A Design of Radio-controlled Submarine Modification for River Water Quality Monitoring

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***Abstract*—In Indonesia, river water plays important roles in human life; for example, for transportation and economic activities of the inhabitants. However, industrial, agricultural and domestic water is discarded into rivers directly in many developing countries, since drainage systems have not been completely constructed. Water quality monitoring using radio-controlled submarine provide an opportunity to develop baseline monitoring system for river water ecosystem health indicator. We propose a design modification of radio-controlled submarine for river water quality monitoring. Our design consists of modification for navigation system by added external motor, IMU and GPS; modification of processing and control system by added micro controllers and mini pc, and modification of water sensors system.**

Keywords—Modification of radio-controlled submarine, river water quality monitoring, Internet of Underwater Things

I. Introduction

River water has been used as drinking water and irrigation water for agriculture and for fish culture throughout the history of mandkind. However, water pollution has become one of the most serous problems in many countries especially in developing countries like Indonesia. In Indonesia, the river also play important roles in transport and economic activities. Therefor, studies of water quality monitoring are important [1].

Advancement of real-time remote monitoring (RTRM) and sensing technologies will become a progressively more important tool for evaluating water quality [2]. Recent engineering and deployment of RTRM technologies by federal and state regulatory agencies, industries, and academic laboratories is now permitting rapid detection of, and responses to, environmental threats imposed by increased nutrient loadings, development of hypoxic and anoxic areas, toxicants, and harmful algal bloom outbreaks leading to fish kill events and potential human health impacts. The under water mapping and analysing the natural conditions has been done by human. Because of the limitations of human body to reach the deep place, unmanned robot will be useful to facilitation a human research. So remotely Operated Vehicle (ROV) will be use in the research for observation the river, sea and the other. In this paper we designed a modification of small ROV for river water quality monitoring.

Research on monitoring water quality in Indonesia has been done until now. Syahreza, etc. studied about feasibility for mapping and monitoring the surface water in the coastal area of Aceh by using Landsat TM satellite data after the disaster of tsunami hit on 2004 [3]. The study tried to monitor small (40-200m width) and medium-sized (200-800m width) rivers and lakes using satellite altimetry through identification and choice of the over-water radar waveforms corresponding to the appropriately waveform-tracked water level. From two references study it can be conclude that, until now mapping and monitoring water quality in Indonesia is using satellite. So there is no research that using Remotely Operated Vehicle (ROV) to mapping and monitoring water quality in Indonesia. Satellite has a problem when monitoring water quality in the small water bodies (small-size rivers as narrow as 80m). Because of that, here we present the modification of Thunder Tiger Neptune SB-1 that can be use for monitoring water quality on the river in Indonesia.

Internet of Underwater Things [4] gave us and idea to make our own device that can perform water monitoring. We combined ROV from market with sensors to help us to monitor water quality.

The rest of this paper is organized as follows: Section II reviews about our design of radio-controlled submarine and modification systems. Section III presents its implementation of our design. Section IV shows evaluation results. Section V concludes this paper with some future works.

II. System Overview

In this section, we describe system overview of radio-controlled submarine and modification systems.

A. *Thunder Tiger Neptune SB-1*

The NEPTUNE SB-1 submarine [5] is the R/C model by Thunder Tiger as shown in Fig. 1. Equipped with high technology operating equipment in the inner hul tub, the system is driven by a ballast tank with pump and motor unit. The submarine can dive from the surface and stay underwater in static and also using propulsion power unit and full elevator and rubber control. Its dimensions are 774mm x 285 mm x 290mm with 7.7kg weight in the surface and 7.95kg when submerged.

We added payload under the Neptune SB-1. We added several devices inside of the payload such as Processing and Controller board to handle navigation, position and also data from sensors.

Fig. 1: Neptune SB-1 from Thunder Tiger.

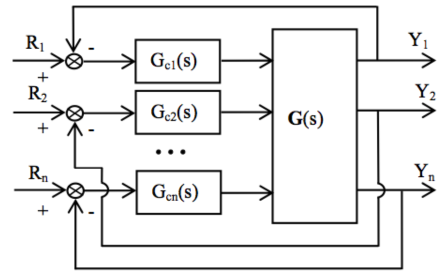


Fig. 4: Multi-loop control system.

B. Navigation System

The movement of Neptune SB-1 are based on X, Y and Z axis. The movement capability of Neptune SB-1 can be shown in Fig. 2.

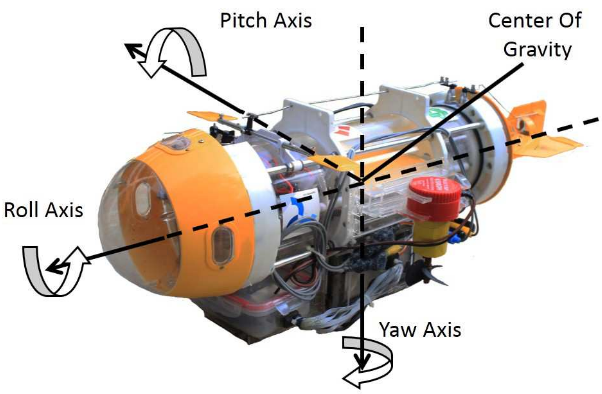


Fig. 2: The movement of ROV based on X, Y, and Z axis.

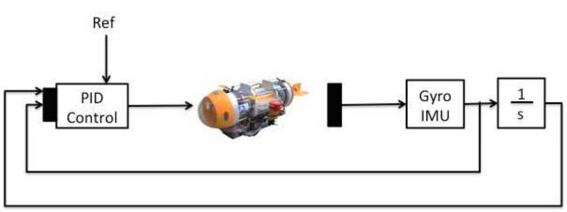


Fig. 3: The block diagram of the ROV navigation system.

Fig. 3 describes about the block diagram of the ROV navigation system. To control the navigation system of our ROV, we used a closed-loop system. in this closed-loop system, it can give a feedback as gyroscope data sensor inside of IMU. Navigation system provides controlling X, Y, and Z axis. In X axis (roll axis), system provides actuator on left and right bilge pump motor. Second is Y axis (pitch axis), system provides servo motor to handle the fin of ROV. and the third is Z axis (yaw axis), system provides actuator as servo motor to control rudder of ROV. On those axises, we used MIMO-PID (Multiple Input Multiple Output - Proportional, Integral and Derivative) system to control navigation system [6].

Implementation of MIMO-PID system has large multiple time delays which is one of main causes for the strong dynamic interactions. To simplify design method we uses multi-loop PI/PID [7]. Consider a general transfer function matrix for multi-delays MIMO processes can be represented as following matrix:

$$G(s) = \begin{bmatrix} g_{11}(s) & g_{11}(s) & \dots & g_{1n}(s) \\ g_{21}(s) & g_{22}(s) & \dots & g_{2n}(s) \\ \vdots & \vdots & \ddots & \vdots \\ g_{3n}(s) & g_{2n}(s) & \dots & g_{nn}(s) \end{bmatrix} \tag{1}$$

From a standard block diagram of multi-loop feedback control shown in Fig. 4, the closed-loop transfer function matrix can be written as

$$\mathbf{H}(s) = \mathbf{G}(s)\tilde{\mathbf{G}}_c(s)(\mathbf{I} + \mathbf{G}(s)\tilde{\mathbf{G}}_c(s))^{-1} \tag{2}$$

Consider a transfer function $\tilde{\mathbf{H}}(s)$ of a diagonal structure for set point closed-loop response. A multi-loop feedback controller can be obtain from rearranging (2) as follows:

$$\tilde{\mathbf{G}}_c(s) = diag\{\mathbf{G}^{-1}(s)\tilde{\mathbf{H}}(s)[\mathbf{I} - \tilde{\mathbf{H}}(s)]^{-1}\} \tag{3}$$

Controller by (3) provides a closed-loop response. From simplification from [7], the multi-loop controller of the *i*th loop can be rewritten by

$$g_{ci}(s) = \Lambda_{ii}(s) g_{ii}^{-1}(s) \left(\frac{e^{-\theta_{ii}s} \prod_{k=1}^{q_i} \frac{z_k - s}{z_k^* + s}}{(\lambda_i s + 1)^{r_i} - e^{-\theta_{ii}s} \prod_{k=1}^{q_i} \frac{z_k - s}{z_k^* + s}} \right) \tag{4}$$

C. Processing and Control System

As processing and control system, our ROV used 2 micro controllers and a mini computer. 2 micro controllers are divided into master and slave. For master, we use Arm F4 micro controller and for slave we use Atmega 328. Raspberry PI B+ used as mini computer in this system.

Master microcontroller handle data from water sensors system, IMU data and also position from GPS, and controlling motors and servos.

Slave microcontroller handle data from radio receiver for remote control. From slave microcontroller connected to master microcontroller, it mean that from remote can control the movement of ROV by controlling motors and servos.

Mini computer use as data storage to keep data from sensors, IMU and also GPS. Its used for data logger and tracking.

The big picture about processing and control system can be see in Fig. 5.

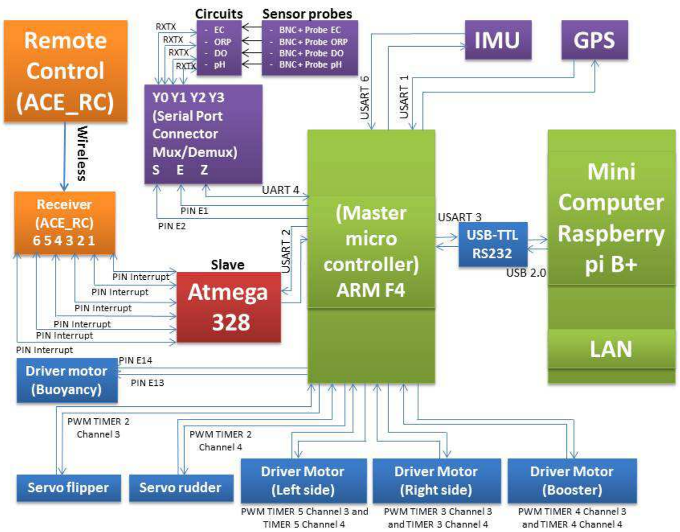


Fig. 5: The processing and control system.

D. Water Sensors System

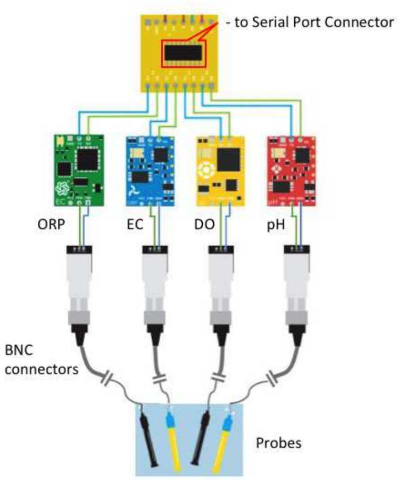


Fig. 6: The water sensors system.

Fig 6 shows about water sensors system that we added into our ROV. We use ENV-SDS full water monitoring kit from Atlas Scientific [8]. Its provides pH, OPR, D.O., and conductivity sensors, and also temperature measurement tool. All these kit connected to multiplexer and transfered into serial data.

III. Implementation

There are three main modifications for our ROV, the first modification is mechanical and sensors parts, second part is payload and the last part is software. In this section, we explain briefly about all modifications.

The size of our modified ROV can be see in Fig. 7 and Fig. 8.

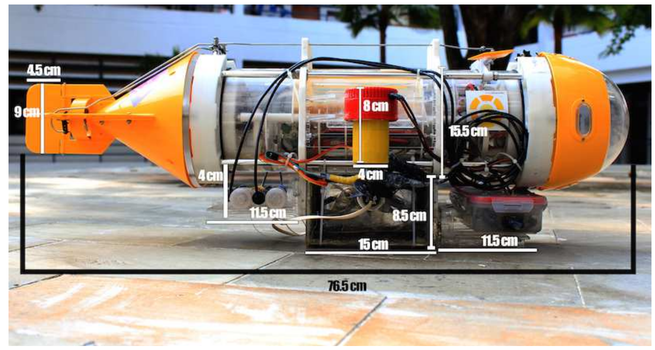


Fig. 7: The size information from side view.

Fig. 8: The size information from top view.

A. Mechanical and Sensors Modification

To increase performance of ROV, we added 2 vertical bilge pumps on the side of ROV. We use rule pump 12 Volt DC automatic bilge pump 500GPH - 2000GPH [9]. Those bilge pumps connected to the motor driver that can be controlled from master micro controller ARM F4. We built the hangers for those bilge pumps from acrylic, we make it permanent to the body of ROV. Fig. 9 shows the connection between motor and payload.

For navigation system, we added SKM53 GPS module and ArduIMU v3 sensors. SKM53 GPS module starter kit (SKGPS-53) [10] is GPS based on MediaTek 3329 SoC include with smart antenna module and high sensitivity. ArduIMU v3 [11] features the new MPU-6000, that includes

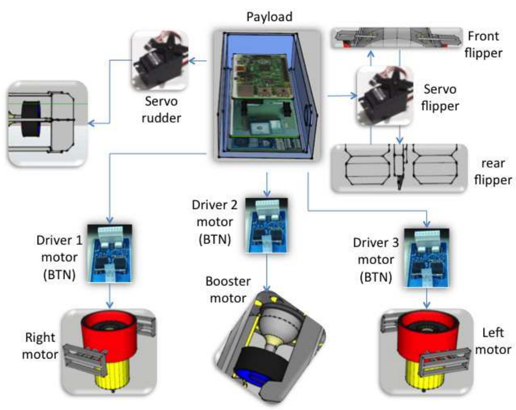


Fig. 9: The connection between bilge motor and payload.

3 axis gyros and accelerates built-in, its process everything internally and uses SPI for max performance.

GPS, IMU and motor driver for bilge pump is located inside of the payload. Fig. 10 shows about the location of external bilge motors and payload.

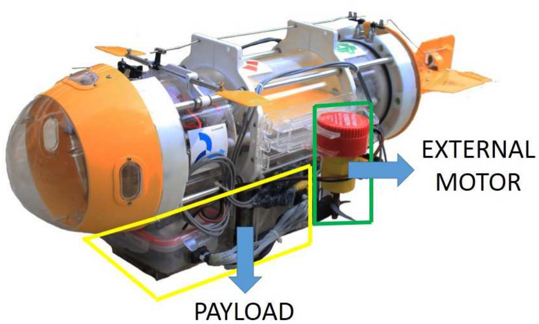


Fig. 10: The location of external bilge motor and payload.

B. Payload

Payload shown in Fig. 11 is located under the ROV. There are three main parts of payload, first is the main box, second is cable box and probes.

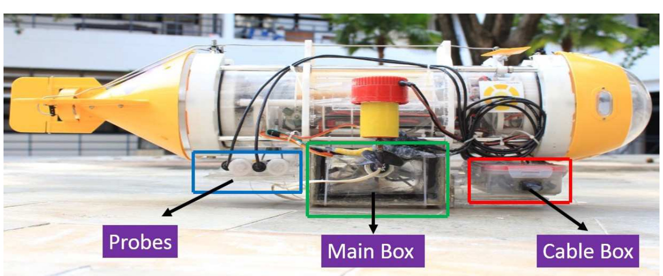


Fig. 11: Payload.

Inside of the main box, we divided into 3 layers. The bottom layer or fist layer is for micro controller and motor drivers. The middle layer, we put water sensors, ArduIMU and SKM53 GPS. The top or third layer is for Raspberry PI. Fig. 12 shows layering inside main box of payload.

C. Software

Software to operate the ROV located on slave micro controller, master micro controller and Raspberry PI.

On slave micro controller, software has an ability to receive digital data from RC transceiver and forward the data into master micro controller. Master micro controller need to translate the data into command controlling motors and servos, and also master micro controller read the data from sensors including GPS, IMU, and water sensors. After reading the data from sensors, master micro controller compiled all the data and transfer it into Raspberry PI. The format of data that transfered into Raspberry PI is: $,LAT,LONG,ROLL,PICH,YAW,CE,ORP,DO,PH#.

On Raspberry PI, the software features are receive data from master micro controller, processing the data, and show the result on a webpage that build-in into raspbian OS and webserver.

IV. Experiment

In this section, we show experiments results for our ROV.

A. River Test

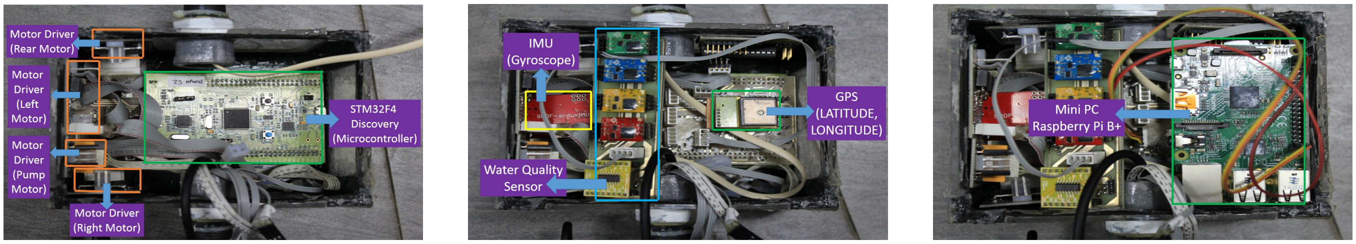
We tested our ROV on river next to our campus, we tried to move our ROV by remote control and ROV can moved flawlessly like the command that we sent from remote control. Fig. 13 shows our ROV on the river. Fig. 14, 15, and 16 describes about stability analysis for movement which is comparing between the reference (command) signal and the system response for pitch, roll and yaw.

Fig. 13: River test.

B. Collecting Data

When ROV move on the river, the probes on payload collect the informations from environment. ROV move along the river from coordinate (-7,277153, 112,7907333) to (-7.27648368, 112.7911453) and took various data from water sensors. The example of data can be see in Table I.

The movement of ROV from GPS tracking is shown in Fig. 17.



(a) Layer 1 (b) Layer 2 (c) Layer 3

Fig. 12: Inside of payload - main box.

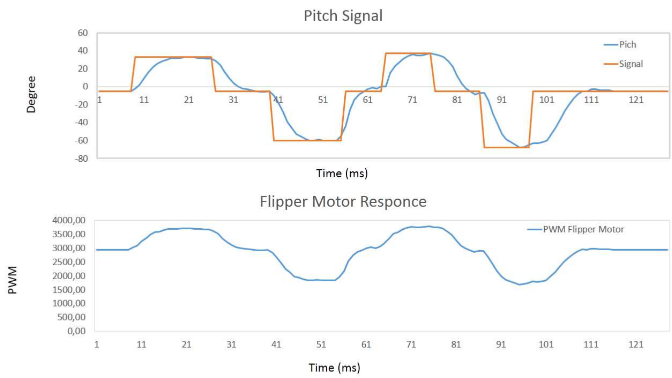


Fig. 14: Signal and response for pitch test.

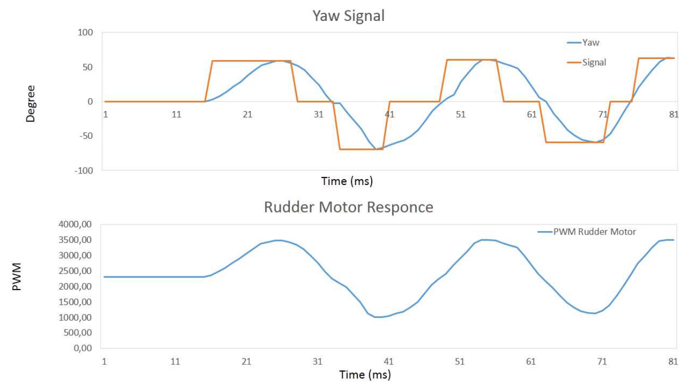


Fig. 16: Signal and response for yaw test.

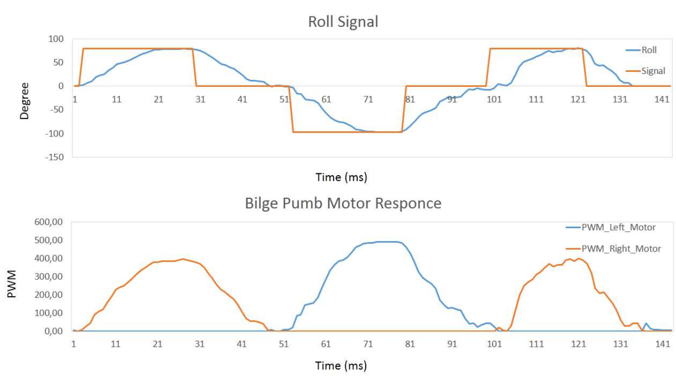


Fig. 15: Signal and response for roll test.

V. Conclusion

This paper presented a first phase of a design of radio-controlled submarine modification for river water monitoring implemented on Neptune SB-1 with modification of navigation system including IMU, GPS and external bilge motor, modification of micro controller and mini pc as processing and control system and also implementation of water sensors system. The experiment results show that our ROV worked and able to move stably in river to collect information from water quality sensors. Our future works include the further improvement of sonar device and application to build 3d reconstruction of river and analysis of water pollution level.

TABLE I: Result.

Time	EC	ORP	DO	pH	Lat	Long
0:00:00	828.10	-100.9	4.83	7.269	-7.2771530	112.7907333
0:00:01	828,10	-100.9	4.98	7.269	-7.2771530	112.7907333
0:00:02	828.10	-100.9	4.84	7.13	-7.2771530	112.7907333
					...	...
0:10:45	639.30	-119.5	4.51	7.021	-7.27648368	112.7911453

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Fig. 17: GPS tracking result test.

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