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Design of Omni Directional Remotely Operated Vehicle (ROV)

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Abstract Nowadays, underwater activities are increased with the increase of oil resources finding. The gap between demand and supply of oil and gas cause engineers to find oil and gas resources in deep water. In other side, high risk of working in deep underwater environment can cause a dangerous situation for human. Therefore, many research activities are developing an underwater vehicle to replace the human's work such as ROV or Remotely Operated Vehicles. The vehicle operated using tether to transport the signals and electric power from the surface vehicle. Arrangements of weight, buoyancy, and the propeller placements are significant aspect in designing the vehicle's performance. This paper presents design concept of ROV for survey and observation the underwater objects with interaction vectored propellers used for vehicle's motions.

1. Introduction

1.1. *Background*

As a maritime country, Indonesia has vast areas of the oceans 70% of the total area that stretches from Sabang to Merauke. The region of Indonesia has abundant marine wealth which has the potential to be managed for the welfare of the Indonesian people. The ocean is being in between the Pacific Ocean, India ocean and South China Ocean. The region is very strategic for many marine biotas live. The Climatic influenced by the climatic in the south (Australia) and in the north (South China Ocean) cause the current stream change regularly in every year. In another side, Indonesia is on track of tectonic plates, which stretches from west to east and from north to south. This causes the region is very rich in minerals, gas, and oil. The seabed layers are quite active with many basins especially in eastern ocean of Indonesia.

In 2010, the diversity of marine ecosystems Indonesia has been known throughout the world where researcher from Indonesia and America working together in an expedition called INDEX/SATAL. The expedition explored the deep ocean around Sangihe Talaud, founding many new ecosystems in deep water and the contour of seabed explains that there are many untouched areas that give information for human such as; the information of organism which can help the human lives, such earthquakes and tsunamis prediction, ancient artefacts, underwater maintenance and seabed basins patterns that can be used to predict the distribution of oil resources in the seabed.

In INDEX/SATAL 2010 event, many researchers explored the underwater ecosystem in varies depth even in underwater where the human cannot work because of the high-water pressure. For this condition, research activities required an underwater vehicle that can operate remotely or autonomously in a risk environmental conditions, such as: ROV (remoted Operated Vehicle), AUV (Autonomous Underwater Vehicle), or UUV (Unmanned Underwater Vehicle). These vehicles can perform some commercial underwater operations such as survey and observation, pipe work installation of submarine cables, instrument maintenance under the sea, and another oceanographic research that can be operated directly from the ships on the surface of the sea (Mother Ship). Using either wired or using acoustical communication works automatically with artificial intelligence control system, [1,2,3].

1.2. *Underwater Vehicle*

Generally, underwater vehicle can be divided in two types; Autonomous Underwater Vehicle (AUV) and Remotely Operated Vehicle (ROV). An autonomous underwater vehicle **(AUV)** is a robot which travels underwater without requiring input from an operator. AUVs constitute part of a larger group of undersea systems known as unmanned underwater vehicles, and vehicles that can be driven from the operator which is at sea level is a classification that includes non-autonomous or remotely operated underwater vehicles. Communication data and source power supplied using through tether. The vehicle controlled and powered from the surface by an operator using remote control.

ROV is a tethered underwater vehicle, commonly used in deep water industries such as offshore hydrocarbon extraction. The vehicle is linked to a surface ship by a buoyant tether or, often when working in rough conditions or in deeper water, a load-carrying umbilical cable is used along with a tether management system (TMS). The TMS is separate assembly which sits on top of the ROV. The purpose of the TMS is to lengthen and shorten the tether so the effect of cable drags where there are underwater currents is minimized. The umbilical cable is an armoured cable that contains a group of electrical conductors and fibre optics that carry electric power, video, and data signals between the operator and the TMS. Once at the ROV, the electric power is distributed between the components of the ROV. However, in high-power applications, most of the electric power drives a high-power electric motor which drives a hydraulic pump. The pump is then used for propulsion and to power equipment such as torque tools and manipulator arms where electric motors would be too difficult to implement in subsea. Most ROVs are equipped with at least a video camera and lights. Additional equipment is commonly added to expand the vehicle’s capabilities. These may include sonars, magnetometers, a still camera, a manipulator or cutting arm, water samplers, and instruments that measure water clarity, water temperature, water density, sound velocity, light penetration, and temperature.

1.3. *Brief history of ROV Design*

British and US navies developed the vehicles during the 1950s and ‘60s. The early British ROV was named Cutlet, used in the 1950s by the Royal Navy to retrieve practice torpedoes and mines. These developments led to the ability to perform deep-sea rescue and recovery operation; as early example, the ROV used to retrieve the atomic bomb lost in the Mediterranean in 1966 when a B-52 crashed during a refuelling operation. This operation employed an early generation ROV, the CURV-I (Cable-controlled Undersea Recovery Vehicle) and in 1973, CURVIII performed the deepest underwater rescue in history when it rescued two men who were stranded 1,575 feet (480 m) below the ocean surface. CURVIII was equipped with an array of TV cameras and lights and a 35-mm camera with a 500-frame color film capacity. It could operate at depths of up to 10,000 feet (~3,000 m), weighed approximately 5,400 pounds (2,400 kg) and could be equipped with a range of mechanical tools and sensors. The CURV family of ROVs are still in use and the latest generation product, the CURV-21, weighs 6,400 lbs (2,909 kg), operates at a depth of 20,000 feet (~6,000 m) and is fitted with high resolution digital cameras, sonar and a fibre optic multiplexing system which can combine up to eight channels of video, sonar, USBL (ultra-short baseline) positioning data, RS232/422/485 data communications and navigation data on a single fibre optic. The vehicle using 400 MHz digital communications network in control navigation.

These military developed the technological groundwork that provided the offshore oil and gas industry with so-called “work-class” ROVs. These became essential tools in the 1970s and ‘80s when much of the new offshore oil and gas development was at a depth that exceeded the reach of human divers. Today's modern ROVs are used extensively in the construction of sub-sea oil and gas developments and in their subsequent inspection, repair and maintenance and vary hugely is terms of depth rating, size, complexity and capabilities. A typical commercial ROV comprises a large flotation pack above an aluminium chassis to provide the necessary buoyancy. In addition to powering the various electrical systems, electrical power can be used to drive a hydraulic pump that is used for propulsion as an alternative to the more normal electrically powered thrusters and to actuate high power equipment such as torque tools, cutters and manipulator arms. Most ROVs are equipped with a video camera and lights and often include sonar systems and in the case of ROVs aimed at scientific research or environmental monitoring, sensors for monitoring water quality, sampling systems and high-resolution cameras are also deployed, [4].

Therefore, the system in ROV is a highly interrelated group of subsystems that, when functioning synergistically, provides an impressive subsea capability. Since the characteristics of the vehicles are multi-variant, with no unique solution, the design process is necessarily iterative. Because of this highly interdependent relationship, ROV system performance is a delicate balance of design and operational characteristic. Commonly, the ROV design system can be divided into a number of major subsystems, these would include; ROV Vehicles, Tools and Sensors, Control / display console, Electrical power distribution, Umbilical and tether cables, handling system

2. Design of ROV, Propulsion System, Communication Data, and Power System

2.1. *Design of ROV*

The concept of the developed ROV is a vehicle for underwater survey and observation with omni directional movement. With this ability, the vehicle can conduct survey and observation activities where the vehicle does not need to maneuver when it moves to sideways, back, front, and others.

Two important parts considered in the design of the vehicle to be stable; point of the center of gravity or center of weight and center of the buoyancy force. These determine the vehicle's stability characteristic, where the vehicle's stability is an ability of the vehicle to return to the equilibrium position when there any external force or moment disturbance. Good stability indicates the center of gravity is underneath the center of buoyancy force and the longer distance between center of gravity and center of buoyancy the higher moment stability and stiffness of motion. Therefore, the vehicle design place buoyant structure at the top of the vehicle and place more weight at the bottom.

In the design of propeller, the vehicle uses ducted propeller where the ducted propeller has advantages than the conventional propeller. The ducted propeller can increase the efficiency of the thrust propeller, has lower diameter compare to non-ducted propeller, and the ducted propeller can protect the propeller from other objects. Ducted propeller installed on the main structure with fixed mounting angles. However, besides the fixed angle mounted on the structure, rotatable propeller also able to be installed that can decrease the number of propeller installed for application to multi-direction movement. In this paper, the fixed propeller angle chooses as it has a simpler in design and installation.

In another side, the vehicle designed to have a capability to keep the vehicle's position in stable position even under force disturbance from current. The vehicle also designed to have same weight to the buoyancy force that ease the vehicle move in vertically. To adjust the weight, pumping system run the pump to fill the ballast system that can pump water in and out to the ballast tank. In construction, the vehicle construction is made using galvanized pipe with the space inside the pipe allowed for ballast tank. Design of the ballast system also consider the total weight required and centre of the weight or gravity. Therefore, in design of the vehicle's weight distribution and the buoyancy of every part are designed properly so it will not decrease the vehicle's stability. The higher stability can make the vehicle very stiff and decrease the ability of the vehicle to rotate in pitch and roll motion. The concept design of the ROV as shown in figure1.

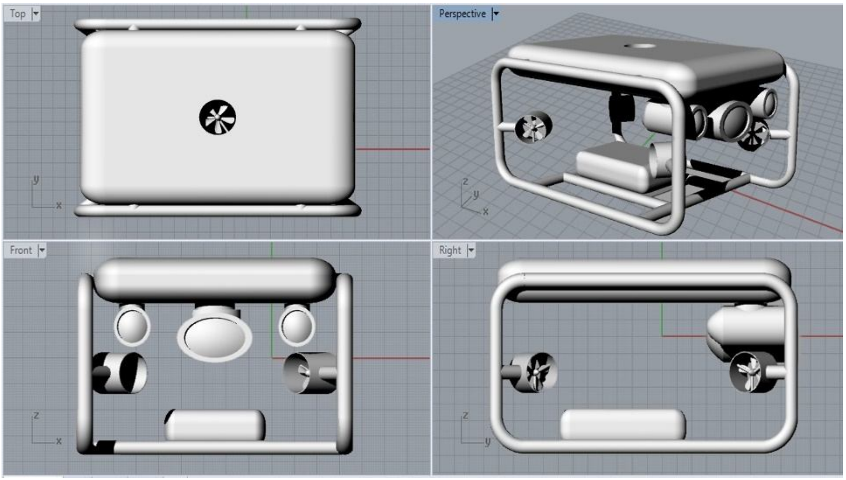


Figure 1. Proposed Developed Design of ROV

In this research, the ROV designed to operate in 100m under the water surface. The dimension of the developed design has 58.60cm length, 42.21cm breadth and 32.60cm high. The model equipped five propellers with 7.0cm diameter, one buoyant tank at top, four dry batteries placed at bottom to increase the vehicle stability and as additional source power. Four propellers are installed at each corner with 45 degrees angle to the axis and one propeller placed vertically at the buoyant tank. The propellers used to control the vehicle motions in six degrees. The design speed of vehicle is 0.5m/s.

2.2. *ROV System*

The ROV system designed to control its motion automatically. It is equipped five brushless motors with electronic speed control (ESC) system, motion sensors, water leak sensor, temperature sensor, current flow sensor, and pressure sensors. The ROV also equipped two cameras and lights as remote eyes for operators and one joystick used as operator command. The speed and rotation of motor are controlled simultaneously. The motion sensor consists of accelerometer, gyrometer, and compass. Four dry batteries placed at lower ROV with total capacity about 28Amph. The electronic systems be placed in box with water tight compartments to protect them from the water leaks and protect being crushed by the extreme pressure exerted on the ROV.

ROV has two systems; remotely operation system and onboard vehicle system. The remote operation system consists of console for display data and video captured, calculate the joystick signals and convert it to the data require for the system on the vehicle. The onboard vehicle system uses a microcontroller with network module to do calculation, control and communication between the sensors and actuator, and linked to remote operator. The diagram for the whole system as shown in figure 2.

2.3. *Propulsion System*

Propulsion system of ROV derived from the advanced of omni-wheel robot moves in omni-directional movement. Propulsion systems designed using five propellers. Four propellers are used to drive the vehicle in horizontal and longitudinal direction. One propeller is placed on the upper side, in line with the centre of gravity, used to drive the vehicle moves vertically. The vehicle uses duct propeller with six blades with some advantages as follows; The ducted propeller has more efficient in producing thrust than a conventional propeller. For the same static thrust, a ducted propeller has a smaller diameter than conventional propeller. The water velocity through the ducted can be adjusted to allow it operate more efficiency. Ducted propeller offers enhanced safety from contact with others object, as shown in figure3.

The four propellers installed at each corner and crossing each other at 45 and 135 degrees to its directional axis. The vehicle’s movement resulted by vectored forces of the propeller’s thrust. The vehicle’s movement is designed to have a motion like omni-wheel robot where it can move in omni-directional or move at certain degree. The omni-four wheels robot and ROV's movement concept are shown in the figure 4.

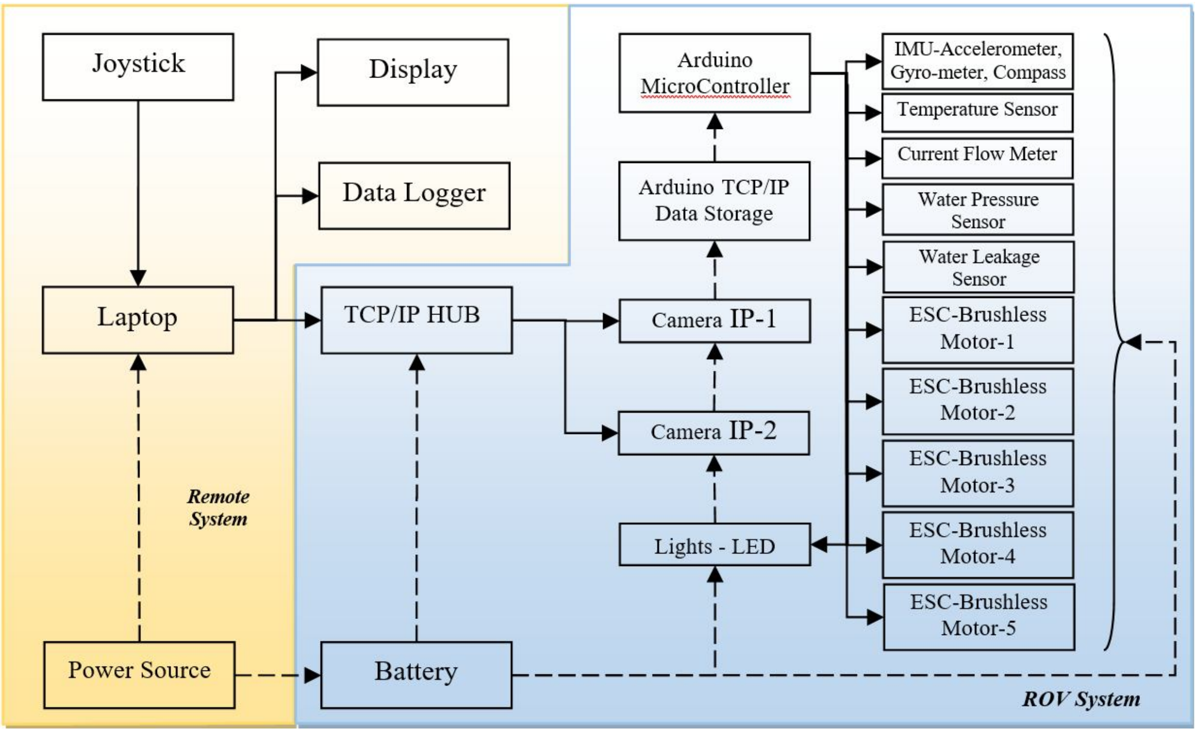
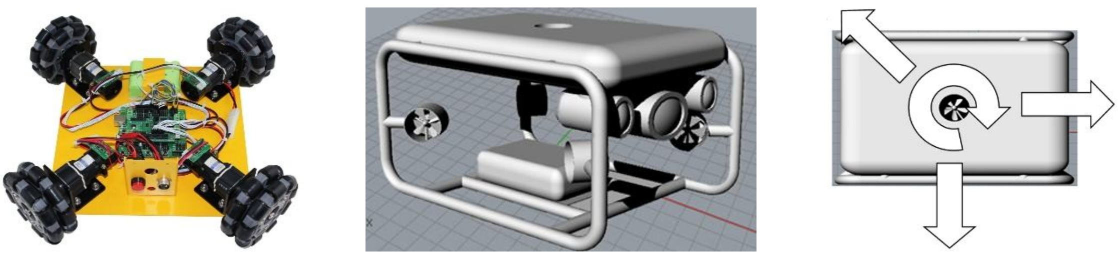


Figure 2. Diagram of ROV System, on-vehicle and remote system

Figure 3. Duct Propeller with Six blades



(a) (b) (c)

Figure 4. (a) Omni four-wheel robot with 45-degree wheel to origin axis, (b) design of ROV, (c) Direction movement of ROV

2.4. *Navigation System*
Navigation the vehicle using four propellers for transversal and longitudinal movement while one propeller for vertical movement. Combinations of the propeller thrust direction in navigation are shown in figure 5.

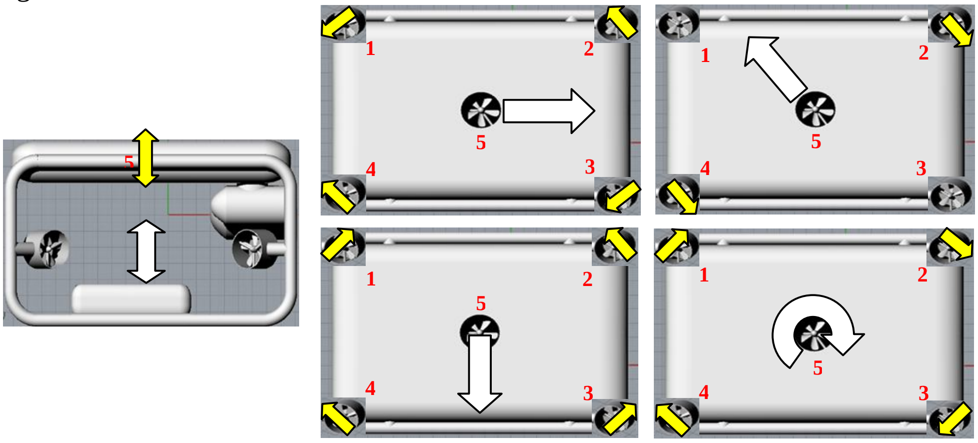


Figure 5. Navigation concept of ROV, yellow arrow is propeller thrust direction and white arrow is vehicle movement directions.

Installation of propeller at each corner of the vehicle must consider the centre of vehicle's movement. The propeller position installed at proper position that will not result a contra force between propeller's thrust. Positioning the propeller in such can make the effectivity of the propeller's forces are decreased. Based on the omni-four-wheel robot, the kinematic model of transformation propeller thrust to the directional force applied are written as follows, [5,6];

$$\begin{bmatrix} F_x \\ F_y \\ F_z \\ M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} c\theta & -c\beta & 0 & 0 & 0 \\ s\theta & -s\theta & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ d\ s\theta & d\ s\theta & 0 & 0 & -l \\ 0 & -d\ c\beta & d\ c\theta & 0 & -l \\ d\ c\theta & -d\ c\beta & -d\ c\theta & -d\ c\beta & 0 \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \end{bmatrix} \quad (1)$$

$$T_i = K_T \times D_i^4 \times n_i^2 \quad (2)$$

Where *F, M, T* are force, moment and propeller thrust respectively, *c* is cosines, *s* is sinus, *d* is horizontal propeller arm to centre of rotation, *l* is vertical propeller arm to centre of rotation, *D* is propeller diameter, *n* is propeller rotation and K_T is propulsion coefficient of thrust. θ, β are angle of propeller where θ is angle for propeller 1 and 3, and β is angle for propeller 2 and 4.
In order to drive the propellers in two rotational direction, brushless motor with Electronic Speed Controller are applied. The motor has high torque and high rpm to high provide power for high thrust propeller.

2.5. *Communication Data*
Communication data between remote operator and vehicle is through optic fibre. The advance of optic fibre compare to cable data communication are the optic fibre that can ignore the signal noise, high speed data, and high capacity data. The optic fibre likely has no limited length to transfer the signal and data. However, in this early research, the optic fibre is replaced using network cable data TCP/IP. This communication data length can go about 100m length.

2.6. *Power System*

The ROV has two power source system, main power from the remote station or operator station and additional power placed at the vehicle. The source of power supplied from the surface ship where the electrical power uses 12-13.6 Volt DC. The vehicle uses four dry batteries placed at the bottom as additional power source for the vehicle system. In order to maintain the voltage value for sensors and microcontroller, some voltage regulators required. The voltage regulator used to supply constant voltage for the whole sensors in the vehicle.

3. Weight, Buoyancy, and Moment Stability Calculation

3.1. *Weight and Buoyancy Calculation*

The ROV is designed to have a high stability and can fly underneath water surface. In designing the ROV, the stability is an important factor that ROV must meet the stability requirement where the center of floatation should be at upper than center of gravity. To increase the stability of the ROV can be done by placing the buoyant tank at upper position and the place the weight at lower position.

In the design of the ROV, the main construction used are galvanized pipes. There fourteen galvanized pipes and eight elbow connectors used. While the buoyant tank made from the fiberglass material. Calculation of the ROV weight, displacement, center of buoyancy and center of gravity provide using the following equations.

The weight of the galvanized pipe obtained by calculating the pipe's material volume than multiply with the specific material, as follows;

$$W_{material} = \pi \times \rho_{pipe} \times L \times \frac{(D_{out} - D_{in})}{4} \tag{3}$$

Where D_{out}, D_{in} are diameter outside and inside of pipe. L is the length of pipe, and ρ is the weight specific of the pipe materials.

The added weight by water ballast inside the pipe is obtained by calculating the inside volume of the pipe using the following equation;

$$W_{ballast} = \pi \times \rho_{pipe} \times L \times \frac{D_{in}}{4} \times h \tag{4}$$

where h is the water high inside the pipe.

The buoyancy of the vehicle could be obtained by calculating the displacement volume of the vehicle and the volume multiply with the water weight specific of the vehicle as follows;

$$\Delta_{Bouyancy} = \pi \times \rho_{water} \times \frac{D^2{}_{out}}{4} \times L \tag{5}$$

The design of the origin axis of the vehicle placed at the middle of x-y axis and at bottom for z-axis. The center of gravity to the origin axis provided from the following equations;

$$M_x = \sum_{i=0}^{i=n} W_i \ x \ X_i + W_{ai} \ x \ X_{ai}$$

$$M_y = \sum_{i=0}^{i=n} W_i \ x \ Y_i + W_{ai} \ x \ Y_{ai}$$

$$M_z = \sum_{i=0}^{i=n} W_i \ x \ Z_i + W_{ai} \ x \ Z_{ai} \tag{6}$$

W_i, W_{ai}, and X_i, Y_i, Z_i, and X_{ai}, Y_{ai}, Z_{ai} are the weight component, added weight by ballast water, the offset of center of weight component, and added weight component respectively. In general, the buoyancy force of the vehicle's component are calculated by calculating the weight displacement of the component equal to the buoyancy force. Then, the moment buoyancy provided by the following equations;

$$M_{bx} = \sum_{i=0}^{i=n} B_i \ x \ X_i$$

$$M_{by} = \sum_{i=0}^{i=n} B_i \; x \; Y_i$$

$$M_z = \sum_{i=0}^{i=n} B_i \; x \; Z_i \tag{7}$$

According to the equations above, calculations above and origin of axis located at the baseline then found the weight of the ROV is 12,17kg, the center gravity of the vehicle and the center of buoyancy are;

G_x = 0.0cm G_y = 0.0cm G_z = 13.32cm

B_x = 0.0cm B_y = 0.0cm B_z = 20.60cm

3.2. *Moment Stability Calculation*

The ability of the vehicle to return to its original state when trim is a measure of the underwater vehicle stability. The vehicles can return to the original state when moment between gravity and buoyancy forces are positive. As mentioned before, the way to increase the stability is to set the distance between center of gravity and the center of buoyancy is high where the center of buoyancy is upper then center of gravity, [2,7]. The moment stability of the vehicle at certain heal angle obtained using the following equation, and the moment stability is shown in the figure 6.

$$M_s = w \times (B_z - G_z) \times \sin(\frac{\theta}{180} \times \pi) \tag{8}$$

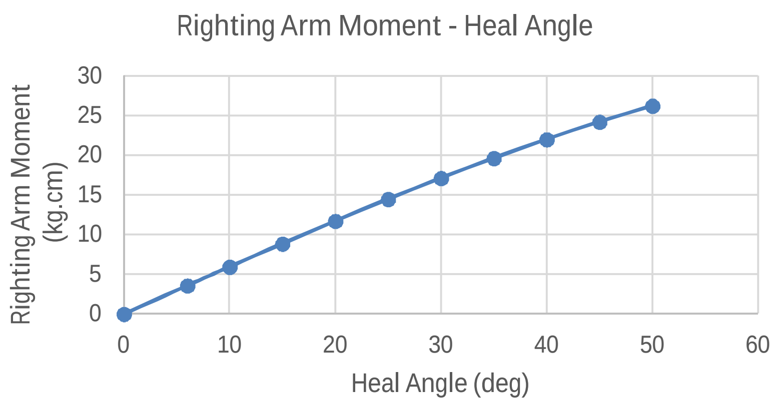


Figure 6. Righting moment arm required to keep the vehicle in stable condition at every heal angle.

3.3. *Drag Calculation*

Drag force is the resistance force caused by the motion of a body through a fluid, such as in water or in air. A drag force acts opposite to the direction of the oncoming flow velocity. This is the relative velocity between the body and the fluid. The drag force calculated using the following equation;

$$D = \frac{1}{2} \; C_\rho \; A \; V^2 \tag{9}$$

Where C_ρ is the drag coefficient, which can vary along with the speed of the body. Typical values range from 0.4 to 1.0 for different fluids (such as air and water), ρ is the density of the fluid through which the body is moving, V is the speed of the body relative to the fluid, A is the projected cross-sectional area of the body perpendicular to the flow direction (perpendicular to V), [8]. The drag coefficients are obtained from the data and the drag force calculated with assumtion no heal angle during the variation of the speed as shown in figure 7.

4. Discussion

Underwater vehicle has various types and systems in accordance with the purpose of vehicle design. ROV is a vehicle operated from the surface of the sea as a work vehicle where underwater environment can disturb vehicle motion performance such as velocity of ocean currents, high pressure water depth. This vehicle has four propellers so that the vehicle can move surge, sway, heave, yaw, pitch and roll and with a propeller placed vertically. The vehicle's design takes the concept of omni-wheel robot where the robot can move in omni directions, [6, 9]

The design of the ROV construction has high stability where the centre buoyancy at 17.28cm above the centre of gravity. From the stability calculations, the righting moment showed an increased graph trend moment up to 90 degrees. The graph showed the stability of the vehicle is always positive so that the vehicle will not run into stability problems when the vehicle in underwater.

The calculation shows an increase of drag force within increase of vehicle speed and the gradient of the drag curve also increase. The ration of drag force to vehicle’s weight at 0.5m/s speed is 0.47 and required a minimum resultant propeller force about 57N.

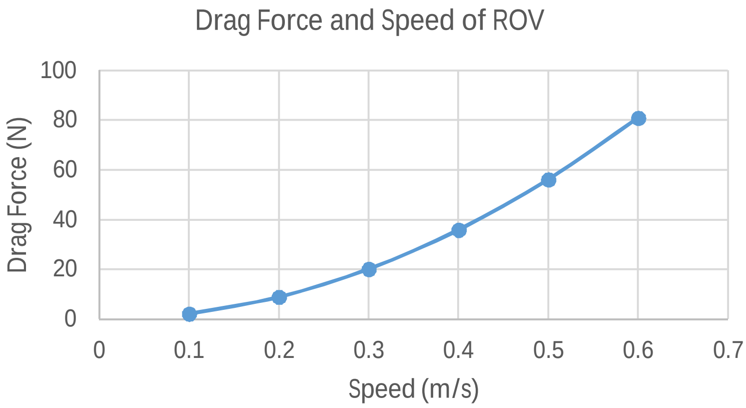


Figure 7. Drag force of ROV for certain speed

5. Conclusion

According to the design of the ROV and the static stability and drag calculations, the ROV design was concluded as following;

- The ROV has a positive stability where the centre of buoyancy at 17.28cm above the centre of gravity.
- The static drag force calculation showed the force required to propel the vehicle still required more analysis where the non-linearity aspect is should be considered

6. Future work

As the future work, this research will continue on developing a numerical time domain simulation program to explore the nonlinearity of the vehicle’s response and develop the control method for vehicle’s keeping position under current disturbance.

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