Makara 07- Autonomous Surface Vehicle

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Abstract—*Makara-07 is an autonomous surface vehicle design and built by students of Universitas Indonesia to participate in RoboBoat Competition which held by AUVSI Foundation in Daytona Beach, USA 20-25 June 2017. In this journal explains Makara-05's hull design, electrical system, software integration and sensors that were used in Makara-07. Makara-07 is designed to accomplish the mission in AUVSI RoboBoat Competition 2017.*

I. INTRODUCTION

Makara-07 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-07 is the most latest and the most sophisticated design with the design parameter of accomplishing the mission on AUVSI Roboboat Competition 2017. This is the third time for Universitas Indonesia to compete in AUVSI Roboboat Competetion in which AMV UI have participated in 2012 and also 2016.

II. MECHANICAL

A. Hull Design

AMV UI team in designing Makara-07 ASV was inspired by M-80 Stiletto, an ASV built by M Ship Company. The hull concept that is used is the pentamaran concept, the concept of using five hull on the ASV. The decision of using the pentamaran concept was based on past experience of designing and literature study on pentamaran.

Fig. 1 Makara-07 ASV

The pentamaran concept is currently being adopted and researched worldwide for the perfection and development of patrol boats and navy vessel. Compared to the mono hull concept, the pentamaran 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 pentamaran concept compared to the mono hull concept[1]. In Makara-07 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. The configuration of the hulls was placed in such way to produce more efficient drag reduction[2].

Table I HULL SPECIFICATION

Specification		
Length	1.3	m
Beam	0.62	m
Dept	0.348	m
Draft	0.09	m
Displacement	22.8	Kg

B. Propulsion

Fig. 2 Propulsion Makara-07

Makara-07 uses twin screw propulsion with two brushless motor that drives the propeller on each side hulls. The motor that were used are two motors 2200kv on each side hulls. The brushless motors are placed on each side hull to earn the maximal performance .The brushless motor is used to drive two skewed propeller with the diameter of the propeller 5 cm. The propeller are made of brass so it could minimize the chance of crack under pressure compared to the nylon propeller.

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

Fig. 3 Air ventilator Makara-07

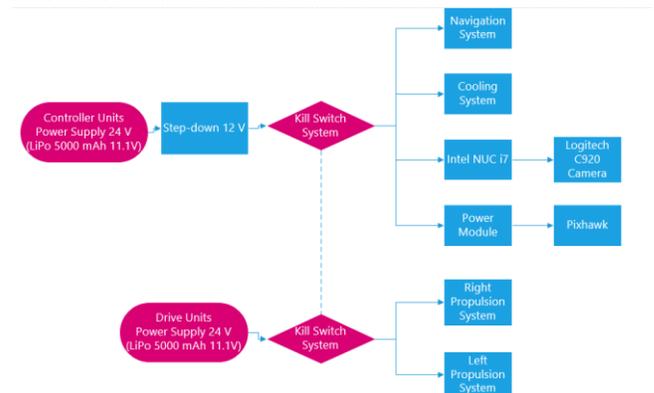## III. ELECTRICAL

A. Power Plant

Fig. 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 Intel NUC and the sensor suite while the propulsion system includes Pixhawk, 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 and has a rating 5000mAh each. 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 which is then sent to the ESCs that control the actuators. On the other side, the system circuit board operating in 11.1V. The system circuit board supplies power to all system components and it consists of a relay which is used to switch on and off the controller circuit and motor circuit board immediately.

B. Control System

In order to have all of the mission tasks done properly, the Makara-07 boat must implement a reliable control system. Its uses a combination of Intel NUC, camera, Pixhawk, Arduino nano, navigation system, and propulsion system, all achieve the favored control system.

Intel NUC 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. Intel NUC 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 Pixhawk.

Pixhawk is an open source flight controller platform that is able to control autonomous vehicles such as multicopters, fixed-wing aircraft, as well as ground rovers. The Pixhawk acts as the low machine language that is able to control the actuators in correspondence with the output signals of Pixhawk 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 Pixhawk 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. Then there is Arduino Nano is used in the system as well. The Arduino Nano 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 onboard resonator, a reset button, and holes for mounting pin headers. In this system, Arduino Nano plays an essential role. It is used to process the data transmitted by the remote control which is give to the relay of the system.

Fig. 5 Control Hardware

C. Wireless Kill Switch

The Makara-07 boat should be able to be stopped whenever there is an emergency signal with diagram of the signal shown 5. 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 controller unit circuit and driver unit circuit. Kill switch system using a PWM signal. The pulse of signal 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. 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 system. 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 microcontroller as the corresponding input pins. On the other side, the output pins are then connected to each appointed components.
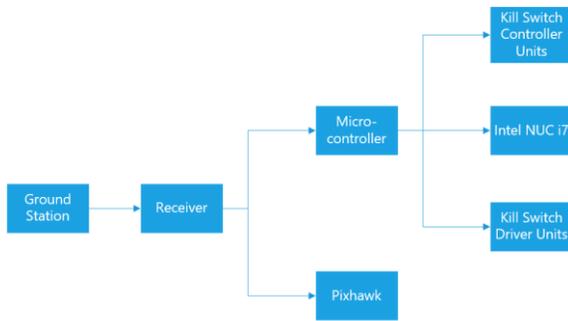
Fig. 6 Wireless Kill Switch System

IV. SYSTEM INTEGRATION

A. Navigation

The boat uses Garmin GPS HVS 17x as the data GPS receiver. Max232 is used to convert RS232 data that produced by Garmin GPS HVS 17x to TTL data protocol. Pixhawk is receiving the TTL data that contains GPS data directly from Max232. An Pixhawk also is used to receive waypoint data which uploaded by source code that developed by our team. Mission Planner as shown on figure 6 is used to validate waypoint that had been uploaded to the Pixhawk. The boat's movement is controlled by Pixhawk that connected to ESC Seaking 180A. Pixhawk receive the data from Intel NUC and GPS, afterwards Pixhawk 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.

Fig. 7 GUI from Mission Planner

B. Image Processing

- *Color Detection*

Makara-07 Roboboat using OpenCV library for image processing, especially for color detection. OpenCV uses color threshold for color detection. Object must have significant color difference with the background in order OpenCV can detect object's color.

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 color, saturation represents the amount to which that respective color is mixed with white, and value represents the amount to which that respective color 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 color 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, color and object will be interpreted.

In order to interpreted the colour detection the step is shown in figure 7.
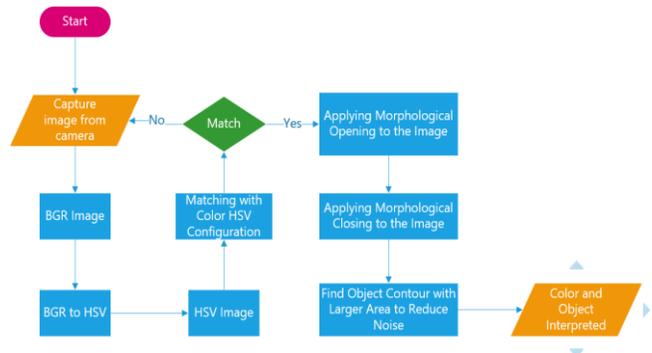

Fig. 8 Color Detection

- *Shape detection*

Shape detection will be required to support the docking mission. Logitech C920 Camera obtain the visual image and processed by OpenCV. OpenCV 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 FindContour and IsConvex 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 approxPolyDP feature. After that, Find Angle feature is used to ensure that OpenCV obtains the image accurately by specifying the contours. The step on how to obtained the image is shown on a diagram on figure 8.
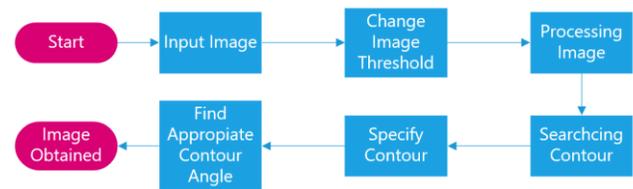

Fig. 9 Shape Detection

C. Communication

The Makara-07 boat uses an Ethernet based communication backbone for the implementation of its onboard systems communication, control, and health monitoring. The main on-board computer, which is the Intel NUC platform, controls the communications with the judges and the task the boat is executing. To ensure the Makara-07 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-07 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-07 boat is the Intel NUC where all the high level programming languages are processed while all the low level ones are processed in the Pixhawk. 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 Intel NUC 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 Intel NUC. The Intel NUC will then process the data and the result of the processing will be sent to Pixhawk 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 Pixhawk. To get an accurate position consisting of longitude and latitude lines of the boat continuously, navigation system are used. They are connected to the Pixhawk, and the data transmitted by them are processed by the Intel NUC.
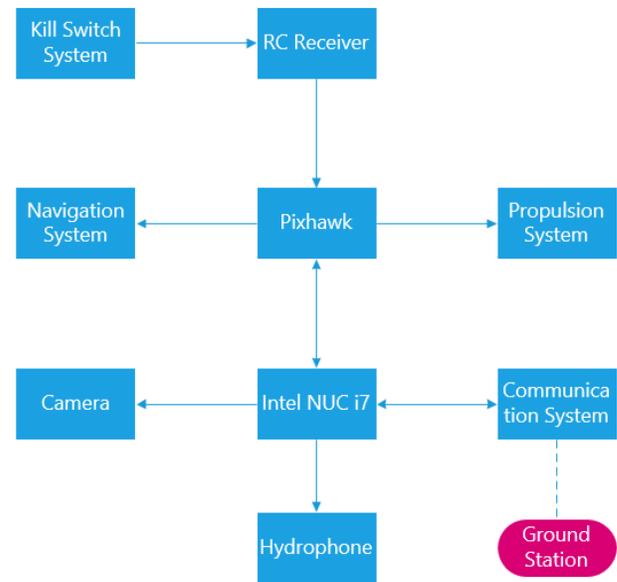

Fig. 10 Communication Diagram

Furthermore, by controlling the Makara-07 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-07 boat can directly use its emergency kill switch to cut the power connection of the Pixhawk so that the boat is in idle state, and the Intel NUC alone can be switched off without affecting the system.

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 OpenCV, Pixhawk, and Arduino [5]. So, a system to complete the mission sequentialy was designed as shown in Fig 10.

In completing the autonomous missions, the master node receive a command from a response server. And then, the master node will process the data based 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 speed challenge arena. In the sequel, the boat will go to the speed challenge arena GPS coordinate. In this step, image processing is used to detect the buoy and the system will build path to circle the buoy and complete the mission. After finishing mission 2, Intel NUC will send http

request to response server and receive a command to run node mission 3. Mission 3 is automated docking mission which its node will be run by two programs, there are image processing and AUAV controller. The image processing program is aim to detect the shape of the dock. After the first dock is reached, AUAV controller program will be triggered to release the AUAV. Then, AUAV will search for the seven-segment shape, take a picture and back to the boat. Thereupon completing mission 3, master node will run he node mission 4 that is find the path. Image processing is used to detect which side of find the path arena is accessible to enter the find the path arena. The last mission is follow the leader. As soon as the boat arrived in the follow the leader arena, AUAV controller program is triggered to activate the AUAV and do the mission.

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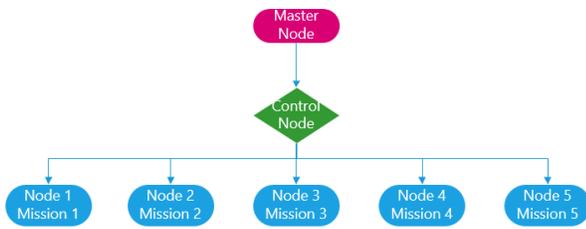

Fig. 11 Software Architecture

VI. AERO MAKARA

Automated Docking Challenge and Follow the Leader is mission that will AUAV to do. For this last challenge, a customized student-developed AUAV shown on figure 11 will be used.

Fig. 11 AUAV

The customized student-developed AUAV uses essential off-the-shelf technologies such as Raspberry Pi 3 to get the high-level programming language and the image processing

of seven-segment recognition processed. Using Navio 2 shield for Raspberry Pi which acts as the low-level programming language that provides set of commands given to the ESCs for vary all of the motor's speed, direction and possibly to act as a dynamic brake, an external GPS antenna 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. Vision delivered by Logitech C920 camera for a real-time image processing.

Before launching the AUAV, 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 AUAV via the 5 GHz wireless network connection to begin its mission of searching and reading the seven-segment hexadecimals on the floating island. The AUAV will use its own external GPS to navigate along the course arena. Once the AUAV begin to flight, it 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 judge's server. The communication and signal diagram of the AUV is shown on figure 12.
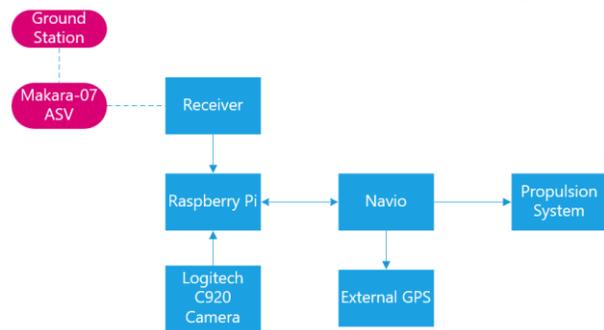

Fig. 12 Aero Makara Signal Diagram

VII. CONCLUSION

Makara-07 is an autonomous surface vehicle with specification of dimension length 135 cm, beam 62 cm, draft 9 cm and displacement 22.8 Kg which is has pentamaran hull design, propulsion and control system proven and along with aero makara AMV UI optimist of capable to accomplish the mission in AUVSI Roboboat Competition 2017.

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