCV library in Python, Image processing algorithms on AUV are designed for the following tasks that have 3 steps are shown in Fig. 7 and listed as follows.

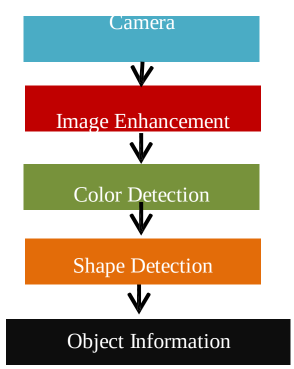

Fig. 7. The block diagram of the vision system module in object detection

1) Image Enhancement

This step images are reduced noise by image blurring that is convolving the image with a low-pass filter kernel. We use Gaussian Filtering and Median Filtering. After noise reduction, Our images are converted to Grayscale and enhancement that the process can sharpen, brighten, and making it easier to detection by CLAHE (Contrast Limited Adaptive Histogram) or Histogram equalization then are converted to HSV.

2) Color detection

The color detection module uses colors that are indexed in HSV (Hue-Saturation-Value) color space because HSV is easy to represent an index of colors by Hue values. After images are acquired from AUV cameras, the imaging data are converted to HSV. The index of colors is obtained by using a user interface to capture an image and record a range of colors.

3) Shape detection

In this algorithm, we assumed that a group of pixels has already been detected in an image by extracting desired colors using a color detection algorithm. The detected groups of pixels is called "blob". Our shape detection algorithm extracts a simple geometric form of an object by using mathematical geometry based on probabilistic and statistical algorithms. The result that contains centroid, area, or angle.

In Imaging sonar system module Blueview m900-130 series Imaging Sonar is used in Robosub competition this year. Imaging sonar is capable of long distant underwater object detection and tracking. The goal of the imaging sonar is assist the navigation subsystem is finding out the target underwater. The imaging sonar transmits the audio pulses and receives the echo from the surrounding environment. The image is formed from the time-delay, direction of the echo and signal power. It can also detect the objects in the inconvenient vision which can help vision and AI parts for detection and tracking the objects. Our imaging sonar system module is written by C++ and python languages. We can separate the programming in two main parts including of detection and tracking the position of the objects. The whole algorithms is given in Fig 8

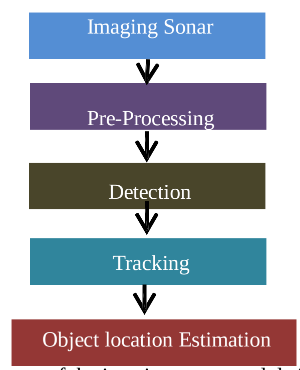

Fig. 8. The block diagram of the imaging sonar module in object tracking

In hydrophone processing module is designed for searching an acoustic signal from the pinger. The detector is mounted under the AUV platform to measure wave heights and periods from four hydrophones as input signals. The signals are amplified before being analyzed. Location output data are then provided.

The software methodology for hydrophones carries out six steps:

1) Sampling

This step is the beginning of the processing where the analog signal is converted to a digital signal.

2) Pulse detection and demodulation

This step is used to detect the pinger pulses where they will be demodulated to a baseband signal. There are two thresholds used in the process, front and power thresholds.

3) Pinger pulse frequency estimation

In the stage, our goal is to estimate the frequency of the transmitted pinger pulse to make sure the detected pulse frequency is equal the frequency of the transmitted pinger pulse that AUV listen. The fast Fourier transform (FFT) is applied to the detected pulses where the pinger frequency is associated with the frequency with the largest magnitude.

4) Delay time estimation.

Since the pulse detection algorithm may not be perfect, and the pinger signal may arrive at hydrophone from different directions and time delays due to multipath nature of underwater sound propagation, the delay-time estimation is used to accurately extract the first arrival pulse of the pinger signal from all four hydrophones for further processing. Here, we assume that the line-of-sight is the shortest path between pinger and hydrophones.

5) Bearing estimation

The azimuth angle and the elevation angle are computed in this step as the output of the system. Here, we measure the phase differences of the arrival signals at all hydrophones. If a pinger is on the right, the phase of the received signals of the right hydrophone should lead the hydrophone on the left. In fact, we have

$$\psi_i = \frac{2\pi}{\lambda} f_i(\phi, \theta)$$

where ψ_i is the phase delay at the i-th hydrophone, λ is the wavelength of the pinger pulse, ϕ is the azimuth angle, θ is the elevation angle, and $f_i(.,.)$ is a function that depends on the geometry of hydrophones with respect to the AUV axes.

IV. EXPERIMENTAL RESULTS

According to the planned schedule, overall seemed to be able to accomplish the goal in every step of the schedule but in some parts, it might be later than what was expected and there was some adaption of the plan during working if the goal could not be reached due to the resource problems.

Mechanical team invented the new gripper which can both catch and release the ball and also there was the improvement of the shape of AUV to make it more suitable for the electronic boards, sensors, cameras and computer inside.

Electronic team had redesigned the new boards and tried to reduce the number of wires inside AUV, so, it would be easier to debug and see where the mistakes were. There was also the development of switches to be more secure.

Software team had improved the algorithms in mission planner, vision,control and sonar parts. New codes for new mission had been written and the was the implementation of program codes. We have tested the code at the pool of the university and after the problems were found, the team tried to fix them immediately.

Hydrophone team had some problems on the boards, thus, we spent more time on debugging the code and fix the board. The test time was shorter than the other teams.

The estimated testing time depended on each team's abilities to finish the their goals according to the plan but we tried to test our AUV as much as we could. Any parts that could be tested alone can be tested first.

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Appendix A Component

Specifications Table

Component	Vendor	Model/Type	Spec	Cost(if new)
Frame	Custom made	-	- Aluminium Profile and Aluminium 6063	500 USD
Waterproof Housing	Custom made	-	- Acrylic tube and Aluminium 6063	1000 USD
Waterproof Connectors	Teledyne, Seacon	Impulse(Teledyne),WET-CON(SEACON)	- Wet mateable - Low cost - 1 to 16 contacts - New pin design removing any potential wear to the - - Sealing interface - Up to 20,000 psig (approx. 45,000ft/13,700m) - 600 VDC with standard cable - 19 amps max current (cable dependant)	1500 USD
Thruster	Blue Robotics	T200	- Max Thrust – Forward: @16V 11.2 lbf5.1 kgf - Max Thrust – Reverse: @ 16V 9.0 lbf4.1 kgf - Max Thrust – Forward: @12V 7.8 lbf 3.55 kgf - Max Thrust – Reverse: @ 12V 6.6 lbf3.0 kgf - Min Thrust: 0.02 lbf 0.01 kgf - Rotational Speed: 300-3800 rev/min - Operating Voltage: 6-20 volts	1400 USD
Motor Control	Blue Robotics	Basic ESC	- Voltage: 7-26 volts - Current: 30 amps (with some cooling)	
High Level Control	Pololu	Mini Maestro 12-Channel USB Servo Controller (Partial Kit)	- Channels: 12 - Baud: 300 - 200000 bps2 - Minimum operating voltage: 5 V - Maximum operating voltage: 16 V - Supply current: 40 mA3	
Battery	Gen ace	Gens ace 5000mAh 22.2V 60C 6S1P Lipo Battery Pack	- Capacity: 5000 mAh - Discharge Rate (C): 60 - Max Burst discharge Rate (C): 120 - Parallel (P): 1 - Voltage: 6S (22.2V)	
CPU	Intel	Intel® Core™ i5-6260U Processor.	- # of Cores: 2 - # of Threads: 4 - Processor Base Frequency: 1.80 GHz - Max Turbo Frequency: 2.90 GHz - Cache: 4 MB SmartCache - Bus Speed: 4 GT/s OPI - TDP: 15.0 W - Configurable TDP-down: 9.5 W	
Internal Comm Network	Custom-made	-	-	150 USD

Component	Vendor	Model/Type	Spec	Cost(if new)
External Comm Interface	D-Link	DGS-105	- Lan : 5 x 10/100/1000 Mbps Ports	20 USD
Programming Language 1	C, C++, Python	-	-	-
Inertial Measurement Unit (IMU)	Lord	3DM-GX5-45	- Position accuracy: ±2 m RMS horizontal, ± 5 m RMS vertical (typ) - Velocity accuracy: ±0.1 m/s RMS (typ) - Attitude accuracy: EKF outputs: ±0.25° RMS roll and pitch, ±0.8° RMS heading (typ) - CF outputs: ±0.5° roll, pitch, and heading (static, typ), ±2.0° roll, pitch, and heading (dynamic, typ) - Attitude heading range: 360° about all axes - Attitude resolution: < 0.01° - Attitude repeatability: 0.2° (typ) - Calculation update rate: 500 Hz	-
Doppler Velocity Log (DVL)	Teledyne			
Camera(s)	IDS Imaging Development Systems GmbH	UI-3260CP-C-HQ Rev.2	- Sensor type: CMOS Color - Shutter: Global Shutter - Sensor characteristic: Linear - Resolution: 2.35 Mpix - Resolution (h x v): 1936 x 1216 Pixel	2000 USD
Hydrophon	Teledyne	TC-4013	- Usable Frequency range: 1Hz to 170kHz - Receiving Sensitivity: -211dB ±3dB re 1V/µPa - TranUStting Sensitivity: 130dB ±3dB re 1µPa/V at 1m at 100kHz	-
Manipulator	Custom-made	-	-	-
Algorithms: vision	OpenCV, Our algorithms	-	-	-
Algorithms: acoustics	Teledyne, OpenCV, Our algorithms	-	-	20000 USD
Algorithms: localization and mapper	ROS, Our algorithms	-	-	-
Algorithms: autonomy	ROS, Our algorithms	-	-	-
Open source software	OpenCV, ROS,Github, Kicad, LTspice, OpenSTM32	-	-	-

Component	**Vendor**	**Model/Type**	**Spec**	**Cost(if new)**
Team size (number of people)	16	-	-	-
HW/SW expertise ratio	5:11	-	-	-
Testing time : simulation	40 Hours	-	-	-
Test time : in-water	90 Hours	-	-	-

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