Makara-05: Autonomous Surface Vehicle

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***Abstract*—Makara-05 is an autonomous surface vehicle design and built by students of Universitas Indonesia to participate in RoboBoat Competition which held by AUVSI Foundation in Virgina Beach, USA 4-10 July 2016. In this journal explains Makara-05's hull design, electrical system, software integration and sensors that were used in Makara-05 . Makara-05 was designed to accomplish the mission in AUVSI RoboBoat Competition 2016.**

I. INTRODUCTION

Makara-05 is an autonomous vehicle design and built by the students of University Indonesia from various major that are joined in the research team of Autonomous Marine Vehicle Universitas Indonesia (AMV UI). The design of Makara-05 is the most latest design with the design parameter of accomplishing the mission on AUVSI Roboboat Competition 2016. This is the second chance for Universitas Indonesia to compete in AUVSI Roboboat Competetion in which AMV UI have participated in 2012.

II. MECHANICAL

A. Hull Design

AMV UI team in designing Makara-05 ASV was inspired by Bone Fish, an ASV built by SAAB. The hull concept that is used is the trimaran concept, the concept of using three hull on the ASV. The decision of using the trimaran concept was based on past experience of designing and literature study on trimaran.

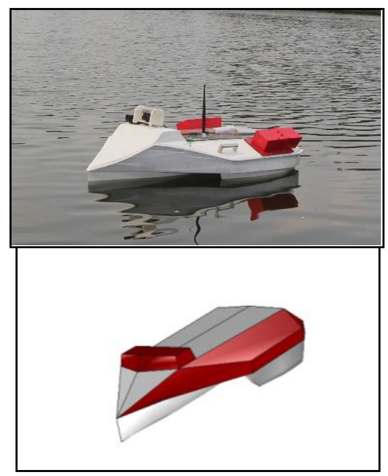


Figure 1. Makara-05 Boat

The trimaran concept is currently being adopted worldwide for the perfection and development of patrol boats and navy vessel. Compared to the mono hull concept, the trimaran concept has many advantages. Less energy used at high speed, greater stability which caused by the side hulls that support the main hull, larger deck area due to the larger beam of the ship, those are the advantages of the trimaran concept compared to the mono hull concept. In Makara-05 ASV, the material used for the ASV is fibre-glass reinforced plastic composite. The decision on using fibre-glass reinforced plastic composite was based on its good strength-to-weight ratio and also it is malleable so it could easily use to produce the ASV body. This ASV was designed using *Bentley Maxsurf 20* application for designing the concept of the ships plan. It was designed up to 10 knots of speed. The Froude number of the ASV was calculated on service speed with the formula :

$$Fn = \frac{v}{\sqrt{gl}} \quad (1)$$

The configuration of the three hulls was placed in such way to produce more efficient drag reduction. The S/L ratio of the ship became the parameter on placing the side hull towards the main hull [1]. Makara-05 has S/L ratio 0.25 which based on our studies shown that trimaran boats have efficient drag reduction when its S/L ratio is 0.25 and its Froude number 0.35. The ASV produced resistant 0.41 kN based on the analysis using *Maxsurf Resistance* software, using the *Wyman Method* [2] at 2 knots speed. In conclusion of the hull specification can be conclude :

Table 1. Hull Specification

Displacement	20,1 Kg
LoA	105 cm
Beam	60 cm
Height	27 cm
Draft	10 cm
S/L	2,5

B. Propulsion

Figure 2. Propulsion System

Makara-05 uses twin screw propulsion with two brushless motor that drives the propeller on each side hulls. The motor that were used are two motors 1000kv on each side hulls. The brushless motors are placed on each side hull to earn the maximal performance and natural cooling system by the water flow beneath the hull. The brushless motor is used to drive three skewed propeller with the diameter of the propeller 5.5cm. A mounting for the motor to place the motor is also designed to the hull and in order to accelerate the water flow a nozzle on the motor's mounting is designed shown on figure 2. The nozzle and the motor's mounting were produced using 3D printer machine with ABS (Acrylonitrile Butadiene Styrene). ABS is an organic polymer use to make plastic that have enough strength and is cheap to produce. The following 3D model is the brushless motor mounting and it's production on the ASV hull:

C. Cooling System

The cooling system that used in the Makara-05 ASV is aim to transfer heat that were produced by the electronic hardware inside of the ASV to outside of the ASV. There are two cooling system that were being used to transfer heat, there are air cooling system and water cooling system. On the air cooling system is used to transfer heat from the electronic hardware inside the ASV to outside of the ASV by using air circulation system. The air circulation in Makara-05 is supported by 3 *mushroom* ventilators with the shape like a square on Figure 3. There are 3 mushroom ventilator, one which is the inlet ventilator located in the center line of the ASV's super structure facing forward align with the air flow from forward to after of the ASV. The other two ventilators which are the outlet ventilator is located on each side of the ASV and it is facing after the ASV.

The other cooling method is using water as the coolant fluid. The natural water cooling system is used to transfer heat that was produced by the brushless motor naturally by the water flow nearby the motor. This is the advantage of placing the motor beneath the hull's draft. Furthermore, the water cooling system is also used to transfer heat from the Electronic Speed Controller (ESC) by streaming the water from the back of the ASV using a tube, then the water flows towards the ESC's heatsink to transfer the heat from the ESC to the water. Afterwards the water that contains the heat from the esc is flown outside of the ASV

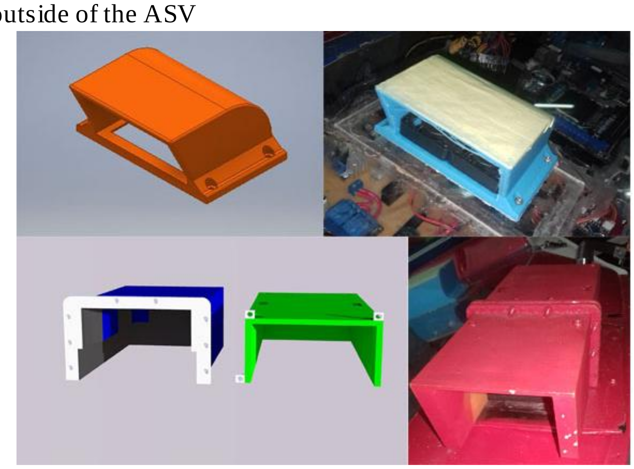
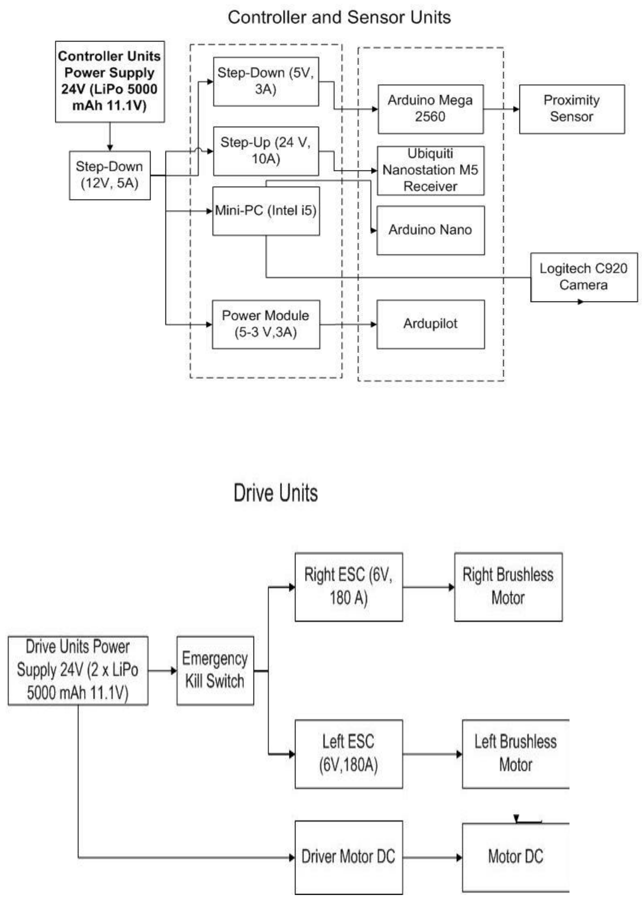


Figure 3. Mushroom Ventilator

III. ELECTRICAL

A. Power Plant



Firgure 4. Power Distribution Diagram

The layout of power distribution system as shown on figure 4 is placed above a board made up of acrylic to minimize exposure to water as well as to ballast the boat achieving acceptable maneuvers, and is mainly designed to provide immediate access with precise amount of power given to each major electrical components and the propulsion system. The main electrical components include mini-pc and the sensor suite while the propulsion system includes Ardupilot, ESCs and actuators.

The operation of the boat is fully enabled by using the student-developed circuit boards and some commercial off-the-shelf technology. The power distribution system utilizes six lithium polymer three-cell batteries with operating voltage of 11.1V each and one lithium polymer two-cells battery with operating voltage of 7.4V. The three-cell batteries has a rating of 5000mAh while the two-cell has a rating of 2400mAh. The power from the batteries is passed through the two different student-developed boards; the motor circuit board and the system circuit board.

The motor circuit board receives 24V of input from the two batteries, 11.1V each, connected in series which is then sent to the ESCs that control the actuators. On the other side, the system circuit board receives four input of 11.1V batteries connected in parallel. The system circuit board supplies power directly to the mini-pc and it consists of a relay which is used to switch on and off the system circuit board immediately, and a step-down transformer that is used to reduce the amount of voltage from the series-parallel circuit to be supplied to the Ardupilot as well as the Arduino.

B. Control System

In order to have all of the mission tasks done properly, the Makara-05 boat must implement a reliable control system. The Makara-05 boat uses a combination of mini-pc, camera, ArduPilot, Arduino Pro Mini, Arduino Mega 2560 Rev3, external GPS+Compass, electronic speed control (ESC) all shown on figure 5, and some off-the-shelf sensors such as proximity sensors, to achieve the favored control system.

Figure 5. Electrical Hardware

Mini-pc is the place where all of the programming of high level language is compiled as well as executed, and it has a full-featured ground station application software called Mission Planner which is used as a configuration utility or as a dynamic control supplement for the boat when put in autonomous mode. Mini-pc stores all of the activities recorded by the camera, either it be pictures or videos, into the computer database that is used for further processing which is the image processing. Processing of images implements mathematical operations by using any form of signal processing for which the input is an image, a series of images, or a video, such as a photograph or video frame, and that the output of image processing may be either an image or a set of characteristics or parameters related to the image. The results of the data of the image processing is then sent to the ArduPilot.

ArduPilot an open source unmanned aerial vehicle (UAV) platform that is able to control autonomous vehicles such as multicopters, fixed-wing aircraft, as well as ground rovers. The ArduPilot acts as the low machine language that is able to control the actuators in correspondence with the output signals of Ardupilot by means of electronic speed controls (ESCs). ESC is an electronic circuit that serves the purpose of an electric motor's speed, its direction and possibly also to act as a dynamic brake. The ArduPilot is tuned by using a PID (proportional-integral-derivative) algorithm which is a technique of a closed-loop control system that try to get the actual result closer to the desired result by adjusting the input in the hope of achieving stability. There are three algorithms in a PID controller consisting of P, I, and D respectively. P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. These controller algorithms are eventually translated into software code lines.

Two well-known microcontrollers; Arduino Pro Mini and Arduino Mega, are used in the system as well. The Arduino Pro Mini is a microcontroller board based on the ATmega328 and it has 14 digital input/output pins in which 6 can be used as PWM outputs, 6 analog inputs, an on-board resonator, a reset button, and holes for mounting pin headers. In this system, Arduino Pro Mini plays an essential role. It is used to process the data transmitted by the remote control which is then used to give low and high signals to the relay of the system, the mini-pc, and the ESCs alone. Moreover, it is also used for rotating the DC motor that carries the autonomous underwater vehicle (AUV) along with its LAN cable for its data transmission between the AUV and the ASV. The Arduino Mega, on the other hand, is implemented in different area. The Arduino Mega is a microcontroller board based on the ATmega1280 that has 54 digital input/output pins in which 14 can be used as PWM outputs, 16 analog inputs, 4 UARTs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It is used in the system for reading the signals of distance sensing and process them.

C. *Wireless Kill Switch*

The Makara-05 boat should be able to be stopped whenever there is an emergency signal with diagram of the signal shown o. The wireless kill switch system is basically a system implemented in the boat so that the boat itself can have an emergency stop by instantly cutting out the power of the main system which consists of Arduiflyer, GPS and Compass, the ESCs and the mini-PC wirelessly from the ground station. This is done by giving power to the 12V relay as well as the 24V relay, but in case of mini-PC, its power is taken out. The ESCs are connected to the 12V relay while the main system is connected to the 24V. However, the mini-PC is not connected to any relays as it gets power from the litihum polymer battery alone. So, when the 12V relay and 24V relay are switched on, the main system and the ESCs are turned off. As for the code, the pulse had previously been measured so that the range could be gain when it is low and high. After the pulse had been determined, the codes are then constructed according to the range that had been specified . The Arduino used is the pro-mini which is connected to Arduino Uno for receiving the power source as well as data transmission. Based on the pulse measured (+/-1000 up to +/-1900), a variable is set to have a value of 1500 so that the on and off state for the relays as well as the mini-PC are appointed. By default on the RC, +/-1000 is set when the position is down while +/-1900 is set when the position is up and the parameter used for all the pulse measured is 9600 baud rate. All of the pins are correctly connected already according to our favor. The RC receiver is connected to the channel pins placed on the pro-mini as the corresponding input pins. On the other side, the output pins on the pro-mini are then connected to each appointed components which are the relays and the mini-PC. Three channels are defined for the process; channel 7 to switch on the 24V relay, channel 6 to switch on the 12V relay, and channel 8 to switch off the mini-PC.

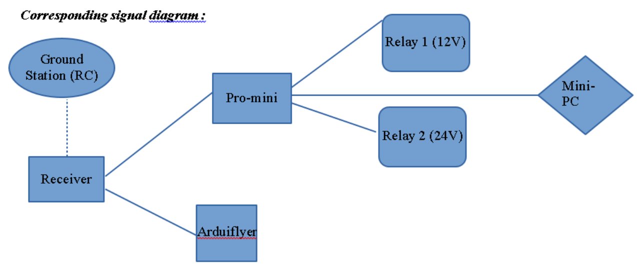


Figure 6. Correspoding Signal Diagram

IV. SYSTEM INTEGRATION

A. *Navigation*

The boat uses GPS Ublox neo m8n module as the data GPS receiver. An ArduPilot also is used to receive waypoint data which uploaded by Mission Planner Software shown on figure 8. The boat's movement is controlled bt ArduPilot that connect to ESC (Electronic Speed Controller). Ardupilot receive the data from Mini-PC and GPS, afterwards ArduPilot will process the data and control the speed and direction of the boat with PID method. PID Method is a conventional and effective method to control boat's speed.

Figure 7. Mission Planner

B. *Image Processing*

• Colour Detection

Makara Roboboat using OpenCV library for image processing, especially for colour detection. OpenCV uses colour threshold for colour detection. Object must have significant colour difference with the background in order OpenCV can detect object's colour.

OpenCV usually capture images and video in 8-bit, unsigned integer, BGR (Blue, Green, Red) format. BGR format then will be converted into HSV (Hue, Saturation, Value) format. Hue represents the colour, saturation represents the amount to which that respective colour is mixed with white, and value represents the amount to which that respective colour is mixed with black. Hue is unique for that spesific color distribution of object. Saturation and value may be varied according to the lighting condition of that environment. Object HSV value will be matched with the colour HSV configuration. If the HSV value matched, then OpenCV will do some noise reduction method. This can be done by applying morphological opening and then morphological closing to the image. After that, program will find object contour with larger area. After that, colour and object will be interpreted.

In order to interpreted the colour detection the step is shown in figure 8

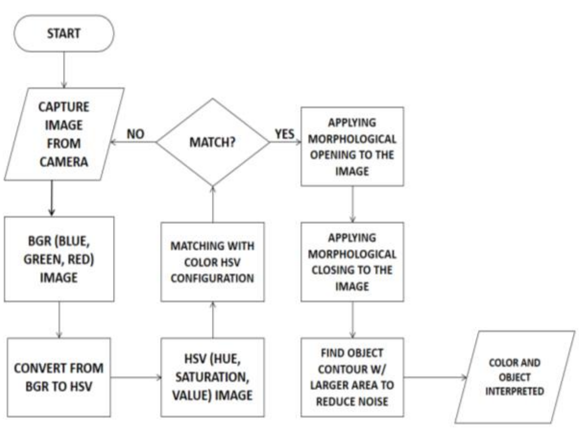


Figure 8. Colour Detection

• Shape detection

Shape detection will be required to support the docking mission. Logitech C920 Camera obtain the visual image and processed by Open CV. Open CV will obtains only the contrast color and change to be black and white image. Canny Feature is required to emphasized some images which taken by the camera. Also, the Find Contour and Is Conyex Features functions as the filter of the visual image. And then, some contours will be available to specified which one is triangle or cross by matching the contours based on side appropriate using approx Poly DP feature. After that, Find Angle Feature is used to ensure that Open CV obtains the image accurately by specifying the contours. The step on how to obtained the image is shown on a diagram on figure 9.

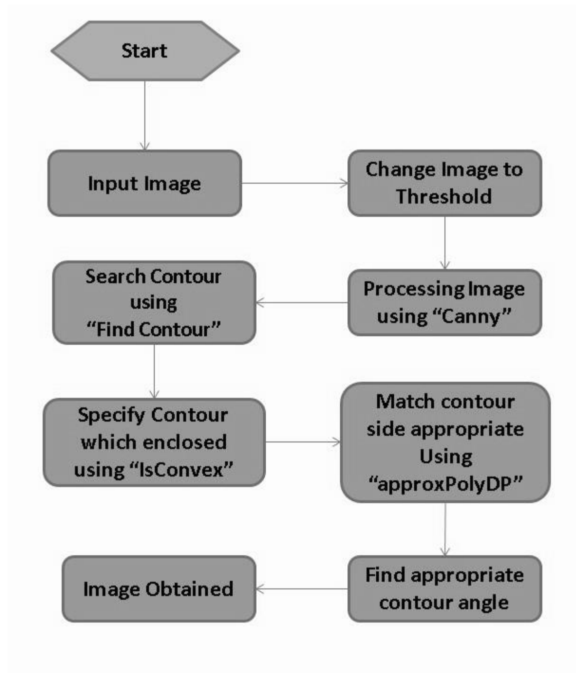


Figure 9. Shape Detection

C. *Communication*

The Makara-05 boat uses an Ethernet based communication backbone for the implementation of its on-board systems communication, control, and health monitoring. The main on-board computer, which is the Intel Core i-5 platform, controls the communications with the judges and the task the boat is executing. To ensure the Makara-05 boat has remarkable external communication that connects with the ground station systems and the judge's network, a NanoStation M5 (NSM5) manufactured by Ubiquiti Networks (UBNT) technology company is used. It is a 5GHz Hi Power 2x2 MIMO AirMax TDMA

Station [3]. It packs some phenomenal performance with a revolutionary design combining a high gain antenna system, advanced radio architecture, and highly researched and developed firmware technology. It has great performance by providing 150+ Mbps real outdoor throughput and up to 15km+ range. Alternatively, the Makara-05 boat can be controlled remotely by using a 2.4GHz commercially available radio control system that allows an independent direct command and control link. This system implements an emergency stop functionality as well as a switch that can change the control of the boat from manual to autonomous and vice versa.

The brain of Makara-05 boat is the intel i5 Processor where all the high level programming languages are processed while all the low level ones are processed in the Ardupilot. One of the software implemented inside the processor is the Robotic operating system (ROS). It is a versatile software that allows easy integration of a wide range of tools including visualization of robot kinematics and sensor data as well as path planning and perception algorithms. Another software utilized is the open source computer vision (OpenCV) which serves as a library of programming functions mainly aimed at real-time computer vision [4]. The high-level programming language used is C. The ground station transmits data to the mini-pc through the Ubiquiti NanoStation M5 that acts as a wifi relay transmitter and the wifi relay receiver on the boat will obtain the data transmitted and sends it to the mini-PC. The mini-pc will then process the data and the result of the processing will be sent to Ardupilot which eventually gives command signals to the two electronic speed controls (ESCs). The ESCs will then rotate the motors in correspondence with the input signals from the Ardupilot. Other hardwares that are connected to the mini-PC include cameras for the image processing and an Arduino Mega 2560 for the data acquisition from the ultrasonic sensors to be sent to the processor. To get an accurate position consisting of longitude and latitude lines of the boat continuously, GPS and compass are used. They are connected to the Ardupilot, and the data transmitted by them are processed by the mini-PC.

Furthermore, by controlling the Makara-05 boat using the 2.4 GHz radio control, the emergency stops can be applied. For instance, when something unexpected happens in the competition, the Makara-05 boat can directly use its emergency kill switch to cut the power connection of the Ardupilot so that the boat is in idle state, and the mini-PC alone can be switched off without affecting the system.

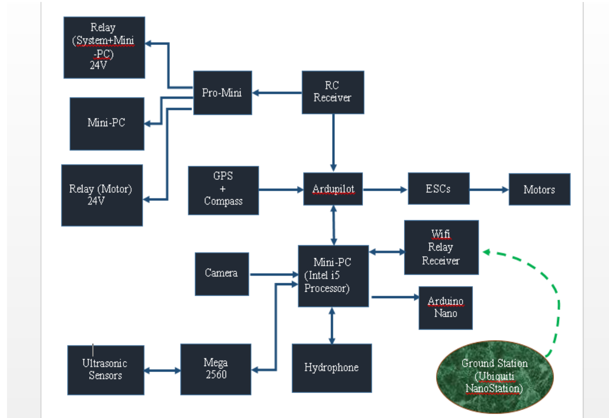


Figure 10. Communication Diagram

V. SOFTWARE ARCHITECTURE

This year, Robot Operating System (ROS) framework as the software on the robot is chosen. Because Robot Operating System (ROS) is open source and supported by many developers. Moreover, the advantages of using this framework is able to integrated with many library such as Open Cv, APM, and Arduino [5]. So, a system to complete the mission sequentialy was designed as shown in Fig 11.

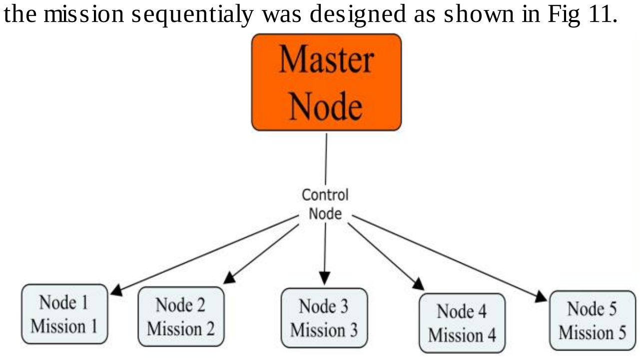


Figure 11. Software Architecture

In completing the autonomous missions, the master node receive a command from a response server. And then, the master node will process the data base on the payload from data response server to decide which node will be run. Master node will control all of node missions. On the first node (node 1) , the image processing program will be run to detect both of the speed gates. After obtaining speed gate data location, the boat will go through the speed gate for completing the mandatory mission. After running the node 1, master node is waiting to receive a command from the response server to run the node 2. Node 2 receive the GPS location data of entrance and exit buoy. In the sequel, the boat will go to the GPS exit buoy's coordinate. In this step, node 2 activates the proximity sensor's program to avoid obstacles. After finishing mission 2, Mini-PC will send http request to response server and receive a command to run node mission 3. Mission 3 is autonomously docking mission which its node will be run by two programs, there are image processing and proximity sensor's programs. The image processing program is aim to detect the shape of the dock. Thereupon completing mission 3, master node will run he node mission 4 that is pinger location. The last mission is interoperability challenges, the boat will stop on the last location and deploy the AUV (Autonomus Underwatre Vehicle). The AUV will detect numbers shown in underwater LCD monitor. After the boat receive a signal that AUV is finishing the mission, the boat will go back autonomously.

The whole program is written in C++ Language. The Mini-PC with Ubuntu 14.04 LTS Linux Operating System is used to process all of high level programming such as image processing and proximity sensing. And ardupilot is aim to process all of low level programming such as controlling the boat's movement and actuator.

VI. AUTONOMOUS UNDERWATER VEHICLE (AUV)

Interoperability challenge is the last of the five mission tasks the ASV ought to do. For this last challenge, a customized student-developed openROV shown on figure 12 will be used

Figure 12. Autonomous Underwater Vehicle

The customized student-developed openROV uses essential off-the-shelf technologies such as an Odroid-U3+ to get the high-level programming language and the image processing of hexadecimals recognition processed, an Ardupilot which acts as the low-level programming language that provides set of commands given to the ESCs, three electronic speed controls (ESCs) which are able to vary all of the electric motor's speed, direction and possibly to act as a dynamic brake, an external GPS+Compass module used for navigation system providing location and time information in all weather conditions along with the orientation that shows direction relative to the geographic cardinal direction, a PS3 eye camera for a real-time image processing, a buck converter to step down the voltage from its supply to its output or load.

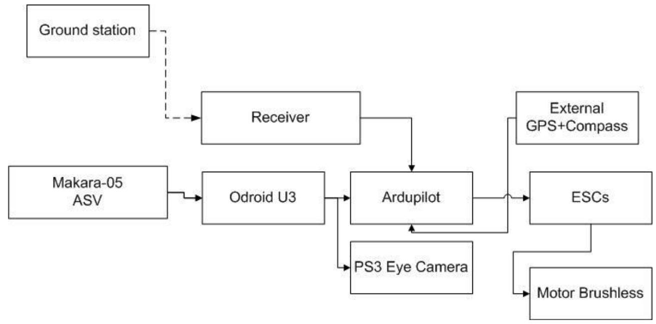


Figure 13. AUV Signal Diagram

Before launching the AUV, the ASV will first use its GPS to navigate to the approximate location of the challenge station by using the camera and the proximity sensors. Once the ASV has pinpointed the approximate location, it will then send a signal to the AUV via the LAN cable to begin its mission of searching and reading the seven segment hexadecimals underwater. The AUV will use its own external GPS as its last point of reference just before being put underwater. Once placed underwater, the AUV will start the image processing to recognize and read the random seven segment hexadecimals, and eventually send the data of the recognized hexadecimals in the form of picture and text to the committee's server. The communication and signal diagram of the AUV is shown on figure 13.

VII. CONCLUSION

Makara-05 is an autonomous surface vehicle with specification of dimension length 105 cm, beam 60 cm, draft 10cm and displacement 20.1 Kg . With the implemented hull design, propulsion and control system proven AMV UI optimist of capable to accomplish the mission in AUVSI Roboboat Competition 2016.

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Competition 2016.

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