A Design of Zeabus AUV

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Abstract—**Kasetsart University has participated in Robosub since 2014. In 2015, a new AUV called Zeabus has been designed with more functions and features to perform more tasks. Devices, computers, and main circuits have been installed in three main hulls. Thrusters have been replaced and driver circuits have been improved. Significant devices such as DVL and hydrophones have been added with more advance processing. Zeabus AUV is operated on *ROS (Robot Operating System).***

Keywords—AUV, ROS, autonomous, robot

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, participated in Robosub 2014 and was able to go into the semi-final round. Unfortunately, due to lacks of some equipment, resources, time, and experience, we could not reach the final round. In 2015, Kasetsart University team has redesigned our AUV to improve the performance of the robot. The name of our new AUV is Zeabus, which is the same as our team's name. This paper describes the design of Zeabus AUV and is organized as follows. Section I describes mechanical design of AUV. Section II explains electrical design including electrical structures and sensors used. Section III provides information of software implemented for AUV control and navigation. Finally, section IV ends the paper with the conclusion.

II. Mechanical Design

A. Zeabus platform overview

The Zeabus platform is mainly made of aluminum. Some parts are made of iron. Three aluminum main hulls containing controllers, sensors, and other circuits are placed on the base painted in black. One long main hull is aligned on the right hand side, while the other two main hulls are aligned in the same line on the left hand side as shown in Fig. 1.

These main hulls contain various devices with different weights. In order to balance the platform due to different
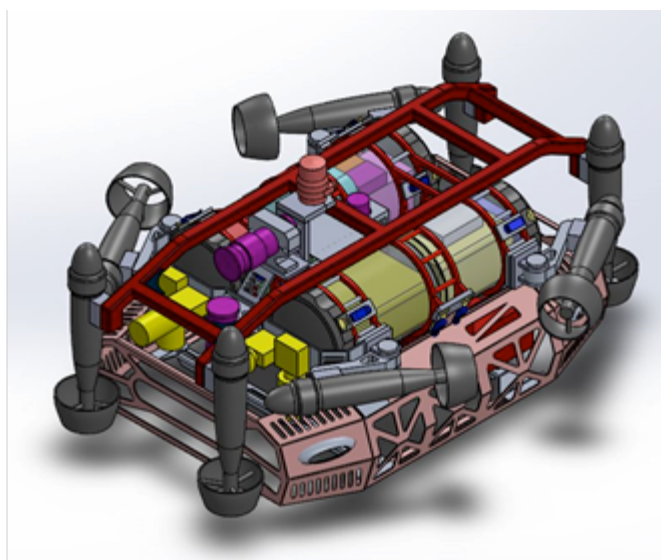

Fig. 1. Zeabus drawing

weights on hulls, the position of batteries on the AUV can be adjusted.

There are eight thrusters installed on the Zeabus platform. Four thrusters is used for the movement on z-axis. For the movement on x-y axis, other four thrusters were installed with adjustable thruster bars. These bars allow us to adjust the angles of four x-y thrusters according to different movement requirements. If there is a need for more movements or faster speeds in a surge direction on x-axis, the angles of the thruster bars will be less than 45° with respect to the left and right hand sides of the AUV. If the amount of movements required on x and y axes are about the same, the angles of the thruster bars will be set to 45°.

B. Platform analysis

Zeabus hydrodynamics was preliminary analyzed in a simulation. An example of a hydrodynamic analysis in a simulation is shown in Fig. 2. This simulation also helps us to estimate physical characteristics of Zeabus such as mass, center of gravity, center of buoyancy, moment of inertia, and volume. Although the actual platform is not exactly the same as in the simulation, these parameters can give some insights for further design and testing.
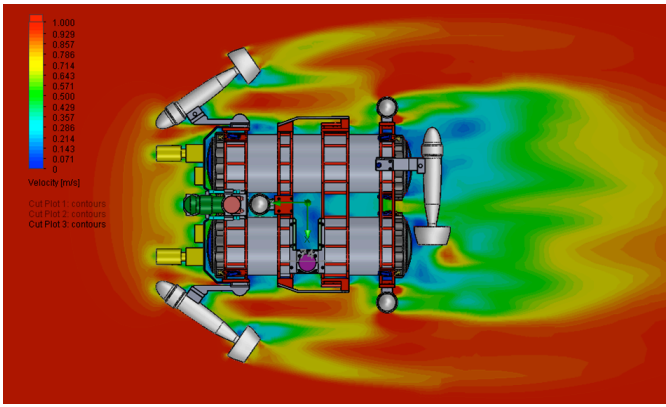
Fig. 2. Hydrodynamic analysis of a preliminary design

C. Thruster performance analysis

Thrusters used on Zeabus are VideoRay Pro 4 thrusters. In order to integrate these thrusters with our control and navigation systems, we have tested the average thrust output from these thrusters with respect to a current input. The testing setup is shown in Fig. 3. In this setup, a thruster will be driven by a brushless DC motor driver at 12 V to push a lever, which is connected to a load cell in order to measure the output thrust. The result is shown in in Fig. 4.
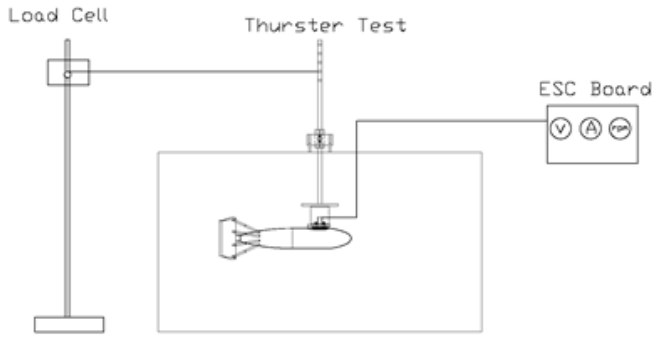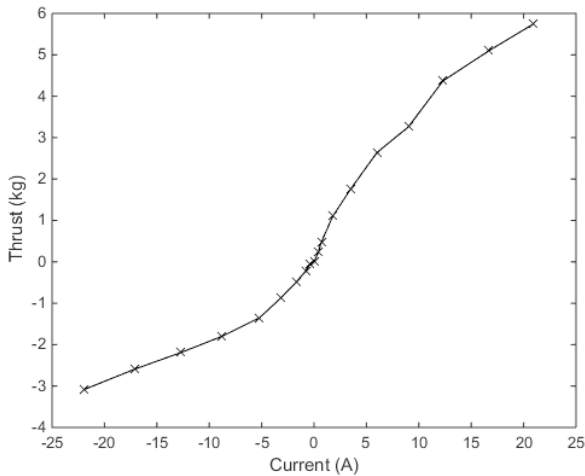

Fig. 3. Thruster testing setup

Fig. 4. Thruster outputs with respect to input currents

The specified current input provided by VideoRay is 17 A, which gives the output thrust at 5 kg. The result from the experiment supports the manufacturer specification. Noticeably, the backward thrust is about a half of a forward thrust due to the thruster design.

C. Gripper

The Zeabus gripper module shown in Fig. 5 is designed as a two-in-one device. It contains a front gripper and a bottom gripper in the same module. Both front and bottom gripper are operated by a pneumatic mechanism.

Fig. 5. Zeabus gripper module

D. Torpedo launcher

A Zeabus torpedo launcher shown in Fig. 6 was made from a PVC pipe. A torpedo can be launched with a power of a spring inside a launcher. A pneumatic lock is used to block a torpedo. In order to fire a torpedo, this lock is released and the torpedo will be launched with a potential energy from a spring. Another torpedo launcher is used as a marker dropper. When Zeabus wants to drop a marker, the AUV just fires a torpedo downward to the target.
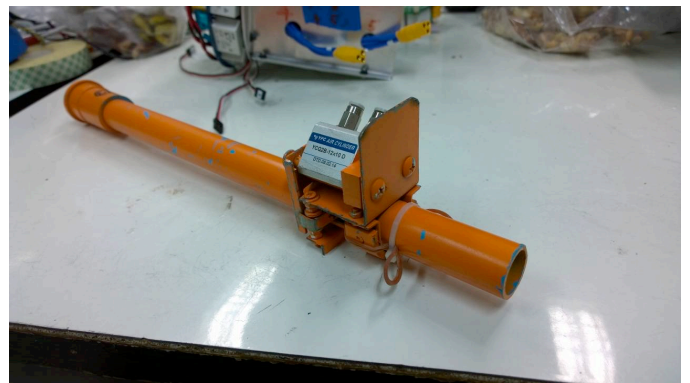

Fig. 6. Torpedo launcher

Torpedoes were made of ABS. Since the density of ABS is closed to water, a fired torpedo will not be significantly affected by buoyancy and can hit a target with more accuracy.
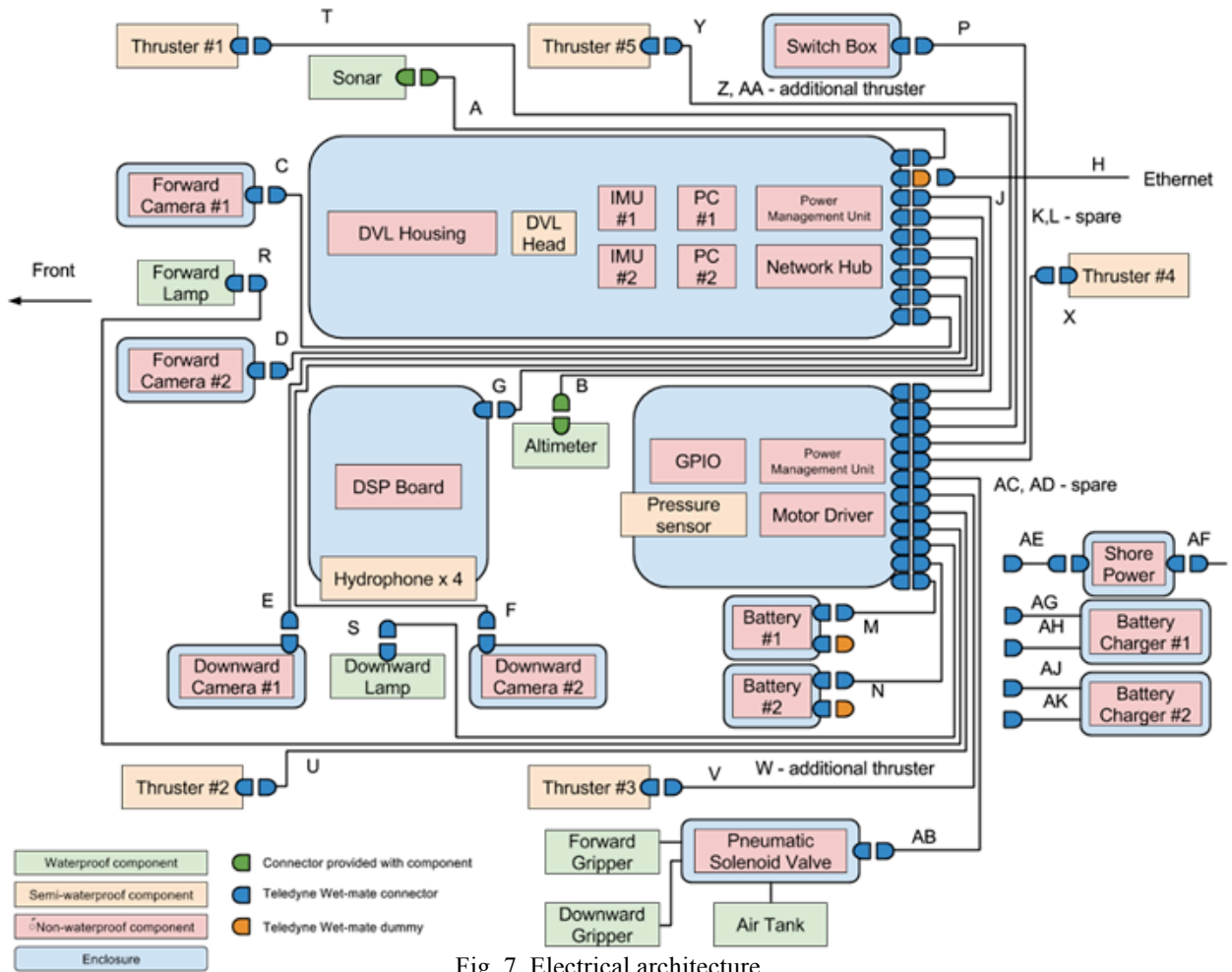
Fig. 7. Electrical architecture

III. ELECTRICAL DESIGN

A. Electrical architecture

The Zeabus AUV is divided into several subsystems 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. Related components are grouped together and separated from others. Components in the same groups are usually used for the same function. Another criterion to group components is how much maintenance those components are required. Finally, the vehicle is divided into many hulls as followed.

1) Navigation hull

This hull consist of:

a) PCs and peripherals

b) IMU (Inertial Measurement Unit)

c) DVL (Doppler Velocity Log)

d) Internal power management unit

These components are grouped in the same hull because these components works together to get information of vehicle navigation. No matter how mission is changed, these components are required. Also, these components are mostly

COTS (Commercial Off-The-Shelf), so they do not require much maintenance. Thus, this hull will be most of the time sealed tightly and not be opened.

2) Power and Actuator hull

This hull consist of:

a) Power Management Unit

b) Motor drivers

c) GPIO

d) Pressure sensor

Because these components depend on mission requirement and vehicle design, they are grouped in the same hull. Power Management Unit (PMU) distributes power from batteries to all devices. Also, these components except the pressure sensor are custom-built so that it might need regular maintenance. Motor drivers are major components that consume power from PMU.

3) Hydrophone hull

This hull contains hydrophones and signal processing equipment. These components are only required on a pinger detection task. This hull can be removed or replaced with other related equipment when the Zeabus AUV does not work on

pinger detection. Also, the signal processing equipment is custom- built so that it might need regular maintenance.

These three aforementioned hulls are the main hulls of the Zeabus AUV. There are extension hulls used for some specific purposes as follows.

4) Camera hull

This hull is actually a housing for cameras. One hull is for two stereo front cameras and another hull is for two stereo bottom cameras.

5) Pneumatic hull

This hull contains pneumatic system equipment for pneumatic actuators including torpedo launchers, marker droppers, and grippers. These equipment are mission based and thus are depended on a AUV design.

6) Battery hull

This hull contains batteries. Batteries need to be accessed very often for recharging. Sealing batteries tight in their own hull separately from other hulls allows batteries to be plugged and unplugged easily and reduces a chance of other hulls to be leaked from opening and closing often.

7) Switchbox Hull

The switchbox hull contains switches and connections to turn on/off and control system functions.

B. Connectors

Zeabus AUV connections are designed based on Teledyne Impulse Wet-Pluggable IL, MCIL-series connectors. Teledyne connectors are specially designed for underwater environment and can be mated in wet condition. Initially, our team requested Teledyne to assemble the whole cables. However, due to overweight and overlength cables realized during our design processes, some parts of cables were cut out. The rests of each cable with connectors were spliced together and potted seal.

C. Sensors

There are several sensors used on Zeabus AUV as follows.
1) DVL (Doppler Velocity Log)
A Teledyne RD Explorer DVL shown in Fig. 8 is used a measured the velocity of the AUV.

Fig. 8. Teledyne DVL

2) IMU (Inertial Measurement Unit)
There are 2 IMUs used in Zeabus. The first IMU is a Lord MicroStrain 3DM-GX3-25. The second IMU is a KVH 1775 FOG IMU. Both are shown in Fig. 9 (a) and 9 (b), respectively. The KVH 1775 will be used as a main IMU, while another one is used as a supporting IMU. Both are mainly used as AHRSs (Altitude Head Reference System).
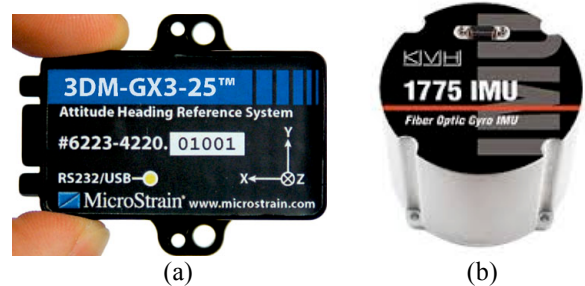

| (a) | (b) |

Fig. 9. IMUs used in Zeabus:
(a) Lord MicroStrain 3DM-GX3-25; (b) KVH 1775 FOG IMU

3) Pressure sensor
A pressure sensor used on Zeabus is US331 manufactured by Measurement Specialties. It is shown in Fig. 10 and used to measure depth of the AUV.

Fig. 10. Pressure sensor

4) Altimeter
A PA500 altimeter manufactured by Tritech is used on Zeabus as another sensor to measure depth with a different approach from the pressure sensor. This sensor measures depth by using an acoustic signal reflection from the bottom of a pool. The PA500 sensor is shown in Fig. 11.

Fig. 11. Altimeter

5) Hydrophone
Four TC 4013 hydrophones made by Teledyne Reson are used to sample an acoustic signal transmitted from a pinger. Four sampled signals will then be processed by a DSP (Digital Signal Processor Board). A TC 4013 hydrophones is shown in Fig. 12.
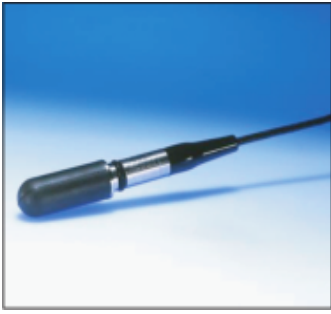
Fig. 12. Teledyne Reson TC 4013 Hydrophone

6) Sonar

A sonar installed on Zeabus is Tritech Micron Sonar shown in Fig. 13. The sonar is mainly used to support localization on the AUV.

Fig. 13. Tritech Micron sonar

IV. SOFTWARE DESIGN

A. 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 PID control algorithm.

3) Vision system module
The vision system module is used when the AUV has to navigate by using vision to finish some tasks.

B. Mission planner group module

In mission planner group module, there are several submodules including sensor fusion, mission planner, path planner, and trajectory generator. Sensors such as IMU, cameras, and hydrophones, will send data through communication channels, and then the sensor fusion software module will fuse all data together in order to process in the next step. This module also checks the power for operations. The mission planner module will use the fused data to choose a strategy to perform tasks based on different criteria. Once the strategy is decided, the path planner module will generate the robot path according to the strategy. The trajectory

generator will then generate actuator trajectories such that the robot will follow the generated path. These trajectories will be 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.
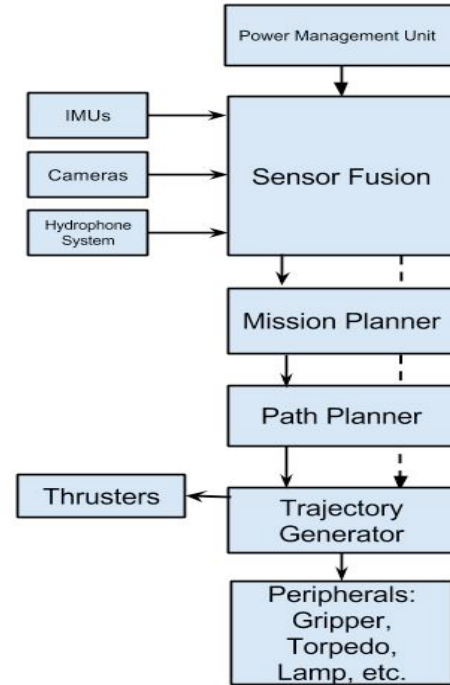

Fig. 14. Mission planner group module

C. Control system module

A PID control concept is used to stabilize the depth and heading of our vehicle. Orientation of the robot can be estimated by fusing all measured data using Unscented Kalman Filter (UKF). Angle estimates are available as Euler angle or quaternion angle outputs. Our robot self-stabilizing algorithm uses an estimated angle and the rate of a change in angle. Eight thrusters will be controlled in this process. Each of the outputs will be carefully calibrated to make the vehicle move in the correct path as much as possible in order to control the robot stability.

D. Vision system module

Our vision system is written by using OpenCV library in Python. Color recognition and color range adjustment can be performed by using a dropper tool and sliding rollers in our GUI to select the range from the minimum to the maximum.

Our image processing algorithms on Zeabus AUV are designed for the following tasks
- Detecting underwater objects by using color detection and shape detection.
- Checking distances between objects and the AUV

There are two main image processing algorithms used on Zeabus AUV, which are color detection and shape detection. Color detection detects colors. The output from color

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detection is sent to the mission planner module for completing each task. Using only color detection cannot accurately identify objects. Hence, shape detection will be used along with color detection to differentiate each object.

1) Color detection

Colors 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 shown in Fig. 15 to capture an image and record a range of colors. An example of color detection to detect an underwater gate is shown in Fig. 15.
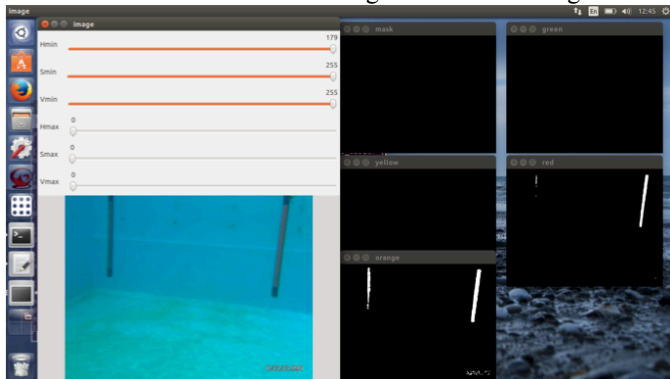

Fig. 15. Vision system interface for gate detection

2) 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. An example of shape detection for underwater buoys is shown in Fig. 16.
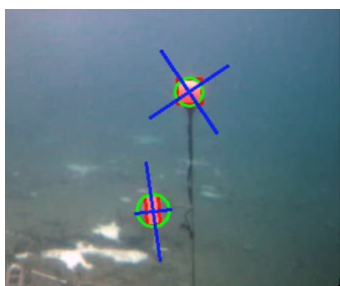

Fig. 16. Shape detection of Buoys

E. Sonar

In order to interpret data with background noise or other interfering signals, Constant False Alarm Rate (CFAR) filter is applied on our sonar data. CFAR is a common adaptive algorithm used in modern radar systems to filter background noise, clutter, and interference signals in a nonhomogeneous environment. Fig. 17 shown data before and after CFAR filter was applied. As shown in Fig. 17, CFAR filter can filter out noise effectively.
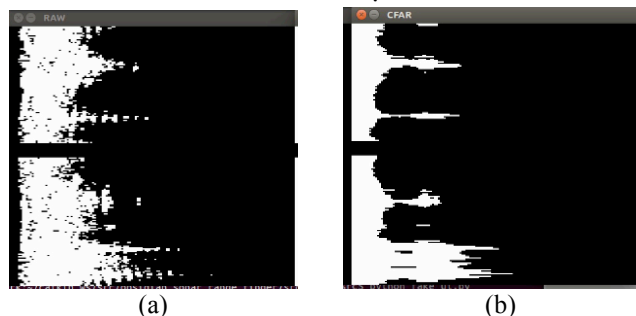

Fig. 17. (a) sonar data bin without CFAR filter, (b) sonar data bin with CFAR filter

F. Hydrophone processing module

Our 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 4 hydrophones as input signals. The signals are amplified before being analyzed. Location output data are then provided. The localization configuration is shown in Fig. 18.
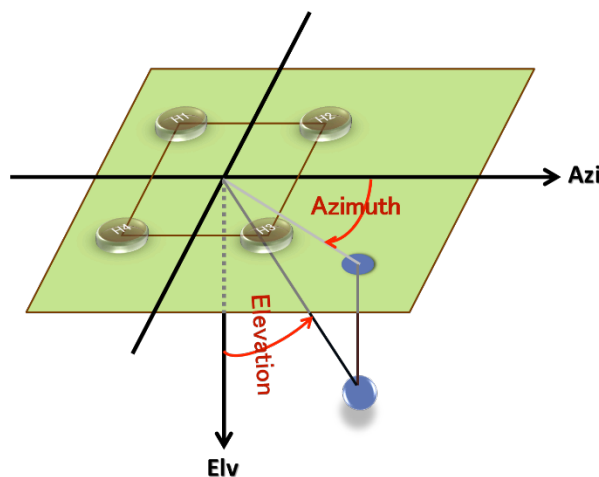

Fig. 18. Localization scenario with 4 hydrophones

The software methodology for hydrophones carries out 4 steps.

1) Sampling and demodulation.

This step is the beginning of DSP processing for recovering the baseband signal.

2) Pulse detection.

This step is used to detect the pulse from a demodulated signal.

3) Delay time estimation.

Phase information is computed in this step to be used in the next phase.

4) Bearing estimation

The azimuth angle and the elevation angle are computed in this step as the output of the system.
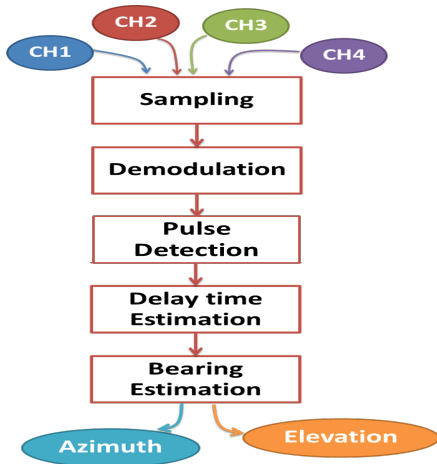
These steps are depicted in Fig. 19.

Fig. 19. Pinger detection methodology

G. ROS (Robot Operating System)

In ROS ecosystem, each program is called a node, which represents a thread. Each node can be operated by Remote Procedure Call in either synchronous mode or asynchronous mode depending on different designs. Each node can communicate via a message protocol or a service protocol.

In asynchronous mode, nodes are divided into publishers and subscribers. A subscriber has to use the same protocol as a publisher with the same message type. A message type can be created by a user.

In synchronous mode, nodes are divided into services and clients. A client can request an action from a service with a service protocol. Two types of messages in the service protocol are a request message and a response message.

ROS also has various libraries, which are utilized in Zeabus AUV such as localization, robot pose estimation, Kalman filter, mapping, navigation, robot geometry. ROS also supports integrations with OpenCV and Gazebo simulator library

The ROS software architecture of Zeabus AUV is shown in Fig. 20. Some of important ROS nodes in Zeabus are:

- /dvl
  This node publishes sensor outputs from DVL.
- /logitech , /gscam nodelet
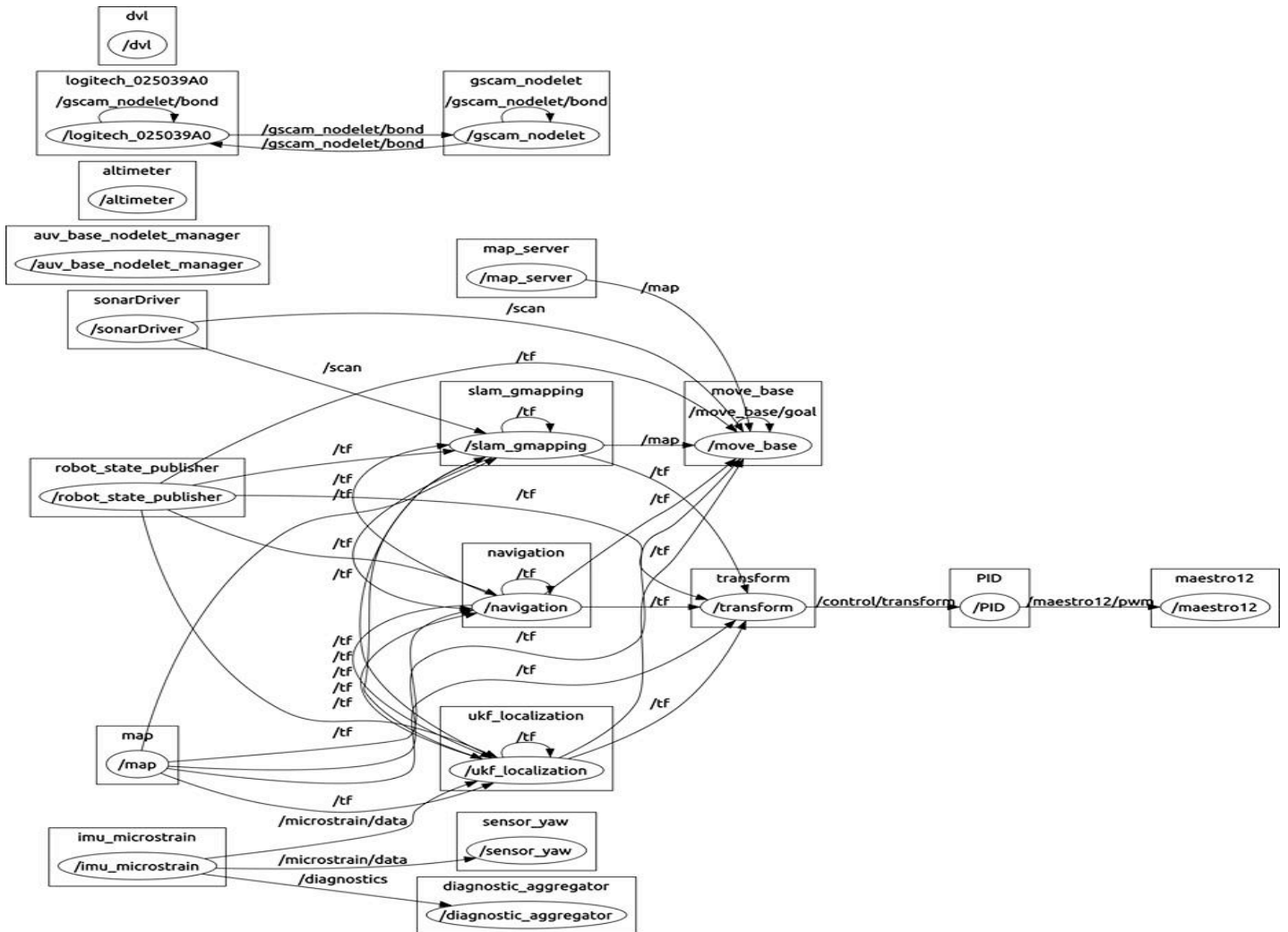 These are nodes for cameras and their drivers.

Fig. 20. ROS software architecture of Zeabus AUV

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- /altimeter
  This node publishes sensor outputs from the altimeter.
- /sonarDriver
  This node publishes sensor outputs from the Sonar.
- /robot state publisher
  This node provides all geometry of the AUV.
- /map_server , /map
  This node publishes the shape of a static map.
- /ukf_localization
  This node reports states of sensor fusions and map localization.
- /slam_mapping
  This node publishes SLAM based map.
- /navigation , /move_base
  These nodes publish planning paths and following paths.
- /transform
  These nodes transforms local based and global based data.
- /PID, /maestro12
  These nodes represent a controller of the AUV.
- /imu_microstrain
  This node publishes outputs from an IMU.

V. CONCLUSION

In this team description paper, a design of Zeabus AUV was described. Technical details of designs on mechanical, electrical and software parts were covered. Our AUV has been improved much compared to the last year. This is a good opportunity for students in the team to learn several advance algorithms and implementation with respect to their education level. However, there are still many details that we still want to improve for better performance. We plan to implement that in Robosub 2016

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