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Remotely Operated Unmanned Underwater Vehicle for Inspection

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Abstract: Nowadays, in technology, humans use machines, mobile devices and robots to make the work easier, effective and faster. However, in Malaysia, there is still a lack of underwater vehicles used for inspection or investigation on the seafloor. The aim of this project is to develop the Remotely Operated Unmanned Underwater Vehicle for underwater Inspection (ROU-VUI) which has a compact size and low cost. This mobile device will act as a pre-screening for detecting underwater problems and for explorations where high-resolution cameras are used for real-time monitoring and recording the video for further analysis. The controller used is Arduino microcontroller and MDSS10A smart drive motor to control the movement of the mobile. The graphical user interface (GUI) LabVIEW is designed to make the inspection and monitoring process easier when it is in the water. An operator will observe the underwater vehicle via a camera that links to the smart phone and graphical user interface.

Index Terms: Underwater Vehicle; ROU-VUI; Embedded microcontroller MDSS10A; Graphical User Interface

I. INTRODUCTION

Over the years, robots have been presented in various area including in rehabilitation field [1-6], salvage operation [7, 8] and manufacturing [9]. Automation and robots are now gaining acceptance across the industry, especially in mass production environments. Through the fourth industrial revolution, there is now a growing request for a method that able to run and incorporate the different machines and robots regardless of their function, physical size, shape and specifications.

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Machine Learning, which is gaining enormous interest from various research and operational audiences are still lacking in terms of its contribution to the advancement of Robotics. Recent robotics development however has shown efforts to embed ML algorithms [10-15], to introduce more intelligent features.

The design of a novel, intelligent system that allows a single point of control will undoubtedly increase the various robots' productivity, while at the same time reducing cost and electronic waste in the long run.

A Remotely Operated Underwater Vehicles, also known as ROVs are underwater robotic devices that operate remotely to carry out tasks in sea floor. There are few ideas from the past leads to creation of submarine. This Development of Remotely Operated Unmanned Vehicle Prototype for Underwater Inspection also known as (ROU-VUI) is a version of a submarine equipment that operated on small scale, low cost and remotely controlled. Basic ROVs component consist of controller, monitor and submersible [16]. After than ten years they were initiated, ROV became notable as many new offshore expansions surpassed the reach of human divers [17]. Furthermore, the ROV can overtake the diver risky task in the deep sea. By using ROVs, marine operations such as salvage, observe, inspect and explore can be done quickly and efficiently over manual operations conducted by human divers [18]. There are various purposes of ROV including searching hydrothermal vent [19], plotting archaeological locations [20], installing underwater infrastructure such as cabling and piping [21] and ecological research [22].

ROVs type and sensor configuration were developed based on their function and mission-related task to be completed [16]. ROV size were classified into four broad categories; the first category is for observation class ROVs (OCROV). These ROV generally smaller (less than 100kg), limited depth less than 1000 ft, DC-powered and inexpensive electrical vehicles. It also known as low-cost ROVs and most of the applications such as applications for academic learning, fisheries and aquaculture, homeland security and public safety are used this type of ROV as they do not have to work hard and require minimal intervention. The second category is the mid-sized ROVs (MSROV). These ROVs were categorized as middle size with weight range from 100 kg to 1000kg, a depth rating more than 3000ft and can be AC and DC power. It also known as "light work class" vehicles. The O&G drill support industry normally used this type of ROVs. The third category is the work class ROVs (WCROV).

They are heavy electromechanical vehicles, high –voltage AC, depth rating more than 10,000 ft and use mechanical power (hydraulic) for locomotion. Due to the added of hydraulic manipulator in the WCROV, it can perform heavy task in the marine subsea industry such as moving heavy pieces, laying burying cable and pipelines and setting mattresses. And the last category is the special-use vehicles. These vehicles are different from ROV categories due to it incapability to swim.

Example of the vehicles fall in these categories are crawling underwater vehicles and towed vehicles.

In this study, the ROVs for monitoring and inspection process has been developed. It has advantages over users who want to conduct underwater surveillance, monitoring and inspection. Additionally, it also has a compact and light design and size. On the other hand, this research study could solves the problem of conventional ROVs used in the deep sea (oil and gas) due to its large size for inspection and exploration but unable to be used in small scale underwater such as rivers, lakes or tanks. Besides that, this device will cut the needs of human power and increasing productivity during underwater inspection activity.

II. METHODOLOGY

The project is separated into three elements. The first element is the mechanical structures, followed by the development of hardware and control systems. All elements will be explained then experiments will be performed to determine the validity of proposed control method.

A. Mechanical Design

When designing the ROU-VUI, it is needed to use light weight parts such as PVC, aluminums and other lightweight materials. The material used will be able to maintain the floatability of the ROU-VUI and it will be necessary to set the specific gravity desired on the ROV. Fig.1 shows the 3D design of ROU-VUI and Fig.2 shows the parts used in ROU-VUI.

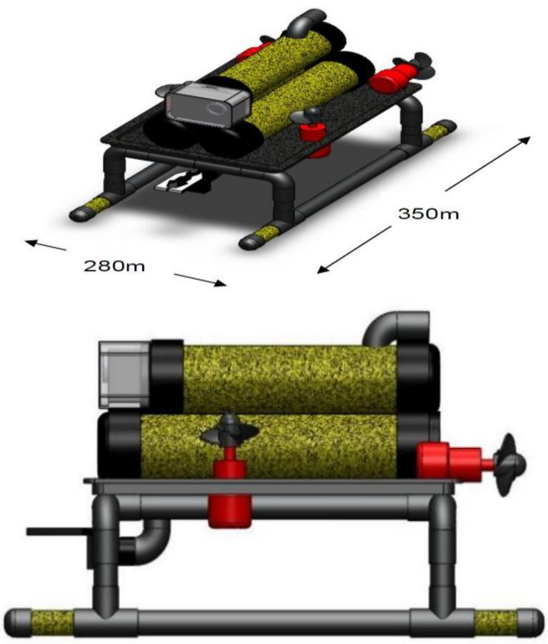

Fig. 1 3D design of ROU-VUI

Fig. 2 Remotely Operated Unmanned Vehicle for Underwater Inspection (ROU-VUI)

B. Hardware Development

ROV-VUI are divided into several components that are required to be constructed electronically and mechanically. In this section, all the components required for this project are mentioned and described. The ROU-VUI block diagram is shown in Fig. 3 and Fig. 4 shows the circuit diagram. The control box containing the microcontroller which is Arduino Mega 2560 and two SmartDriveDuo - 10 that using lipo battery 11.1 V 2200 mAh for each board. The Arduino is connecting to the computer USB port to receive the data from graphical user interface. Then it will transmit the data to the driver and components.

1. *Microcontroller*: Arduino Mega 2560 is a microcontroller board based that acts as main controller for control all motors. It has 54 digital i/o and 16 analog pins. Arduino Mega 2560 has many digital inputs and PWM output to control 5 motor by connect with driver motor compare the Arduino Uno.
2. *Motor driver*: SmartDriveDuo-10 that is used to control the high current brushed DC motor (10 A). It is very compatible with Arduino Mega 2560 and can connect with Arduino. This driver has 2 digital pins for PWM (speed) and 2 for DIR (direction), which easily connect to Arduino. In addition, the SmartDriveDuo-10 build with LED indicator for motor direction. The motor speed and direction can be controlled by the 2-selectable pin on the SmartDriveDuo-10 motor driver that to be stack on the Arduino Mega 2560.
3. *Power supply*: Power supply unit (PSU) used in this project is TNK ADPATN-S1203A switching power supply. Output voltage and current supplied are 12 VDC and 3 A respectively. This PSU will directly supply to the SmartDriveDuo-10 to control the 12 Volt DC Bilge Pump 1100 GPH.
4. *Bilge pump 1100 GPH 12V*: Bilge Pump 1100 GPH presents remarkable pumping control for its size and cost. Most of the Bilge Pump utilised in the ship to remove bilge water. The Bilge pump is an anti-airlock protection, no burn-out when run dry, vibration less operation, silent and efficient long-life motor. The bilge pump is a ready-made DC motor in a watertight housing. Thus, it is suitable to use for ROU-VUI.
5. *Servo motor with gripper*: The servo motor will operate to move the gripper for opening and closing to pick an object. It will move clockwise or anti clockwise according to the program that have been set.

The dimension of servo motor is 40x20x39 mm with weight of 40 g, the operating voltage is 6 V, with 0.12sec/60degree of speed and 4.5 kg/cm of torque.

6. *High definition camera*: High definition camera from Eken is used on ROU-VUI. There is choice of resolution from video mode setting from 720P or 1080P quality. In addition, this Eken can switch to camera mode to capture the picture from single mode, burst mode or time lapse capturing. The camera is connected to the smartphone through apps and can be used to monitor the movement of ROU-VUI.

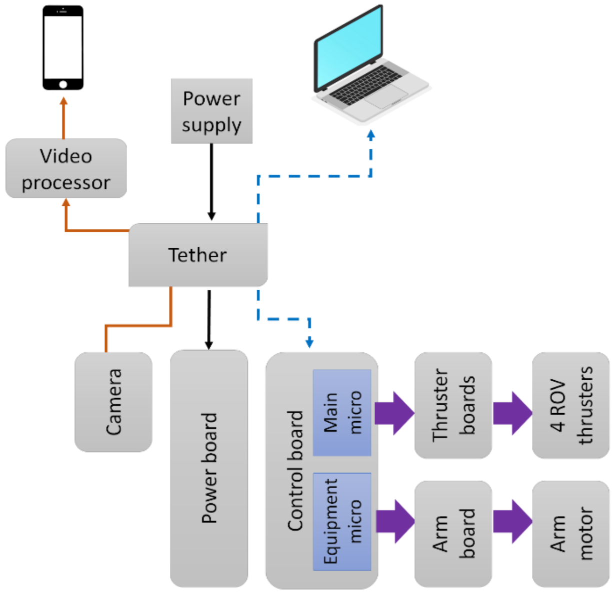

Fig. 3 Block diagram of ROU-VUI

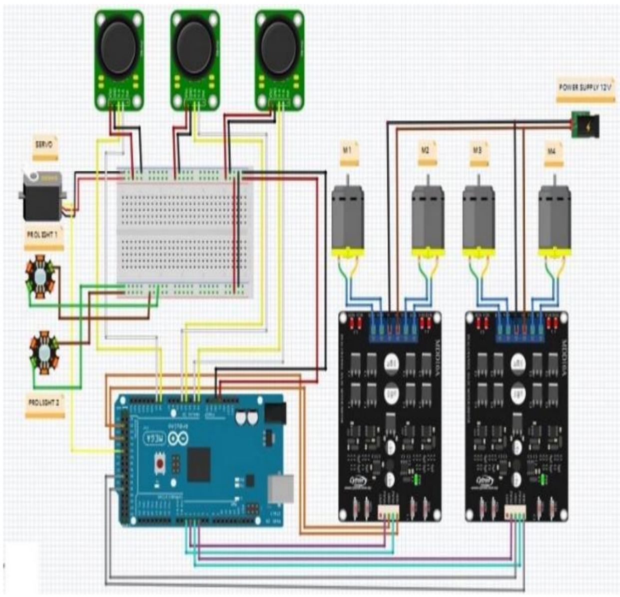

Fig. 4 ROU-VUI circuit design

III. CONTROL PROGRAMMING

Fig. 5 illustrates the correlation between ROU-VUI frame with main frame. (X_m, Y_m) in the figure is the main frame and (X_r, Y_r) is the ROU-VUI coordinate plane. Initially, ROU-VUI is assumed to be at the base location with the coordinate is measured as (0, 0).

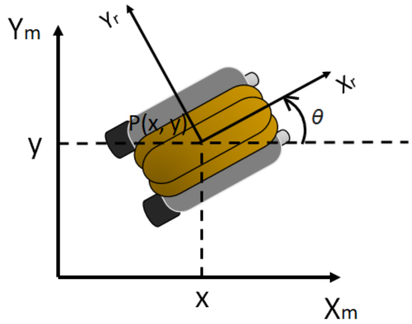

Fig. 5 Relationship between main surface plane with ROU-VUI coordinate plane

When ROU-VUI rotates on the z-axis as presented on Fig. 5, by changing to final coordinates, it gives a new coordinate to ROU-VUI and is measured as (x, y) on the main frame.

The matrix can be stated as below

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & dx \\ -\sin\theta & \cos\theta & dy \\ 0 & 0 & dz \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \qquad (1)$$

where *dx*, *dy* and *dz* are the coordinate for displacement, *x'*, *y'*, *z'* are the coordinates regarding to main surface plane, and *x*, *y*, *z* are the coordinates on the ROU-VUI plane. Fig. 6 shows the geometrical relationship for ROU-VUI.

As shown in Fig. 6, the gripper arm has one turning joint named *L* joint. θ_a and θ_g are the angle for joint *L* and gripper *G*, respectively. The coordinate value for object can be determined using below equation. Since the gripper is always fixed with arm joint *L*, there is no need to consider the gripper angle θ_g.

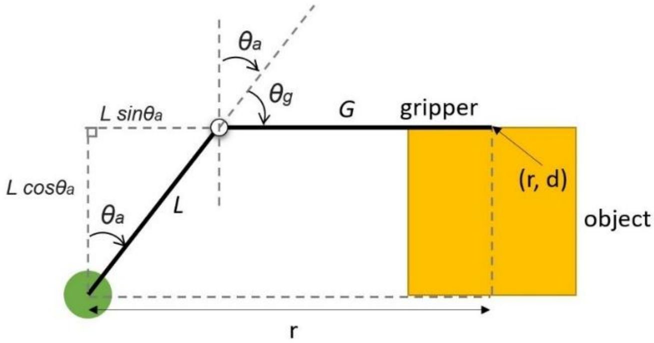

Fig. 6 Geometrical of ROU-VUI

$$r = L\sin\theta_a + G$$
$$d = L\cos\theta_a \qquad (2)$$

As explained in Fig. 5, when ROU-VUI rotates on z-axis, it will produce new coordinates with angle θ. Therefore, r can be divided into x and y elements and can be presented as below

$$x = r \cdot \sin\theta$$
$$y = r \cdot \cos\theta \qquad (3)$$

Final matrix for ROU-VUI system is as foll

$$\begin{bmatrix} xf' \\ yf' \\ zf' \end{bmatrix} = \begin{bmatrix} x' + [L\sin\theta_a + G] \cdot \sin\theta \\ y' + [L\sin\theta_a + G] \cdot \cos\theta \\ z' + L\cos\theta_a \end{bmatrix} \qquad (4)$$

where xf', yf' and zf' are the final coordinates of grasp points regarding to the main surface plane and x', y' and z' are transformation of ROU-VUI coordinate plane. All the equation will be used in the development of the prototype ROU-VUI.

$$\begin{bmatrix} x' \\ y' \\ \theta' \end{bmatrix} = \begin{bmatrix} cos\theta \\ sin\theta \\ 0 \end{bmatrix} v + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \omega \quad (5)$$

The above equation is to verify the position and angular location for ROU-VUI, where v and ω are the driving and turning velocity with respect to the coordinates regarding to the ROU-VUI coordinate plane (X_r, Y_r) and x', y' and θ' are the coordinates on the main frame (X_m, Y_m). At that point, assuming differential drive vehicle as the kinematic model of ROU-VUI resulting,

$$v = \frac{r(\omega_R + \omega_L)}{2} \quad (6)$$

$$\omega = \frac{r(\omega_R + \omega_L)}{d} \quad (7)$$

where d is the distance of instantaneous center of rotation and r is radius.

All the information is observed and measured by Arduino. Fig. 7 shows the flowchart of ROU-VUI using 4 motors and HD camera for control and monitoring purpose. These codes and models will be used to program the movement of ROU-VUI to operate underwater.

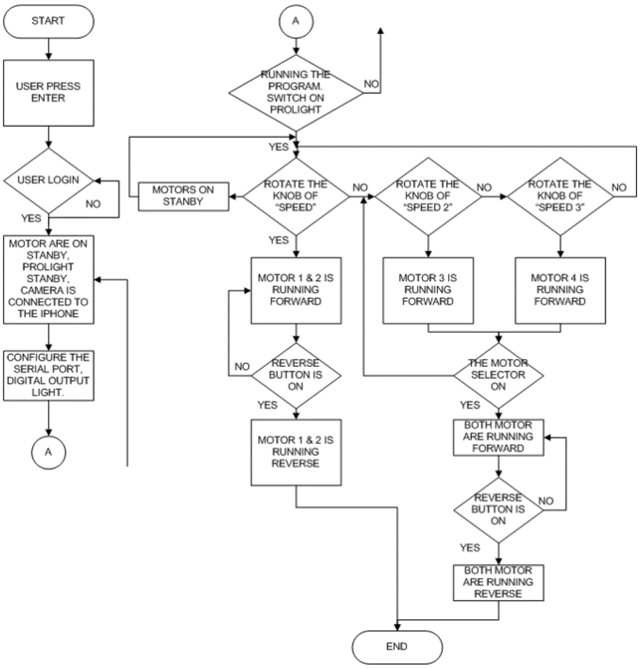

Fig. 7 Flowchart of ROU-VU

IV. RESULT

The hardware is setup based on the circuit and ROU-VUI design. Inside the control box containing the microcontroller which is Arduino Mega 2560 and two SmartDriveDuo - 10 that using lipo battery 11.1 V 2200 mah for each board as shown in Fig. 8. The Arduino is connecting to the computer USB port to receive the data from graphical user interface. Then it will transmit the data to the driver and components.

Fig. 8 Main control box

Fig. 9 shows the control panel of ROU-VUI. This panel is designed by using Graphical User Interface (GUI) LabVIEW. In this study, using the LabVIEW (GUI), some security features have been developed such as users need to login before it is directed to the control system. To connect with LabVIEW, it is needed to configure serial ports at Arduino Mega 2560 to send command data and control ROU-VUI. Besides that, the user needs to select the digital output of light 1 and light 2 before the button is pushed on. Then, data from LabVIEW will be sent to Arduino to be controlled as programmed. Two separate SmartDriveDuo-10 is used to control 4 high current brushed DC motor (10A). By changing the flow of current in the motor, it can change the direction or movement of rotational motor for thruster.

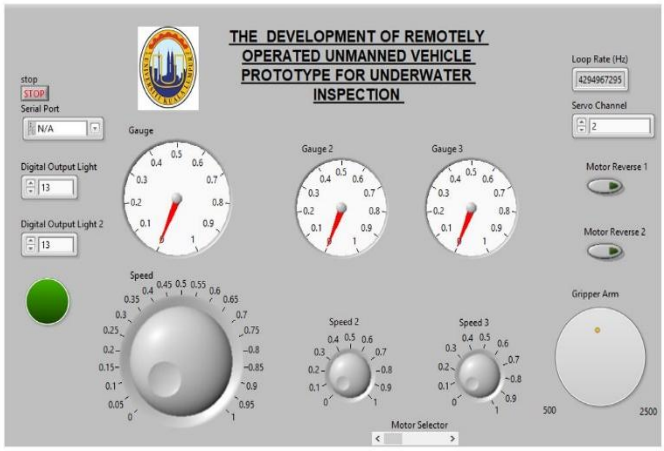

Fig. 9 Control panel of ROU-VUI.

When the system is running, all knob for controlling the motors are in standby mode as shown in figure 10. The knob of speed is used to control the movement of ROV-VUI up and down while the knob speed 2 and speed 3 for forward and reversed. Motor selector is used to make the vehicle turn right or turn left. The speedometer is presented the speed of the motors. Furthermore, the Gripper Arm knob is used to control the gripper open and close or pick up an object. By using graphical user interface, it can easy to control, monitoring and get more information during inspection and underwater operations. ROU-VUI has been tested for dive into water and returns back to the surface of water for a certain water depth. Fig. 10 shows ROU-VUI operating in the lake where the water is turbid and turbulent as the sea. Experiments have been conducted several times to ensure ROU-VUI can function and operate well.

During the experiments, the ROU-VUI is highly manoeuvrable in the water and has been exploring at the bottom of the lake for some time.

Fig. 10 ROU-VUI tested on lake

Generally, ROV is set up with a video camera and lights. In order to examine the condition of the underwater during pre-inspection, the high definition camera has been used and installed on the ROU-VUI. Fig. 11 shows images taken when ROU-VUI performs exploration and inspection in water. As a result, clear images can be taken in the water for the swimming pool when ROU-VUI is at a depth of 1.5 m. This is because the pool using a biological filtration technology to ensure the water is always clear and unpolluted. However, unclear images have been captured while diving in the lake at the same depth. The vision of ROU-VUI is limited due to the turbid and unclean water.

Fig. 11 Image taken using a high definition camera connected to the handset.

Fig. 12 shows the experimental results for ROU-VUI to dive into the water for a certain depth and Fig.13 shows the experimental results for ROU-VUI to swim to the water surface. The ROU-VUI is different from remote control vehicles working in the air or ground. It is unoccupied and are common in deep water industries such as underwater piping inspection and exploration. From Fig. 12 and 13, it can be seen that the ROU-VUI can dive to 1.5 m depth for 0.54 s and can swim back to the water surface for 0.94 s. The total average of ROU-VUI to dive is 0.41 s while to swim to surface at same depth is 0.71 s. The results of the experiment also show that the time taken by ROU-VUI will be decreased to reach at a certain distance when its velocity is increasing. Thus, it can be confirmed that the ROU-VUI can be operated as a tethered mobile device for inspection and underwater exploration.

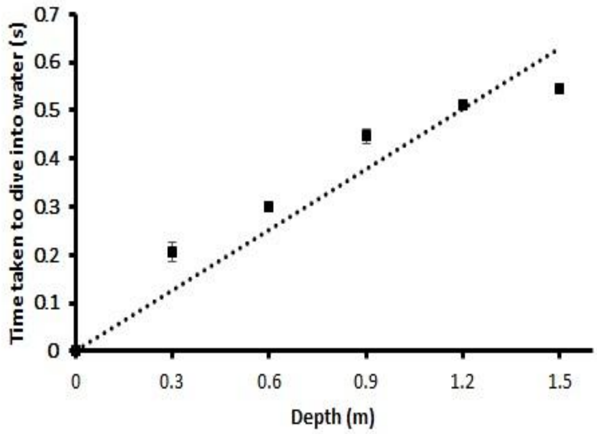

Fig. 12 Experimental results for ROU-VUI to dive into the water

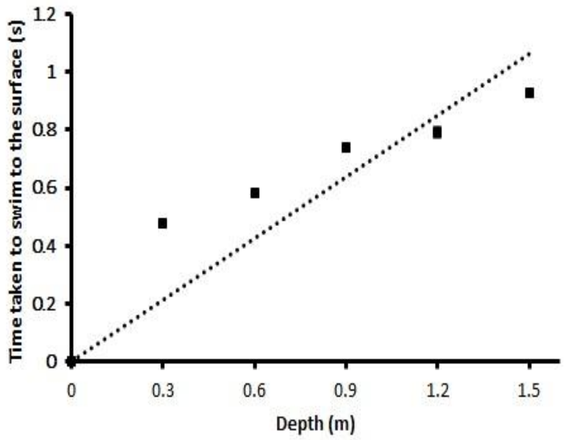

Fig. 13 Experimental results for ROU-VUI to swim to the water surface

V. CONCLUSION

From the experimental results, Remotely Operated Unmanned Underwater Vehicle for Inspection (ROU-VUI) has achieved its purpose and aim effectively. In addition to being compact and lightweight, it also comes with LabVIEW graphical user interface (GUI) system for easier exploration and monitoring operations. The ROU-VUI is also equipped with high-definition cameras to monitor and record the environment during underwater inspection and can be connected to the smartphone for supervision. Moreover, the robot arm placed in front of the vehicle will be able to facilitate ROU-VUI to pick up and hold objects found during operation. From the experiments, ROU-VUI able to dive at a water depth of 1.5 m for 0.54 s and can swim back to the water surface for 0.94 s. It is recommended to use a more powerful motor pump for better results.

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