Design and Implementation of Zeabus AUV for Robosub 2019

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***Abstract* — Kasetsart University has participated in Robosub since 2014. In 2019, we proudly present an 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 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 efficient. 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 22st Annual International RoboSub Competition, our team has significantly redesigned Zeabus to improve the overall performance and we truly aim the best result in the competition which is exciting presented in theme of vampire.

II. COMPETITION STRATEGY

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. Because there are not enough team members, our team members actually mostly spend time in Zeabus laboratory. We separate responsible to 3 parts consist of Mechanic, Electronic and Software.

From a previous AUV, which was built by a former team, was rebuilt by the mechanic team to having high durability and strength. Moreover, mechanism parts as a gripper and a torpedo launcher was assembled which are specific for the tasks. The electronic team has had reliable devices already and the team is responsible with enhance more performance fix any broken devices. Lastly, the software parts which includes AI, Control, Vision, Hydrophone and Sensor parts. From the strategy is developed to focus on how to accomplish the tasks. 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. Anyway, 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 aims AUV stable the most to make the best result from Vision part which 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 was broken and won't installed in in this year. AI part plans to make AUV rotate itself. AI part also requests data from Vision 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 appropriated accessibility. Furthermore, its material of hall is mostly anodized aluminum 6063 which prevent corrosion. However, heavy battery has been a concerned issue, in this case, AUV frame is aluminum profile which make the new AUV can be adjust weight along longitudinal by moving heavy battery and also is constructed easily. Especially, to complete the tasks, we choose pneumatic system to run mechanism parts which compressed CO_2 is utilized as gas within the system.

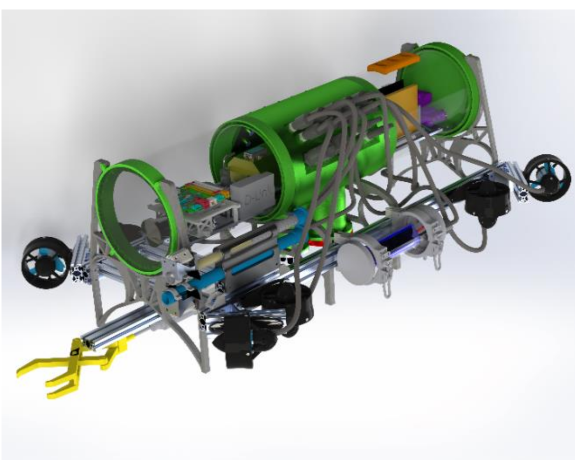

Fig. 1. Zeabus platform

As the task called "Stake through the heart", the torpedo launcher was design following torpedo length. The torpedo is launched by spring which was calculated sufficient k-constant to produce an enough force that can 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.

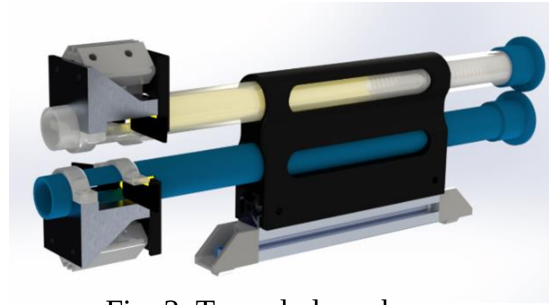

Fig. 2. Torpedo launcher

Especially, the torpedo was precisely shaped to has its density lower than water as 0.98 gram per cubic centimeter and also was coated by epoxy resin so that to minimize skin friction drag. Its model was imitated from submarine and torpedo missile shape via analytical method in Fluent Ansys to reach the best performance.

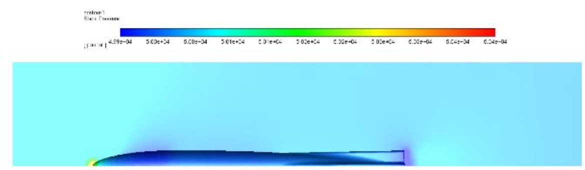

Fig. 3. Contour Static Pressure

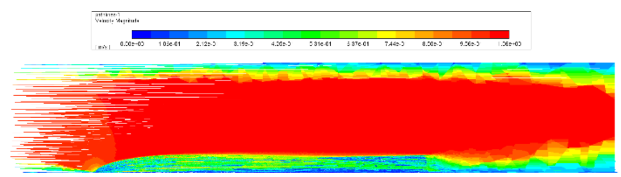

Fig. 4. Pathlines Velocity Magnitude

For the 3 tasks, including Garlic drop, Octagon, and Slide door to open heart, namely, the gripper was specifically designed to simply manipulate and can handle all of the tasks as well. Moreover, the Zeabus gripper, of which its material is vinyl plastic, has high durability and it will be driven by the pneumatic linear actuator. This gripper shown in Fig. 5 is installed at the front of the AUV as shown in Fig. 1.

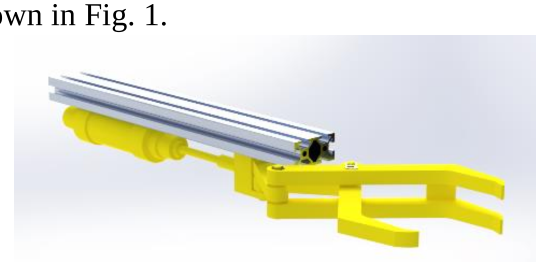

Fig. 5. Gripper

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. 6 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

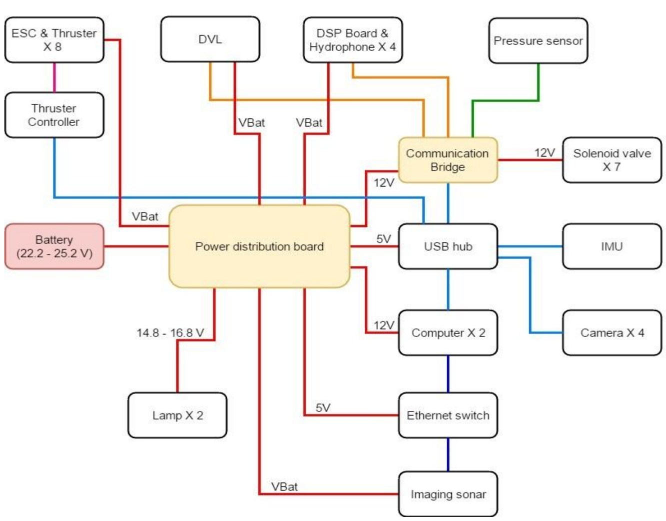

Fig. 6. Electrical modules and connections

C. Software overview

The Zeabus software system is composed of:

- *Mission planner group module*
- *Sensor system module*
- *3) Control system module*
- *4) Vision system module*
- *5) Hydrophone Processing Module*

Fig. 7. Software Overview

1) The mission planner integrates all of software module and strategic them together; in case there are defined position and direction to next task until the vision detects the task. Then, the module hand over the analytical data to the control.

2) The sensor fusion notifies a position respected with the earth or pool map. The nodule integrates 3 sensors consisting of pressure sensor, IMU, and DVL as shown in Fig. 8. Then, the detected data will be analyzed following a limit of hardware that is frequency 10 Hz.

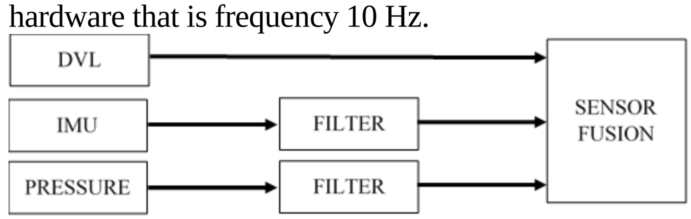

Fig. 8. Sensor Fusion Overview

3) The control system stabilizes the AUV and directs its movement via Simple Fuzzy System; namely, the system get only error input then prints force output in coordinate ENU (East-North-Up).

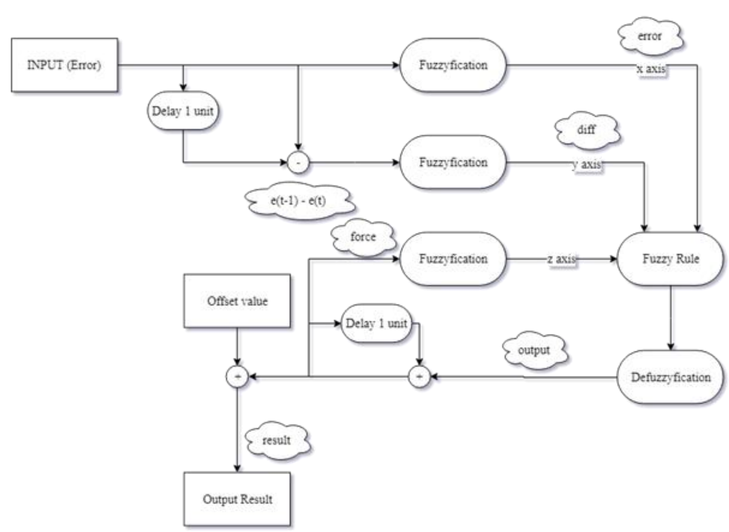

Fig. 9. Control Fuzzy System

4) Vision system module; IDS U-eye camera UI-3260CP-C-HQ Rev. 2 is used in the Robosub competition for 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. 10 and listed as follows.

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, the 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) HAAR Cascade

HAAR Cascade is the machine learning algorithm to detect any objects that you want in an image by using a simple feature detection frame extract features from a photograph then select the best features with Adaboost. The cascade is trained by using a lot of positive image and negative images.

3) 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.

4*) 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 are 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.

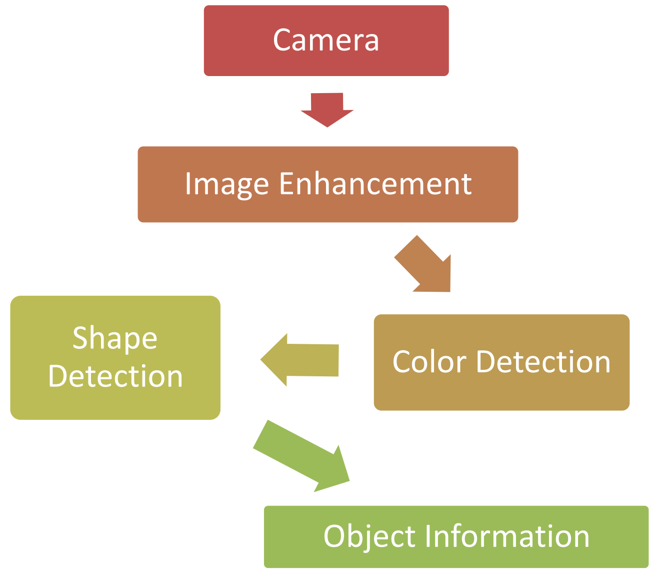

Fig. 10. Block diagram of the vision system module in object detection

5) 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:

I. Sampling

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

II. 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.

III. *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.

IV. 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.

V. 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 ψi 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 $f i\ (\phi\ , \theta)$ 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 not what we expected and there was

some adaption of the plan during working if the goal could not be reached due to any problems.

Mechanical team invented the new gripper and torpedo that compatible with every task. There work as what we expected.

Electronic team had redesigned the new boards and tried to reduce the number of wires inside AUV so it would be easier to fix any debug. There was also the development of switches to be more secure and good accessible.

Software team had improved the algorithms in mission planner, vision, and control part. The reliable codes for new mission had been written and the was the implementation of program codes. We have tested the code in a pool of our university and after any problems were found, the team can fix them immediately. The control testing, we integrate Crisp set and Fuzzy set together for Fuzzy Rule so that to analyze a particular situation. Although, the Simple Fuzzy System can be difficulty stabilize which the error is closed to zero, it can be tuned the fluctuate error to that to cover value zero.

Hydrophone team had been improved so we spent time on coding to enhance reliability.

All in all, we didn’t get a preferred result in previous year leads us to have a strong ambition to do our best in this year. Even if, we don’t expect to achieve every task, we have the great strategy that it will lead us to pass through the final round.

ACKNOWLEDGEMENT

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APPENDIX A COMPONENT

SPECIFICATIONS TABLE

Component	**Vendor**	**Model/Type**	**Spec**	**Cost (if new)**
Frame	Custom	-	- Aluminium Profile and Aluminium 6063	500 USD
Waterproof Housing	Custom made	-	- Acrylic tube and Aluminium 6063	1000 USD
Waterproof Connectors	Teledyne, Seacon	Impulse (Teledyne), WETCON (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	

Component	Vendor	Model/Type	Spec	Cost (if new)
Algorithms: autonomy	ROS, Our algorithms	-	-	-
Open source software	OpenCV, ROS,Github, Kicad, LTspice, OpenSTM32	-	-	-
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
External Comm Interface	D-Link	DGS-105	- Lan : 5 x 10/100/1000 Mbps Ports	20 USD
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	-

Component	Vendor	Model/Type	Spec	Cost(if
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
Hydrophone	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	-	-	-
Programming Language 1	C, C++, Python	-	-	-
Team size (number of people)	9	-	-	-
HW/SW expertise ratio	5:11	-	-	-
Testing time : simulation	100 Hours	-	-	-
Test time : in-water	300 Hours	-	-	-

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