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DESIGN THE AUTO DEPTH CONTROL FOR UNMANNED UNDERWATER VEHICLE CONTROL USING THRUSTER SYSTEM

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Bachelor of Mechatronics Engineering

May 2013

“I hereby declare that I have read through this report entitle “*Design the auto depth control for unmanned underwater vehicle control using thruster system*” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Mechatronic Engineering”.

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DESIGN THE AUTO DEPTH CONTROL FOR UNMANNED UNDERWATER VEHICLE CONTROL USING THRUSTER SYSTEM

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A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Mechatronic Engineering

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YEAR 2013

I declare that this report entitle “*Design the auto depth control for unmanned underwater vehicle control using thruster system*” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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ABSTRACT

In the world of underwater vehicle industries, thruster are important to control the direction, the depth and the speed of the Remotely Operated Vehicle (ROV).There are many types of ROV design and structure, and it all comes with different size of thruster design. The problems that occur in the underwater where require a person to dive in the water at a certain depth in a long time are difficult and endanger the divers' safety. Thus, an auto depth control system is prepared to implemented into the previous UTeM ROV (UTeRG-ROV). This project focuses on the operation principle on which the UTeRG-ROV can submerge and emerge using thrusters and help the UTeRG-ROV to maintain at the specified depth. This project is to develop a prototype of thruster that has the auto depth control which attached to the UTeRG-ROV to demonstrate the basic operation of auto depth control as well as it operation in the water. The thrusters have its own saturation point which means it has a maximum depth that the thrusters can submerge the UTeRG-ROV. Therefore, ballast tank is used to submerge deeper. The maximum depth the UTeRG-ROV can submerge by using thruster system is 0.7m. The thruster model will thrust and submerge until it reaches a set point which is 0.5m and maintain at the set point depth. The depth was based on pressure sensor measurement.

ABSTRAK

Dalam dunia industri kenderaan air, thruster adalah penting dalam mengawal arah, kedalaman serta kelajuan "Remotely Operated Vehicles" (ROV). Terdapat pelbagai jenis reka bentuk dan struktur ROV, dan ia datang dengan reka bentuk saiz thruster yang berbeza. Masalah-masalah yang berlaku di dalam air di mana memerlukan seseorang untuk menyelam di dalam air pada kedalaman tertentu dalam masa yang lama adalah sukar dan membahayakan keselamatan penyelam. Oleh itu, sistem kawalan kedalaman auto dilaksanakan ke dalam UTeM ROV (UTeRG ROV). Fokus projek ini adalah kepada prinsip operasi di mana UTeRG-ROV boleh tenggelam dan timbul menggunakan thruster dan ia juga membantu UTeRG-ROV untuk kekal pada kedalaman tertentu. Tujuan projek ini adalah untuk membangunkan satu prototaip thruster yang mempunyai kawalan kedalaman auto yang dilampirkan kepada UTeRG-ROV untuk menunjukkan operasi asas kawalan kedalaman auto serta operasinya di dalam air. Thruster mempunyai tahap tepu tersendiri, ini bermakna ia mempunyai kedalaman maksimum dimana tahap maksimum thruster boleh menenggelamkan UTeRG-ROV. Oleh itu, tangki digunakan untuk tenggelam lebih dalam lagi. Kedalaman maksimum UTeRG-ROV boleh tenggelam dengan menggunakan sistem thruster adalah 0.7m. Thruster akan memberi tujahan dan tenggelamkan sehingga ia mencapai titik set iaitu 0.5m dan kekal pada kedalaman titik set yang di tentukan. Kedalaman adalah berdasarkan ukuran tekanan pada sensor.

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LIST OF SYMBOLS

R	-	Propeller Radius, m.
T	-	Thrust Force, Newton.
Q	-	Propeller Torque, Nm
ω_m	-	Motor Rotational Rate, rad/sec.
N	-	Reduction Gear Ratio.
Lift	-	Lift Force, N.
Drag	-	Drag Force, N.
A	-	Tunnel Cross Sectional Area
θ	-	Angle of Inlet to Blades, rad.
a,	-	Effective Angle of Attack, rad.
p	-	Blade Pitch, rad.
U_a	-	Section Average Flow Velocity, m/s.
U_p	-	Propeler Velocity,m/s.
C_{Lmax}	-	Maximum Lift Coefficient
C_{Dmax}	-	Maximum Drag Coefficient

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Remotely Operated Vehicle (ROV) is an underwater robot that designed on purpose for surveillance, monitoring and collecting data for all underwater activities. It is a widely safe use mechanism type for underwater vehicle serve mostly military, commercial, and scientist needs. The main purpose of the invention of this robot is to do the operation that hazardous to human being or at a depth which has high pressure that could affect the system of human body. The majority of ROV's in services are used by the oil industry for maintaining oil rigs and pipelines [17].

ROV are divided into several classes referring to their work ability. The first class is pure observation which is focusing on video observation and usually come in small size and light. The second class is observation with playload option. This class of vehicle must capable to carrying additional sensors and able to carry at least two additional sensors without loss of original function. The third and fourth class are the work class vehicle and the seabed working vehicle respectively [18]. The work class ROV need more space on installing the tools to do the underwater task. In this project, the ROV that been focused on are the observation class ROV where the ROV is smaller than the work class ROV. The observation class of ROV is used for visual inspection and capable of carrying playload of over 30kg. Sensor and camera are usually mounted to the observation class ROV's to done the routine of surveillances of subsea structures [17].

1.2 Motivation

Nowadays, discovery of underwater world become more popular among scientists and engineers. New technological devices that can submerge into the deep oceans in order discover more about the underwater world are invented day by day. ROV is a very common vehicle for underwater researcher to help them in investigating the underwater species of animal and plant at the bottom of the ocean that normally human can't do. It emphasizes the difficulty of working to conduct these operations at such extreme depths, where humans can't directly interact with the malfunctioning equipment [1].

In the mean time, the ROV are already developed with thrusters in order to make the robot to move upward, downward, forward, reverse, right and left. However, not all of the ROV installed with the auto depth control system using thrusters or ballast tank. The auto control system is built for maintaining the ROV at specified depth for a long time.

The system indirectly helps the researcher to record a video and take a sample at certain depth of the sea as shown in Figure 1.1. This system is also has been applied in oil and gas industries, where this auto depth control systems is used to help the underwater maintenance at the offshore. The ROV needs to maintain at certain depth to do the inspecting or monitoring job on the piping or chain.

Figure 1.1: The Underwater Research using ROV [4]

1.3 Problem Statement

A ROV that named as UTeM Underwater Research Group ROV (UTeRG-ROV) was invented in 2012. However the previous ROV do not have auto depth control system. The ROV is loaded with thrusters which controlling upward, forward and reverse movement of the ROV. Without the auto depth control, the ROV cannot stay at current depth and it hard for the researcher to take out any data at a specified depth. Hence, an enhancement of previous ROV in term of depth control is needed.

Therefore, the auto depth control for ROV using thruster system is proposed. The auto depth control of the ROV is designed to assist the ROV in maintaining the specified depth using thruster system.

1.4 OBJECTIVES

The objectives of this project are:

1. To design the auto depth control using thrusters system
2. To analyze the sensitivity of the chosen pressure sensor and validate the results obtained.

1.5 SCOPES AND LIMITATION

The scopes and limitation of this project are:

1. The project only focuses on auto depth control system using pressure depth sensor by completing the existed ROV prototype.
2. Two thruster are used to submerge the ROV.
3. The selected pitch is 45^0.
4. The ROV were tested in a pool with depth 1.5 meter.
5. The main source of power supply was from 12V battery.

K-Chart on Designing the ROV

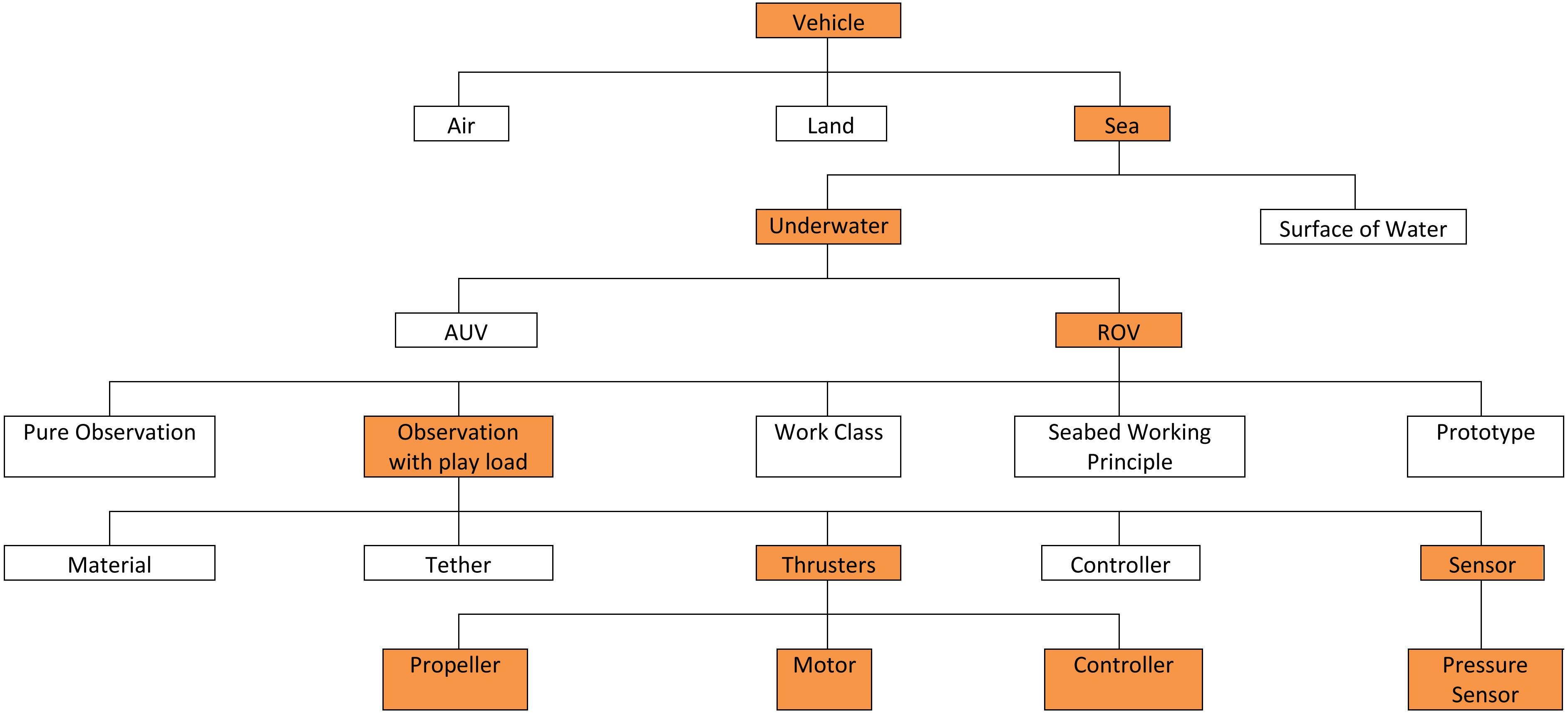

Figure 1.2: K-Chart

CHAPTER 2

LITERATURE REVIEW

This chapter discuss on the general information of the auto depth system which will be used for UTeRG-ROV. The type of motor use and the selection of propellers in which size, diameter, number of blade and blade pitch to the centre are included in this study as well as pressure sensor. The facts and information are collected from reliable source and elaborated based on the understanding of the review. The previous research information, methodologies and design are used as references and guidelines for this project.

2.1 Motor

Motor is a machine which converts electric energy into mechanical energy. The electric motor is one of the prime mover type for a mechanical system. Motor come in various shapes, sizes, and technologies, each designed has its own functionality. As information, the most common thrusters' motor on ROV systems is selected due to its power, availability, variety, reliability, and ease of interfaces. Motor is a one part in thrusters that influenced the thrusters' performance. The motor drive its shaft to move the propeller hence the thrusters. There is several type of motor that commonly use in ROV thrusters. The motor is selected due its ability to give out the higher torque and speed. The low power consumption also must be considered in motor selection.

Table 2.1: Comparison of various motor technologies

Motor Type	Advantages	Disadvantage
Variable Reluctance Permenant Magnet	1. High specified tourque.	1. Suffer from high axial flux losses. 2. Technology is not well

(VRPM) Motor		understood.
Brushed DC Motors	1. Proven technology. 2. Simple control.	1. Low specific torque. 2. Wear on brushes make reliability an issue. 3. Due to brushes there are also interference noises.
Induction Motors	1. Robust and inexpensive. 2. Technologies is well understood.	1. Motor size tends to be large for this application. 2. Control is complex and expensive.
Switched Reluctance Motors	1. Construction is robust and simple. 2. Bulk of losses appear on stator which is easy to cool. 3. Torque is independent of polarity of phase current which allows the reduction of semiconductor switches in the controller in certain applications. 4. Torque-speed characteristics can be tailored more easily compared to induction motors or permanent magnet motors.	1. Has inherent high torque ripple that causes vibration and noise. 2. High peak currents and high controller chopping frequency that cause electromagnetic interference. 3. Higher controller switching frequency also cause high core loses and the motor require a more expensive grade of steel.
Hydraulic Motors	1. High specified torque.	1. Many mechanical parts makes reliability an issue. 2. Efficiency of a hydraulic motor system is low.

Brushless Permanent Magnet (PM) Motors	1. Brushes are eliminated hence removing the problem of speed limitation and electromagnetic interference, as well as has a better reliability when compared to Brushed DC motors. 2. The amature is on the outside stator which allows better cooling and higher specified outputs. 3. Permanent magnet excitation reduces rotor losses and improves efficiency.	1. Rare earth magnet are costly. 2. Magnet can suffer from corrosion and demagnetization under fault conditions.

Table 2.1 shows the comparison of various motor topologies that could be used as a drive for the thrusters systems. Conventional thrusters for work class underwater ROV are driven by hydraulic motors as shown in Figure 2.1. They are normally used because hydraulic motors are able to produce a higher specific torque when compared to traditional electric motors (such as induction motors). This would mean that if traditional electric motors were used to drive thrusters for ROVs, they would result in a much larger electric thruster unit. This is undesirable, as a larger electric motor would impede the flow of water through the propeller, as well as increase the overall space required on the vehicle to accommodate the thruster unit and increases the overall weight of the vehicle. Hydraulic thruster systems tend to be significantly less reliable compared to their electric counterparts[6]. This is due to the many mechanical parts in a hydraulic thruster system that tend to wear with time, with broken seals and water leakage into the system being amongst some of the common faults. A hydraulic system breakdown can be very costly because it takes a long time to repair. A typical system breakdown would involve replacing the broken part, followed by flushing the hydraulic system and refilling it with oil, priming and testing the system. This is a process that can take 7 to 10 hours, and operational costs such as the ROV operator and the ROV support vessel are still being paid during this time.

Figure 2.1: Hydraulic Thrusters

In addition, hydraulic thruster systems are inefficient. Most hydraulic thruster systems have efficiencies less than 53% [5], which is very low compared to possible efficiencies that may be achieved by all electric thruster system of 80 to 85% system efficiency. This efficiency improvement has implications on other components of an ROV system such as the reduction in size of the transformer, switchgear, and umbilical, due to the required power transmitted for the job.

Advances made in permanent magnet material and alternative electric motor topologies have made the use of all-electric thruster systems feasible. Electric motors can now be designed to have similar efficiencies and torque outputs for a much smaller size compared to traditional electric motors, albeit at a significant increase of cost if expensive rare earth magnets are used. There are many advantages of using an electric thruster systems. Electric motors used for thruster systems have a linear response of torque to control signal when compared to hydraulic motors that have dead bands at low velocities. This is an important feature for ROV tasks that require better positioning and accurate repeatability of motion, such as tasks like repair, maintenance and construction [7].

The electric thruster system designed in this project is the tip-driven electric thruster, where the motor is structurally integrated into the propeller and duct. This removes blockage of flow through the propeller, resulting in an improved thrust production for a similar power requirement, as well as allowing for a shorter thruster length and bi-directional thrust, which are advantageous for thrusters of ROV.

2.2 Propeller

The momentum theory of propellers was originally found by Rankine and Froude shows that for a propeller actuator disc, thrust can be expected to depend on the square of the flow velocity through the blading and that the energy efficiency of the propeller is increased when the thrust loading on the blade is reduced [13]. This theory does not explain deeper on how the shape of the propeller blade is related to the thrust of the ROV. The theory of aerodynamic is closely related to the blade element theories, in which the lift and drag forces generated from any element of the blade's cross section are added over the total length of the blade [15]. The local angle attack at blade section is related to the lift and drag forces. A representation of lift and drag coefficients as a function of effective angle of attack is then required to complete the calculation of the amount of thrust and torque. Lift and drag coefficients available for many different parts of the wing for small angles [19].

Figure 2.2: Example of propeller with different size [19]

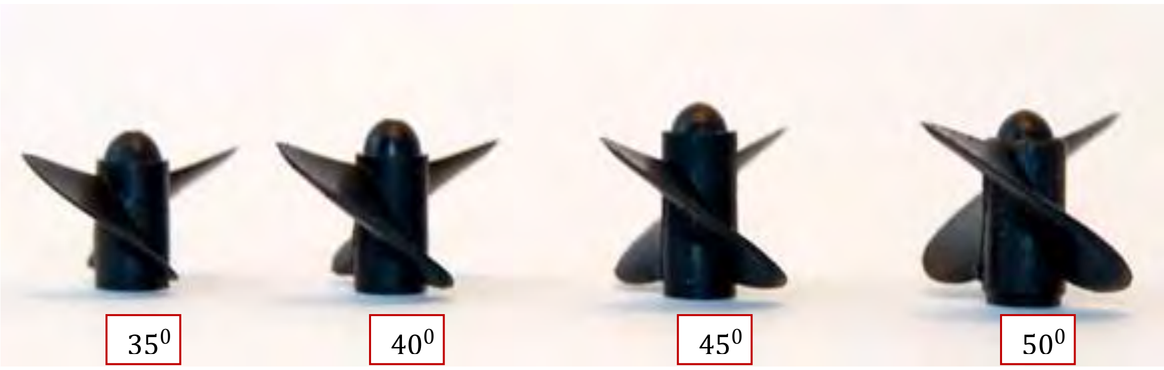

Figure 2.3: Pitching angle of the propeller [19]

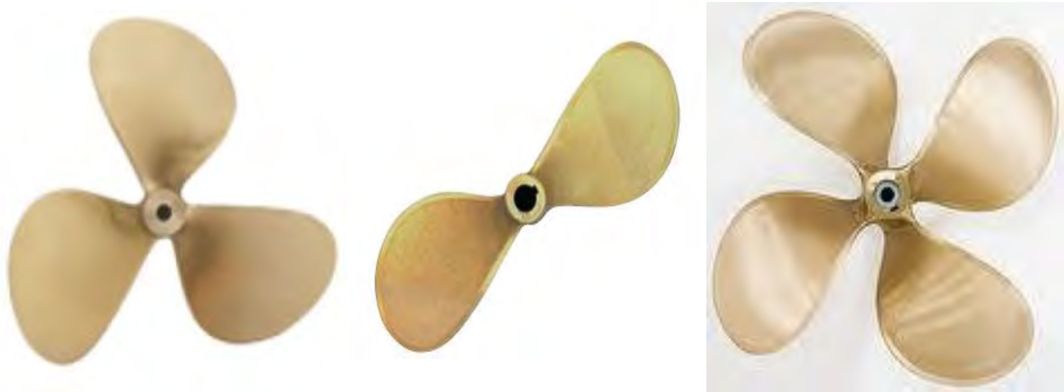

Figure 2.4: Propellers with different number of blade [19]

Gear reduction which directly connect the fan motor, and to a certain blade, tangential speed measured at a few simple radial position (usually taken at 0.7R), is such that the velocity of the fluid relative to the blade is given by,

$$U_p = \frac{0.7 r \omega_m}{N} \quad (2.1)$$

Now, depending on the velocity of the incoming fluid particles relative to the propeller blading, U_a, an inlet effective angle of attack is established, modelled by the variable, as in Figure 2.5 where:

$$\alpha_e = (\pi/2 - p) - \arctan\left(\frac{U_a}{U_p}\right) \quad (2.2)$$

The total relative velocity squared magnitude is then

$$v^2 = U_p^2 + U_a^2 \quad (2.3)$$

According to both theory and experiments in aerodynamics, blade develops lift and drag lift which is perpendicular to the line power component immediate action impinging flow on the blade. Drag force is consistent with the flow. Both are related to the square of the magnitude of the inflow velocity relative and depend on the effective angle of attack. For small angles, the lift force is linear with α_e, while the drag force is modelled better by $\alpha_e|\alpha_e|$.. The resulting model for the lift and drag forces on the blades is: