DESIGN AND ANALYSIS A CONTROLLER

FOR AUV PATH NAVIGATION SYSTEM

FAHMI AMIRUL BIN MOHAMMAD

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DECLARATION

I have declared that this project report entitled "Design and Analysis A Controller For AUV Path Navigation System" is the results of my own work accept cited in references.

Signature : ....

Name of Supervisor : ....

Date : ....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Maintenance).

Signature : ....

Name of Supervisor : Dr. MOHD KHAIRI

Date : 4/7/19

DEDICATION

To my beloved parents Rosnah Bte A.Samad and Mohammad Bin Mohd Zain.

ABSTRACT

The uses of Autonomous Underwater Vehicle (AUV) is widely used in multiple field with each AUV have their own specific task given. AUV is designed to ease human work and extend the capability of human that are unable to do it such as operate for a long period of time in underwater and operate in a high-risk condition. For example, AUV been used in Oil and Gas industries to check underwater piping and it also been used in military as a valuable asset in surveying. AUV is not only been used in heavy industries but it is also being used for recreational purposes too. Most of the AUV have the same problem that hard to overcome which is to maintain its movement path to desire location. The water current is unpredictable this will make the AUV to drift away from its original path especially when the AUV operate in a deep ocean where the water current is really strong. Maintaining the AUV path is one of the big challenges in designing AUV so that it can operate efficiently with less disturbance towards its movement. If the AUV deviate away from its movement path this will causes the AUV to reach the desire location longer time as the AUV need to return to its original path and worst scenario the AUV might not reach its destination. Therefore, this project was carried out to design and analysis a controller for the AUV path navigation system. A PID controller was chose as the controller for the AUV. The mathematical modeling of the AUV is obtain and Simulink software were used to do the simulation of the AUV. The proportional gain, integral gain and derivative gain of the PID is study to understand the effect of each gain towards the speed and positioning of the AUV. Each PID gain effect the speed and positioning of the AUV differently and each gain is carefully selected to design a PID configuration that can improve the speed and position. The PID configuration undergoes fine adjustment to tweak some error. During the fine adjustment certain PID gain were changed to suit the configuration and the result is some gain manage to improve the speed and position.

ABSTRAK

Penggunaan Autonomous Underwater Vehicle (AUV) digunakan secara meluas di dalam pelbagai bidang di mana setiap AUV mempunyai ciri-ciri tertentu untuk melaksanakan tugasan yang diberikan. AUV dicipta untuk memudahkan tugasan manusia dan melaksanakan tugasan yang diluar jangkauan manusia seperti beroperasi dibawah permukaan air bagi tempoh masa yang lama serta beroperasi dikawasan yang mempunyai risiko bahaya yang tinggi. Sebagai contoh, AUV digunakan di dalam bidang minyak dan gas untuk memeriksa paip di dasar lautan dan AUV juga digunakan dalam bidang ketenteraan sebagai asset penting untuk pemantauan. AUV juga bukan sahaja digunakan di dalam industri berat malahan digunakan sebagai tujuan rekreasi. Kebanyakan AUV mempunyai masalah yang sama yang sukar untuk diselesaikan iaitu untuk mengekalkan laluan pergerakan ke destinasi yang dikehendaki. Arus air sukar untuk diramal ia menyebabkan AUV mudah untuk menyimpang daripada laluan pergerakan yang asal terutama apabila beroperasi di laut dalam dimana arus air sangat kuat. Mengekalkan laluan pergerakan AUV adalah cabaran yang besar dalam mencipta AUV supaya AUV dapat beroperasi dalam kecekapan yang tinggi dengan sedikit gangguan terhadap pergerakan. Sekiranya AUV menyimpang daripada laluan pergerakan ini akan menyebabkan AUV untuk sampai ke destinasi yang dikehendaki dengan mengambil masa yang lama disebabkan AUV perlu membetulkan semula laluan pergerakannya dan bagi senario yang paling teruk AUV mungkin tidak akan sampai ke destinasi yang dikehendaki. Oleh sebab itu, projek ini dilaksanakan untuk mencipta dan menganalisa pengawal bagi pergerakan AUV. PID telah dipilih sebagai pegawal pergerakan AUV. Model matematik bagi AUV tersebut telah diperolehi dan perisian Simulink digunakan untuk membuat simulasi.'Proportional Gain', 'Integral Gain', 'Derivative Gain' untuk PID tersebut telah di periksa dahulu untuk memahami bagaimana ianya mempengaruhi kelajuan dan pergerakan AUV. Setiap 'Gain' memberi kesan yang berlainan terhadap kelajuan dan pergerakan AUV dan setiap 'Gain" telah dipilih secara terperinci untuk digunakan sebagai konfigurasi PID bagi menambah baik kelajuan dan pergerakan AUV. Konfigurasi PID tersebut telah melalui proses pelarasan untuk membaiki ralat. Semasa proses pelarasan, 'Gain' pada PID telah diubah mengikut kesesuaian konfigurasi dan hasilnya sebahagian 'Gain' mampu memperbaiki kelajuan dan pergerakan.

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Next, I would like to thank FKM Panther team for assisting and guide me especially during the Singapore Autonomous Underwater Challenge 2019. Hence, I would like to thank to my course mate for their moral support and suggestion.

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CONTENT

LIST OF FIGURES

LIST OF ABBREVIATIONS

AUV	Autonomous Underwater Vehicle
PID	Proportional Integral Derivative
DOF	Degree of Freedom
W-frame	World-fixed reference frame
B-frame	Body-fixed reference frame

LIST OF SYMBOLS

x_B	=	Surge B-frame
y_B	=	Sway B-frame
z_B	=	Heave B-frame
ϕ_B	=	Roll B-frame
θ_B	=	Pitch B-frame
ψ_B	=	Yaw B-frame
x	=	Surge W-frame
y	=	Sway W-frame
z	=	Heave W-frame
ϕ	=	Roll W-frame
θ	=	Pitch W-frame
ψ	=	Yaw W-frame
0_B	=	Origin of B-frame
0_w	=	Origin of W-frame
X	=	Degree of freedom of B-frame
η	=	Degree of freedom of W-frame
R^{BW}	=	Euler convention
v	=	Velocity vector of B-frame
$\dot{\eta}$	=	Velocity Vector of W-frame
τ	=	Force-torque vector of thruster input
v_B	=	Linear velocity of B-frame
ω_B	=	Angular velocity vector of B-frame.
v_W	=	Linear velocity of the W-frame
ω_W	=	Angular velocity of W-frame

$J(\eta)$	=	Coordinate transform matrix that brings the W-frame into alignment with B-frame
S	=	Sine
C	=	Cosine
T	=	Tangent
$M\dot{v}$	=	Mass and Inertia Matrix
$C(v)$	=	Coriolis and centripetal matrix
$D(v)$	=	Quadratic and linear drag matrix
$g\ (\eta)$	=	Gravitational and buoyancy matrix
τ	=	Force vector/ torque vector
M_{RB}	=	Mass of rigid body
M_A	=	Mass of added mass
m	=	Mass of the AUV
r_g	=	Center of gravity of AUV with respect of B-frame
I_B	=	AUV inertia tensor with respect to B-frame
C_{RB}	=	Coriolis rigid body term
C_A	=	Coriolis added mass term
$D_l(V)$	=	Linear drag matrix
$D_q(V)$	=	Quadratic drag matrix
X	=	Axial quadratic force
f_G	=	Gravitational force vector due to AUV weight
f_B	=	Buoyancy force vector caused by AUV buoyancy
L	=	Mapping matrix
U	=	Thrust Vector

CHAPTER 1

INTRODUCTION

1.1 Background

In this era where technology is becoming more and more sophisticated, AUV is not a something new anymore. AUV stand for autonomous underwater vehicle are untethered unmanned maritime robotic platforms. AUV is one of the categories of unmanned underwater vehicle (UUV) while the other one is remotely operated underwater vehicle, ROV. ROV have its own limitation where AUV can handle it. The need for a communication tether and a control platform for ROV have limited the use of ROV and also its capabilities due to the depth of water. This is where AUV become in handy because AUV doesn't need any human to operate it because AUV will think by itself in order to execute given mission. During 1957, the first AUV was developed by Stan Murphy, Bob Francois and later on by Terry Ewart at Applied Physics Laboratory at University of Washington. There're wide range of AUV application such as for commercial use, research, hobby, air crash investigation, and also military application.

1.2 Problem Statement

An autonomous underwater vehicle (AUV) is the machine that can operate underwater autonomously without the help from the operator. AUV is widely used in many field such as for maintenance of underwater structure like oil rig and bridge, detecting and mapping submerged wreck and obstruction that are potentially dangerous for commercial and recreational vessels navigation. Since the MH370 tragedy AUV became well known around the globe in aiding the search of the crash airplane. The usage of AUV is very challenging especially for its navigation. The ocean current is unpredictable thus the AUV can easily drift away without a proper navigation system. The main problem with AUV is to create a navigation system that can ensure the AUV move to the desired location accurately. Nowadays, researcher is still struggling in creating the almost perfect navigation system for AUV. This project is focus on creating the proper navigation system for the PID by using PID as its controller.

1.3 Objective

The objective of this project is as follow:

1. To design and analysis the controller for AUV to make it move according to desired path.

1.4 Scope of Project

The scopes of this project are:

1. The controller is for AUV developed by FKM team as shown below

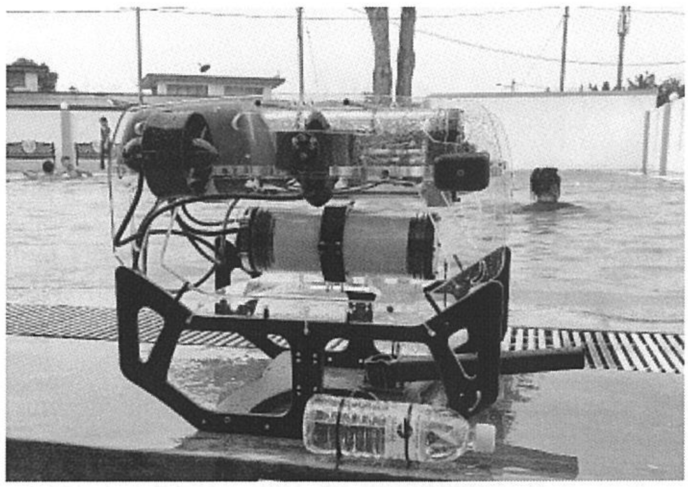

Figure 2.1 FKM team AUV.

2. The dimension of the AUV is not exceed $140 \times 100 \times 100\ cm$ and less than 50kg in mass.

3. The controller is design to improve the positioning and speed of AUV.

4 Simulink software is used to simulate the AUV in the real world.

5. The simulation is only for surge degree of freedom only.

CHAPTER 2

LITERATURE REVIEW

2.1 Autonomous Underwater Vehicle (AUV) Design

Designing an AUV has several stages that generally can be divided into two stages which are designing the mechanical structure and the other one is the development of internal and external electrical design. It's vital to have a proper knowledge when designing AUV especially about the concept, theory, and physical law of AUV while it's underwater in a vary condition. A proper mechanical and electrical design play an important role in order to determine the successful of the AUV because it will aid the AUV navigation. The structure and design aspect that need to be focus are such as hull design, propulsion, electric power, and submerging. After the AUV is well designed a controller is added to navigate and ensure the AUV move according to the trajectories and also reached the desired location without overshoot. This controller act like a brain that instruct the AUV to move with the helped of the mechanical and electrical structure of the AUV so if the AUV have any defect with its design then the brain can't operate efficiently. Figure 2.1 shows commercial AUV that is customizable.

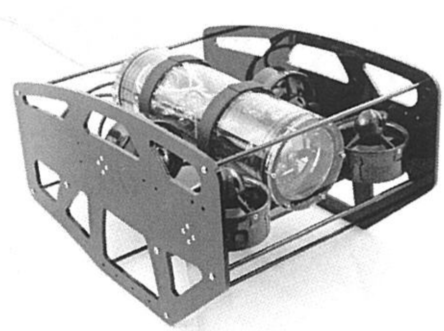

Figure 2.2 Blue Robotics automated underwater vehicle.

2.2 AUV Controller

There're many types of controller being used in AUV to help its navigation such as PID, Fuzzy, Feed Forward Controller and Velocity Feedback Controller but the most commonly used are Fuzzy and PID controller. The controller selection depends on the characteristic of the AUV because not every controller suitable for every AUV this is due to each AUV have different specification and job scope. Every AUV doesn't limited to only one controller only it can have more than one controller as stated by the author their AUV have 3 controllers onboard and it's also not a compulsory to have more than one controller. The AUV that have many controllers onboard, each of the controller will have different output such as there will be controller that controlling the motion axis of the AUV and there will be controller that will control the speed of the AUV. Whereas, the AUV that only have one controller, the controller will control both of the motion axis of AUV and the speed of the AUV. In designing AUV one must consider the motion axis which is 6 degree of freedom (DOF) as shown in figure 2.2. The controller will take all of the 6 DOF into calculation to come out with a suitable equation of motion but this is complex. Hence, in order to make the AUV less complicated the controller only responsible to 3 Degree of Freedom (DOF) instead of 6 DOF because If the AUV is symmetry the DOF can be decoupled into 3 DOF which are Surge, Heave and Yaw degrees of freedom.

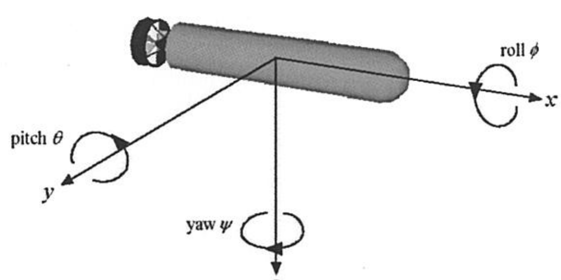

Figure 2.3 shows 6 degree of freedom.

2.3 Comparison of PID and Fuzzy

The advantages of PID controller is it provide of simple, clear, practical parameter of stable and reliable while it disadvantage is mathematical model need to be accurately establish. Fuzzy doesn't need an accurate mathematical model resulting the limitation of sensitivity and stability of the AUV. In general, Fuzzy logic controller tuning process is mainly by trial-and-error while for PID the tuning process are by tuning the value of the system parameter. In term of rise time, and overshoot PID give a better performance compare to Fuzzy.

2.4 Proportional Integral Derivative (PID)

As mention in 2.2 AUV Controller the controller that are mostly been used are PID and Fuzzy controller. Matlab/Simulink can run both of the controller but they have different tuning process and the way they work to get an output is much different. PID means Proportional-Integral-Derivative (PID) where it is a mechanism that have a control loop feedback. The way the PID work is by continuously calculates the difference value between the setpoint to the system and the measured process variable. The difference value is known as error value $e(t)$ which then will be corrected based on the proportional, integral and derivative as the PID name itself. The PID can be expressed mathematically as

$$u(t) = K_p e + K_i \int e + K_d \frac{de}{dt}$$

Where:

$u(t)$	: Output of the system
K_p	: Proportional gain
K_i	: Integral gain
K_d	: Derivative gain
e	: Error between setpoint and the measured process variable
$\int e$	: Summation error of steady state error
$\frac{de}{dt}$	: Rate of change of error

K_p will make sure the error is small and if there is any deviation from the setpoint then it will alter the system to closer to the setpoint but it doesn't have much effect to counter steady-state error.

K_i is the gain that will reduce or eliminate the steady-state error due to the uniform or slow changing imbalance or disturbance towards the system. Overtime the steady-state error will accumulate and become larger hence, K_i create a required request for actuation to eliminate it.

K_d act as a damper for the system. It's used to reduce the rate of change of the state in order to avoid from overshoot and oscillations. Thus, K_p and K_i can be larger and have more control of the system. Figure 2.3 illustrates basic close-loop depth control using PID controller.

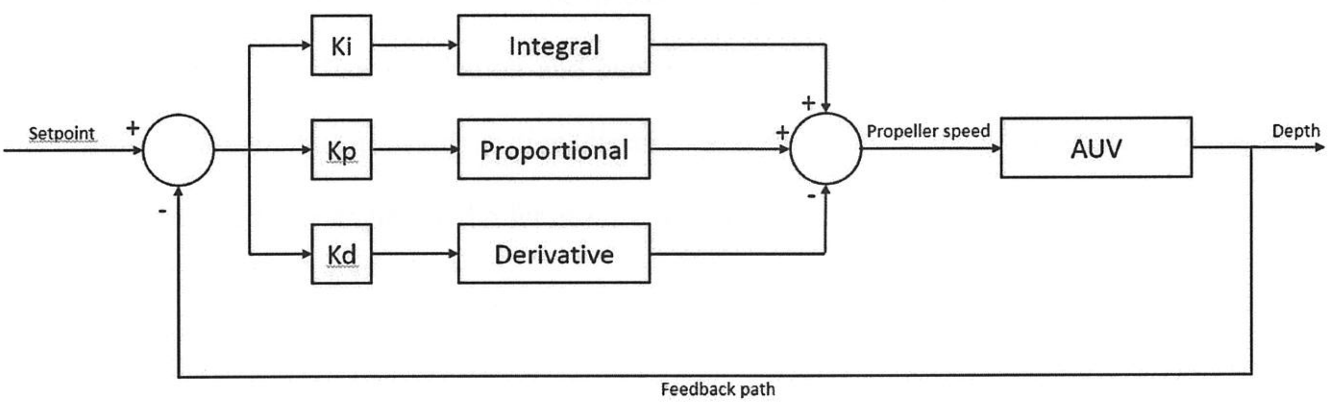

Figure 2.3 PID controller used for depth control.

CHAPTER 3

METHODOLOGY

3.1 Overview of Kinematic and Dynamic Model of AUV

Controlling an AUV underwater is intricate due to the complex and nonlinear force that acting upon the AUV while working underwater. The example of the forces are environmental disturbances, thruster force, gravity and buoyance force, Coriolis and centripetal force, lift forces, damping and hydrodynamic drag.

Dynamic Model of AUV will be discuss on next section which will describe about the hydrodynamic damping, gravitation and buoyance force, mass and inertia, and Coriolis and centripetal force. The afterwards section, discuss about Kinematic of the AUV where state space representation, Euler angles, and reference frame explained.

3.2 Dynamic Model of AUV

Newton Euler equation of a rigid body in fluid is derived to get the Dynamic Model of the AUV (W & C, 2001). Later, the equation is able to do simulation and to formulate control algorithm for the AUV. The dynamic model is as below and it's not considering environmental disturbance

$$M\dot{v} + C(\nu)\nu + D(\nu)\nu + g(\eta) = \tau \quad (3.1)$$

Where,

$M = M_{RB} + M_A$: Mass and inertia matrix.

$C(V) = C_{RB}(V) + C_A$: Coriolis and centripetal matrix.

$D(V) = D_q(V) + D_l(V)$: Quadratic and linear drag matrix.

$g\ (\eta)$: Gravitational and buoyancy matrix.

τ : Force vector/ torque vector.

3.2.1 Mass and Inertia Matrix

$$M = M_{RB} + M_A \tag{3.2}$$

Mass and Inertia matrix is a submission of rigid body, M_{RB} and added mass, M_A. Added mass is a part of hydrodynamic force and moment. It's also known as pressured induced force and/or moment which is the result of AUV body force motion.

The expand equation of rigid body, $M_{RB}\dot{V}$ from (3.1) is

$$M_{RB}\dot{V} = \begin{bmatrix} m\dot{v}_B + m\dot{\omega}_B \times r_g \\ I_B\dot{\omega}_B + mr_G \times \dot{v}_B \end{bmatrix} \tag{3.3}$$

Where,

m : Mass of the AUV.

r_g : Center of gravity of AUV with respect of B-frame.

$$r_g = [x_G \quad y_G \quad z_G]^T$$

I_B : AUV inertia tensor with respect to B-frame

$$I_B = \begin{bmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{yx} & I_{yy} & -I_{yz} \\ -I_{zx} & -I_{zy} & I_{zz} \end{bmatrix} \tag{3.4}$$

$$I_{xx} = \int (y^2 + z^2)\, dm \qquad I_{xy} = I_{yx} = -\int (xy)\, dm$$

$$I_{yy} = \int (x^2 + z^2)\, dm \qquad I_{yz} = I_{zy} = -\int (yz)\, dm$$

$$I_{zz} = \int (x^2 + y^2)\, dm \qquad I_{xz} = I_{zx} = -\int (xz)\, dm$$