PENSHIP V4 Autonomous Surface Vehicle

Iwan Kurnianto Wibowo[1,a], Ahmad Zurkoni[2,b], Irwan Privasa Baraputra[3,c], Rakhmat Faizal Ajie[4,d], Moch. Ardhy Windhy Saputra[5,e], M Sholahuddin Al-Ayyubi[6,f]

[1-7] Electronic Engineering Polytechnic Institute of Surabaya

Raya ITS, Keputih, Sukolilo, Surabaya, Indonesia.

[a]eone@pens.ac.id

[b]azhurz@ee.student.pens.ac.id, [c]irwanprivasabaraputra@me.student.pens.ac.id, [d]rakhmat17@ce.student.pens.ac.id, [e]windhywinz@it.student.pens.ac.id, [f]ayyubjbr@gmail.com

Abstract

PENSHIP V4 is a fully autonomous surface vehicle built to participate in the 8th Annual International Roboboat Competition 2015. PENSHIP V4 was designed with custom catamaran hull to increase speed and manuever capability. In order to accomplish the missions regulated in the Roboboat 2015, PENSHIP V4 is equipped with an algorithm established in an embedded system based on computer and mini microcontroller hardware. This paper describes the hull design, electrical design, control system, speed optimation and algorithms to completing the challenges presented in the Roboboat Competition 2015.

Key word : PENSHIP, autonomous surface vehicle, Roboboat, catamaran

I. INTRODUCTION

PENSHIP V4 is a smart autonomous surface vehicle designed and built by students at the Electronic Engineering Polytechnic Instutute of Surabaya (EEPIS). This boat is 4th generation of PENSHIP roboboat. First participation is on 2013 ago. PENSHIP is one of the competitors of Roboboat 2015 and this is the second time for PENSHIP to join the competition. Ahead of this competition, in the same kind of contest in national level, PENSHIP had been proclaimed to be the winner. The journey of PENSHIP from the preparation of national to international contest has experienced some changes. This paper explains the changes and improvements that have been made to our last roboboat. The biggest changes is on the design of hull and vision system. This year, PENSHIP releases new hull design and propulsion system. PENSHIP adopts catamaran hull single thruster that designed for drag race with easy manueverability, shown in Figure 1. Electrical design PENSHIP have been improved to increase stability. New electrical design is more efficient.

II. MECHANIC DESIGN

The ship is designed with the shape of multihull or catamaran, as shown in Figure 1, to avoid water stability problem on water surface for both calm and wavy water. Design objectives were increase speed and stability. The design for these hull has been developed only short time. First trial, the boat can travel safely at high speed, stable and easily controlled.

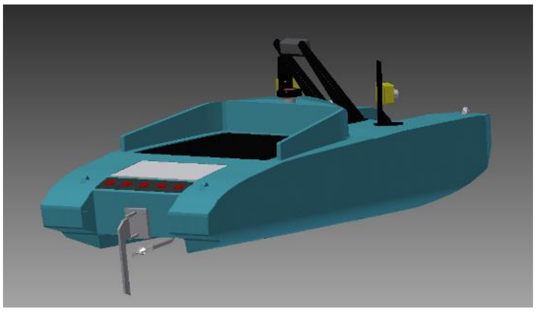

Figure 1. PENSHIP V4

Making process of PENSHIP V4, is 70% use manufacturing process. PENSHIP V4 ships designed with a form multihull, catamarans, to avoid stability problems at the water surface, both the water is calm and the water was choppy. Dimension of PENSHIP V4 is 98 cm x 42 cm x 17 cm made from balsa wood and fiber layers with a hull weight of 3 kg. Balsa wood base material makes it easy to realize the design and have a light weight. The execution of balsa wood cutting is done using a laser cutting, shown in Figure 2. So the material have very high level of precision size. Balsa wood pieces together using glue. Hull was given a color that does not affect the work of the computer vision. The center of grafity of the payload is located in the middle of boat. Height of the boat is optimized by taking into account the size of the ball and the wind are likely to interfere with the movement of the boat. Boat design with a solid frame and size precision heavily influence the movement of the ship. Payload fused with the hull. Payload capacity is up to 10 kg. Payload designed waterproof to protect electronic devices from water damage. Cover and payload frame is made from acrylic material. All acrylic cutting process is done using laser cutting, to avoid gaps or uneven surfaces. Payload functions as a place to accommodate hardware and computer of boat. Menu buttons and LCD mounted above the rear payload to facilitate the user in setting up and tuning the boat.

PENSHIP V4 adopted a single thruster system mounted on the rear of the hull. PENSHIP using KV 2070 brushless motor with a propeller diameter of 4 cm, 2 leaves which used to have the rotation speed of 2070 KV. Speed variation derived from changes in the value of Pulse Width Modulation on microcontroller. A rudder length of 12 cm and a width of 3 cm are used to control the direction of the ship. By adjusting the direction of the rudder to the right or left, then the boat can be turned. Rudder is rotated by the servo mounted in the rear hull.

a. Cutting b. Assembling c. Assembling exterior

Figure 2. Making process of hull PENSHIP V4

The rotation of motor thruster is designed can rotate two direction, clockwise and counter clockwise, allowing the boat to drive in forward and reverse.

III. HARDWARE ARCHITECTURE

New PENSHIP V4 hardware architecture is implemented this year. Hardware architecture design is compact and simple, shown in Figure 3. Power supply is provided by two 11.1 Volt Li-Po batteries, 5000mAh and 1000mAh. 5000mAh Li-Po battery supplies power of brushless motor thruster through electronic emergency switch. 1000mAh Li-Po battery is used to supplies electronic hardware system. Onboard power systems make regulated 5V power sources available.

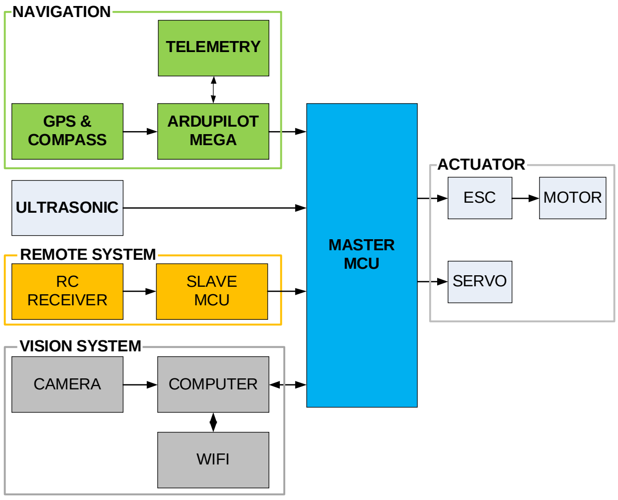

Figure 3. Hardware architecture of PENSHIP V4

A. *Microcontroller System*

PENSHIP V4 electronics system based on AVR Embedded System. It consists of two main parts, namely master and slave microcontroller. With two separated system, the task can be execute paralely. The master microcontroller manage working system of boat. Slave microcontroller function to manage raw data from sensor, such as receiver remote.

An independent direct/manual control link is maintained with the boat at all times using remote control. Remote system receive data/command from transmitter (remote control) to control the movement boat manually. Like a emergency button, this system has the ability to implement emergency stop functionality, to switch between manual control state or autonomous control. Remote control range has been tested up to 500 meter in open area around lake.

B. *Data Communication Platform*

A 10 inch laptop is placed in the middle of the payload. Specifications laptop is Intel Atom dual core 2 GHz and 2 GB RAM. Laptop running the majority of computing tasks on the boat, such as image processing, vision, and communication. Communication between laptop and master microcontroller board is done serially. Laptop send commands to the microcontroller as a result of the decision processing boat navigation.

PC and microcontroller communicate using UART. The data transmitted is shown in figure 4. The Data transmitted from PC is in form of command to move the ship while PC receives sensor data form the microcontroller. It is planted a simple artificial intelligence into the ship that generate decisions where the ship must go or move.

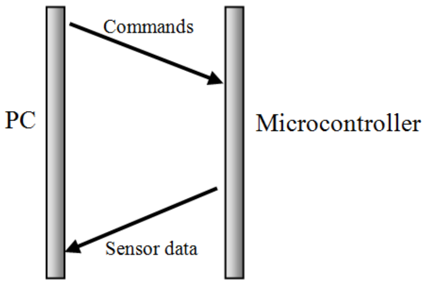

Figure 4. Data communication between PC and microcontroller

C. *Sensor*

To accomplish missions in the Roboboat 2015 competition, PENSHIP V4 is equipped with some additional sensor including digital compass, ultrasonic, GPS, and camera.

- Digital Compass Sensor

Ideally, in robotic navigation that use IMU (Inertial Measurement Unit) sensor in determining orientation and direction, PENSHIP V4 is using compass sensor as to determine the ship orientation because it considers the existence of another additional system that is image processing. With the same price, compass sensor is more powerful in resulting and determining the orientation angle. PENSHIP V4 use CMPS10 digital compass module.

- GPS

GPS provides location and time information in all weather conditions, anywhere on or near the earth where there is an unobstructed line of sight to four or more GPS satellites. This GPS integrated with with HMC5883L compass. It can be mounted away from sources of interference. It features active circuitry for the ceramic patch antenna, rechargeable backup Capacitors for warm starts, and I2C EEPROM for configuration storage. PENSHIP V4 use u-blox LEA-6H GPS & MAG from ArduPilot Mega.

- Ultrasonic Sensor

Ultrasonic sensor is used to detect obstacles in front of the boat or in the side of the boat. Although it is not as effective as when using LIDAR that is relatively much expensive, the result of the detection of ultrasonic is considered sufficient in this application. Ultrasonic sensor is also used to detect gate. PENSHIP V4 use SRF05 ultrasonic.

D. *Actuator*

An actuator is a type of motor that is responsible for moving or controlling a mechanism or system. It is operated by a source of battery energy. Actuator mounted on the PENSHIP V4 boat are brushless motors and servo. Brushless motors are used as the main driver of the boat. Servo motor is used to drive the rudder and the camera. Servo with rod set is a complete self-enclosed steering unit that provides fast rudder movement through midships and maximum torque at the hadvover positions.

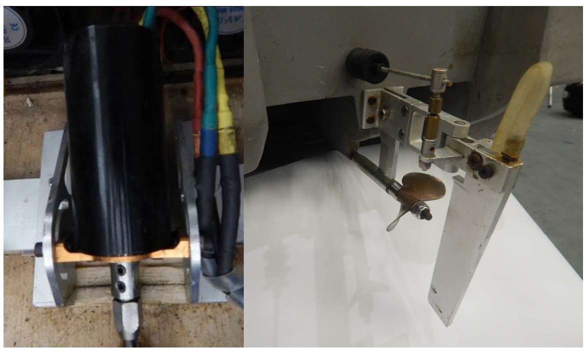

Figure 5. Actuator for steering the boat

IV. SOFTWARE ARCHITECTURE

4.1 SOFTWARE MANAGEMENT

The software configuration of PENSHIP V4 consists of some important part like shown in Figure 6.

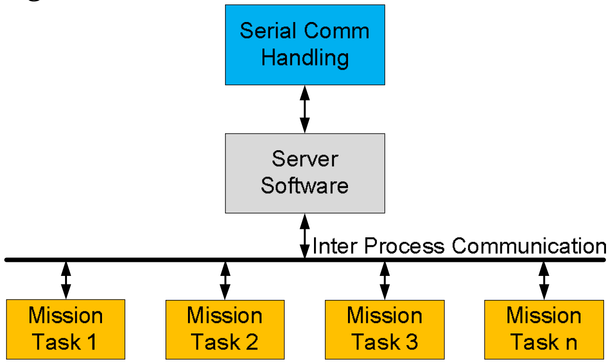

Figure 6. Process of software management for PENSHIP

To make it easy in developing the software in the future, it is designed a software that runs autonomously doing it's jobs specifically. The software exchanges information both data and flag through File Mapping IPC (Inter Process Communication). File Mapping method is used because the method doesn't behave like FIFO does (first in First Out) so that value of the captured variable does not lose. Figure 7 shows one of program debugs of the software configuration result.

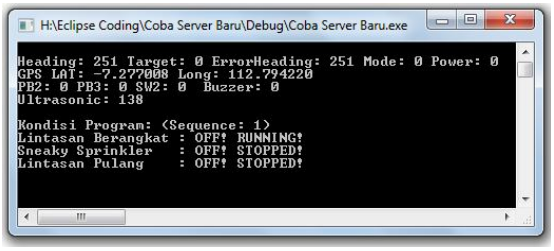

Figure 7. Debug of software management for PENSHIP

A main software, that is a server responsible of the main and basic functions that communicate with microcontroller through serial port and control any software that is permitted to run at the time. Therefore, the software is able to run synchronically and respectively.

4.2 NAVIGATION SYSTEM

Navigation system is very important to control the movement of a boat from one place to another. There are two main navigation in PENSHIP V4, waypoint navigation and heading control system.

WAYPOINT NAVIGATION SYSTEM

Waypoints are sets of coordinates that identify a point in physical space. Coordinates used can vary depending on the application. For terrestrial navigation these coordinates can include longitude and latitude. Waypoints have only become widespread for navigational use by the layman since the development of advanced navigational systems, such as the Global Positioning System (GPS) and certain other types of radio navigation. Waypoint navigation system of PENSHIP V4 use ArduPilot Mega module. ArduPilot Mega supports autopilot system for boat. With ArduPilot GPS Navigation system, it allow boat to reach the desired waypoints. Waypoints can be marked on a computer mapping program or mission planner and uploaded to the ArduPilot Mega board. After waypoint reached, boat will execute a task/challenge.

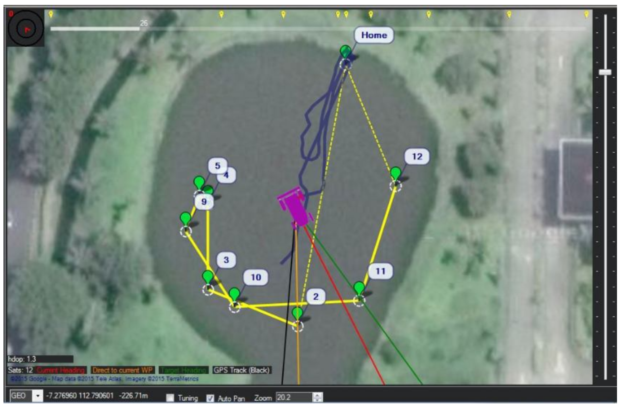

Figure 8. Visualization of PENSHIP V4 waypoint navigation on mission planner monitor

HEADING CONTROL SYSTEM

Heading Control System designed to keep a boat on a pre-determined heading/direction throughout its passage. To eliminate disturbance of current and pulse moment effect in the heading control of boat, need to present an automatic heading controller based on compass feedback. A smart controller was designed to compensate for these problems.

The basic control method used in PENSHIP is conventional PID method. Conventional PID method is able to provide good response in controlling the heading of the boat. The implementation of conventional PID method does not require high computation system[2]. Therefore, it is implementable in hardwares based on embedded system in the PENSHIP. A proportional-derivative controller (PD controller) is a control loop feedback mechanism (controller) widely used in industrial control systems.

A PD controller calculates an error value as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable. The designed controller is effective to eliminate the current disturbance and yaw impulse moment. This system will allow the boat to follow a given heading by giving a feedback from the digital compass. PD Controller design of PENSHIP V4 shown in Figure 9.

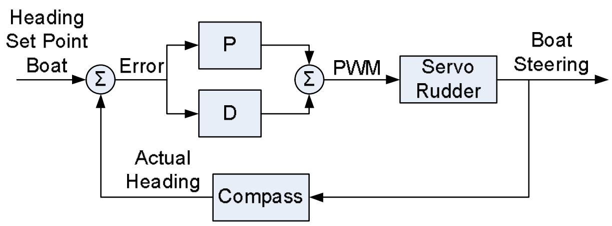

Figure 9. PD Controller design of PENSHIP 2015

PD control system receives input in form of heading set point command from button. Furthermore, the value of the boat heading that is captured from the compass sensor is compared to the set point. Then, the error value will be captured. The rudder will automatically act on the slipstream of the propeller, and create a turning moment on the boat which will turn the boat un the appropriate direction. As the boat turns, the error will reduce and eventually the boat will assume a heading approximately equal to the desired heading at which time the error is zero. Results of testing the boat's response in moving forward with the set point heading 0° is presented in the chart Figure 10. Boat running starts from a position heading -1°. With control of the P and D, rise time required ships to reach set point is 0.9 seconds. The resulting overshoot reaches 5°. Error steady state minimum of -3.0° and a maximum of 1.7°. Attenuation of controller D was considered quite good if visually see the movement of the ship. Controller PID with sampling rate 100Hz adjustment, it is obtained a responsive output toward external disturbance as shown in Figure 10.

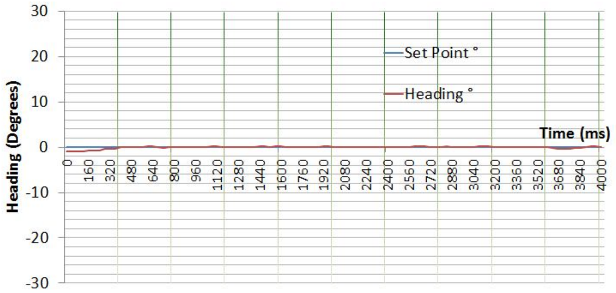

Figure 10. PD Controller design of PENSHIP 2015

V. MANDATORY & MISSION TASKS

There are some missions that became our focus. The missions are navigation test, obstacle avoidance, automatic docking, and return to the dock.

5.1 NAVIGATION TEST

Boat fast running straight ahead with implementing heading control system based on PD controller. PENSHIP has got a simple algorithm to detect gate. Initially, it thresholds the image based on certain range for the needed color segmentation. The kind of color used is Hue, Saturation, and value (HSV) because they are effective to differentiate among colors compared to the other kinds of color[4]. This is because HSV is more sensitive in detecting colors in the camera input which its light intensity changes. The result is object in green and red depending on the threshold range. The output is stored in the matric which is then changed into contour and measured the height and the width using aproxypoly. Only objects with more height and more width that are considered as gate. The other objects are only considered as noise and will not be processed.

5.2 OBSTACLE AVOIDANCE

To detect balls/buoy, the algorithm used is almost the same as the algorithm to detect gate. The difference is on the object. Object with certain diameter will be considered as buoy, while the other object will be considered as noise and will not be processed. A yellow or black buoy marks each obstacle. PENSHIP V4 also use sonar sensor (ultrasonic) to avoid the obstacle. Camera is assisted by the ultrasonic sensors determine the distance of the ship with the ball to be safe to avoid the ball.

5.3 AUTOMATIC DOCKING

To go to the front of the dock where the symbol is located, the boat using a navigation system with the help ardupilot integrated with GPS and compass. PENSHIP V4 use the OpenCV function Canny to implement the Canny Edge Detector to recognize symbol in automatic docking mission. Also known to many as the optimal detector, Canny algorithm aims to satisfy three main criteria:

- Low error rate: Meaning a good detection of only existent edges.
- Good localization: The distance between edge pixels detected and real edge pixels have to be minimized.
- Minimal response: Only one detector response per edge.

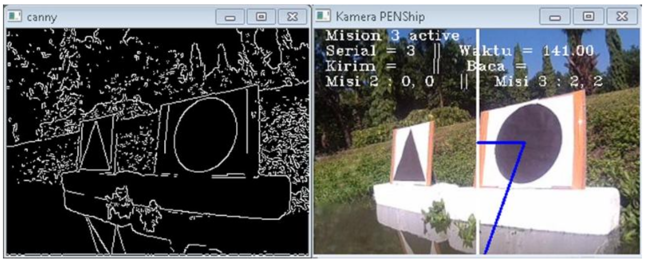

Figure 11. Symbol recognition using canny edge detector

To satisfy these requirements Canny used the calculus of variations – a technique which finds the function which optimizes a given functional. The optimal function in Canny's detector is described by the sum of four exponential terms, but it can be approximated by the first derivative of a Gaussian.

Among the edge detection methods developed so far, canny edge detection algorithm is one of the most strictly defined methods that provides good and reliable detection. Owing to its optimality to meet with the three criteria for edge detection and the simplicity of process for implementation, it becomes one of the most popular algorithms for edge detection.

Figure 12. PENSHIP 2015 completes symbol recognition in automatic docking mission.

5.5 RETURN TO THE DOCK

Boat can return to the dock using the autopilot system that has been built. The accuracy to reach the dock is 3 meters. ArduPilot Mega set when it has completed the final mission, then returned to the dock using GPS information.

VI. DISCUSSION

This year, we began with a goal to design a that can accomplish the Roboboat 2015 mission. We try to find the best hull and vision system. Difficulties encountered is how the boat is able to adapt to changing outdor light. Image processing parameter settings should always be changed according to changes in outdor light.

VII. ACKNOWLEDGEMENTS

Thanks to EEPIS and Garuda Indonesia for the funding support to conduct this research and the departure to Virginia and also to the manager of Graha Sepuluh November for lending the lake for about six months.

VIII. REFERENCE

[1] Y. Ronald, W.Hui,"Multihull and Surface-Effect Ship Configuration Design : A Framework for Powering Minimization", Journal of Offshore Mechanics and Arctic Engineering, 2008, vol. 130.

[2] Ogata, Katsuhiko. Modern Control Engineering Third Edition. New Jersey : Prentice Hall, Upper Saddle River. 1997.

[3] Ogata, Katsuhiko. 1991.Teknik Kontrol Automatik – translation: Ir. Edi Laksono, Jakarta:Erlangga

[4] Gary Bradski dan Kaebler Adrian "Learning OpenCV", 2008.

[5] J. Danielson, " Conceptual Design of a High-Speed Superyacht Tender: Hull Form Analysis and Structural Optimization", Independent Thesis Advance on Naval System, Sweden, 2012.

[6] N. R. Hesher Etal, “Catamaran Boat Hull Contruction”, United States Number 3.067.711, Dec, 1962.

[7] R. J. Perette, “High Speed Catamaran Hull and Boat, United States Patent Number 5.458.078, Oct, 1995.

[8] Y. Ronald, W.Hui,”Multihull and Surface-Effect Ship Configuration Design : A Framework for Powering Minimization”, Journal of Offshore Mechanics and Arctic Engineering, 2008, vol. 130.

[9] Kaess, Michael et al., “Towards Autonomous Ship Hull Inspection using the Bluefin HAUV”, in Proceedings, of the 9th International Symposium on Technology and the mine Problem series: Unmanned System, Technologies, Concepts, and Application, May 2010.

[10] T. Statheros, G. Howells, and Klaus McDonald Maier, “ Autonomous Ship Collision Avoidance Navigation Concepts, Technologies and Techniques”, Journal of Navigation Vol. 61 Issue 01, Jan 2008 pp 129 – 142.

[11] X. Hong, C.J. Harris, P.A. Wilson, “Autonomous Ship Collision Free Trajectory Navigation and Control Algorithms.”, Proceeding 7th IEEE International Conference on Emerging Technologies and Factory Automation,Barcelona, oct 1999.

[12] Ogata, Katsuhiko. Modern Control Engineering Third Edition. New Jersey : Prentice Hall, Upper Saddle River. 1997.

[13] Ogata, Katsuhiko. 1991.Teknik Kontrol Automatik – translation: Ir. Edi Laksono, Jakarta:Erlangga