Faculty of Manufacturing Engineering

ADAPTIVE SIMPLIFIED FUZZY LOGIC CONTROLLER OF UNMANNED UNDERWATER VEHICLE FOR DEPTH AND PITCH CONTROL

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ADAPTIVE SIMPLIFIED FUZZY LOGIC CONTROLLER OF UNMANNED UNDERWATER VEHICLE FOR DEPTH AND PITCH CONTROL

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DECLARATION

I declare that this thesis entitled "Adaptive Simplified Fuzzy Logic Controller of Unmanned Underwater Vehicle for depth and pitch control" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature any other degree.

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APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfilment of Master of Manufacturing Engineering (Manufacturing System Engineering).

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DEDICATION

To my beloved mother and father

ABSTRACT

Fuzzy Logic Controller (FLC) is an intelligent control that completed and performed with inference rules and membership function. Unmanned Underwater Vehicle (UUV) is a submarine-like robot device that can deploy for underwater tasks, such as deep sea survey and rescue operation, repair and maintenance for seabed petroleum gas pipeline. Fuzzy Logic Controller has various efforts and advantages instead of linear controller to control the depth and pitch angle of an UUV due to the ability of FLC to adopt the hydrodynamics uncertainties underwater. However, conventional fuzzy logic controller (CFLC) requires more computational power due to their Multi Input Single Output (MISO) method, complex processes and decision making that deal with rules based storage, membership function, fuzzification and de-fuzzification processes. In this project, an Adaptive Simplified Fuzzy Logic Controller (ASFLC) is proposed for depth and pitch angle control of an UUV, where ASFLC is a controller operate by using Single Input Single Output (SISO) method. ASFLC simplified the rules based storage and reduce the inputs for UUV's depth and pitch angle control parameters. Performance of proposed ASFLC is validated by simulation in Matlab/Simulink. ASFLC cre ated based on the signed distance method, which eventually reduces the controller as a single-input single-output (SISO) controller. As a result, the rise time and settling time of depth and pitch angle is faster and overshoot of the system is reduced compared to conventional fuzzy logic controller and provides a significant reduction in rules, tuning parameters and a simpler control structure, as compared to the conventional FLC.

ABSTRAK

Pengawal Fuzzy Logic (FLC) merupakan suatu kawalan pintar yang disiapkan dan dilaksanakan dengan kaedah-kaedah inferens dan fungsi keahlian. Kenderaan dalam air tanpa pemandu (UUV) adalah sejenis robot yang berfungsi serupa kapal selam, tetapi kenderaan ini bukan sahaja digunakan untuk melaksanakan tugas dibawah air, malah ia juga berupaya membuat kajian serta menjalankan operasi menyelamat di laut dalam dan pembaikan/penyelenggaraan untuk saluran paip gas petroleum dasar laut. Pengawal Fuzzy Logic mempunyai pelbagai kelebihan berbanding dengan pengawal linear tradisional dari segi mengawal kedalaman dan padang sudut suatu UUV kerana keupayaan FLC untuk menganalisasi terhadap ketidaktentuan hidrodinamik dalam air. Walau bagaimanapun, pengawal Fuzzy Logic tradisional (CFLC) memerlukan lebih banyak kuasa daripada sistem komputer disebabkan ia menggunakan kaedah Lebih Input Satu Output (MISO), dimana CFLC lebih kompleks dari segi proses dan CFLC membuat keputusan berasaskan storan, fungsi keahlian, proses fuzzification dan proses de-fuzzification. Dalam projek ini, Adaptive Simplified Fuzzy Logic Controller (ASFLC) telah dicadang dan dilaksanakan untuk mengawal kedalaman dan kawalan sudut padang kenderaan dalam air tanpa pemandu, dimana ASFLC beroperasi berdasarkan kaedah Satu Input Satu Output (SISO). ASFLC mempermudahkan penyimpanan dalam storan berasaskan peraturan dan mengurangkan input untuk kawalan kedalaman dan kawalan sudut padang UUV. Prestasi ASFLC yang dicadangkan telah disahkan dengan menjalankan simulasi Matlab/Simulink. Dengan bantuan kaedah signed distance method (SDN), ASFLC akhirnya dapat mengurangkan input pengawal dan menjadikannya sebagai pengawal Satu Input Satu Output (SISO). Sebagai keputusan, kawalan masa kenaikan dan masa penetapan sistem UUV dari segi kawalan kedalaman serta sudut adalah lebih cepat dan peratusan terlajak sistem telah dikurangkan jika berbanding dengan pengawal Fuzzy Logic tradisional dimana ASFLC juga mengurangkan peraturan storan pengawal, parameter penalaan dan struktur kawalan yang lebih mudah dengan ketara.

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LIST OF SYMBOLS

m	-	Meter
Tr	-	Rise time
Ts	-	Settling time
OS%	-	Percentage overshoot
Ess	-	Steady state error
°	-	Degree of angle
d	-	Depth

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CHAPTER 1

INTRODUCTION

1.1 Background

Within past few decades, there has been an explosion of interest in Autonomous Underwater Vehicle (AUV) and Remotely Operated Underwater Vehicle (ROV). AUV as shows in figure 1.1 and ROV as shows in figure 1.2 are being utilized to explore the ocean depth, survey and aid in salvage operations, and are even used in keeping the safety of soldiers and sailor.

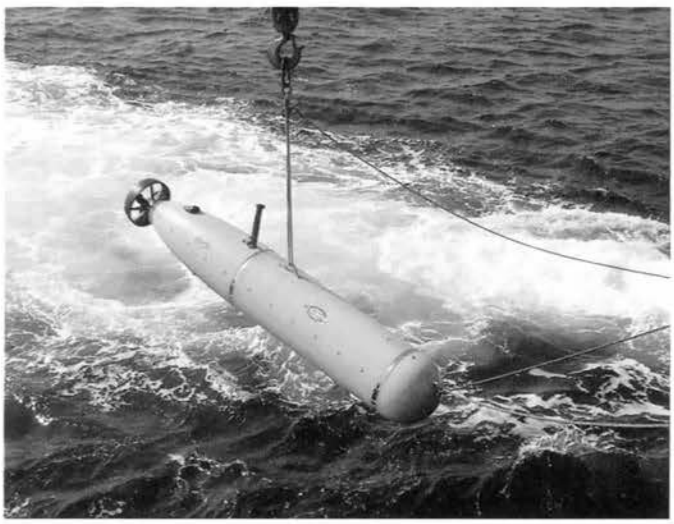

Figure 1.1: Autonomous Underwater Vehicle (Joey, 2007).

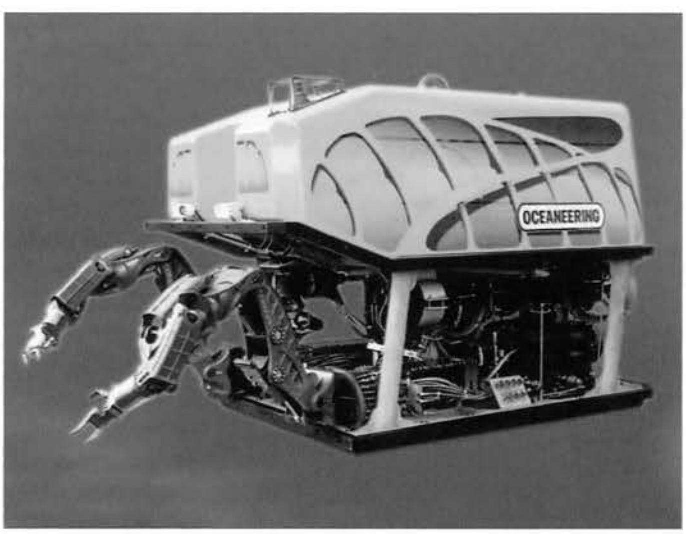

Figure 1.2: Remotely Operated Underwater Vehicle (Joey, 2007).

Yanrui Geng et al. (2010) pointed out that next generation of UUVs will need to be able to navigate in water with a variety of obstruction: pier pylons, kelp beds, oil platforms, etc (shown in figure 1.3). The usage of an UUV in typical military mission is to map an area and detect or determine if the seabed area have any mines. It also can make sure that an area (such as a harbor) that is protected monitoring by UUV for detect new unidentified objects. In the field of anti-submarine warfare, UUV also can use to aid in the detection of manned submarines.

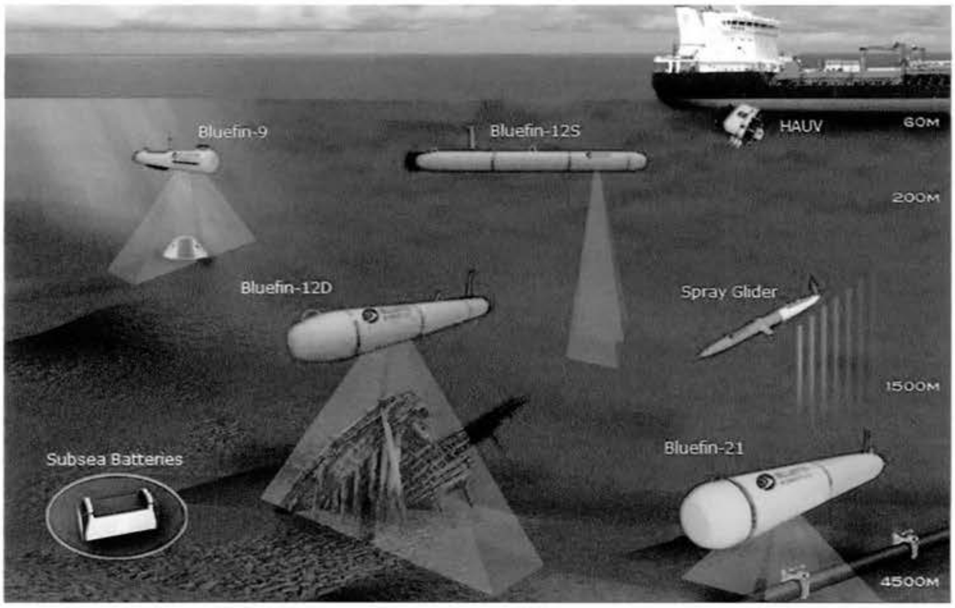

Figure 1.3: Bluefin Robotics AUV (Mr Smith, 2008).

In this project, the main purpose is to propose an adaptive simplified artificial intelligence controller for pitch and depth control of an UUV which called Adaptive Simplified Fuzzy Logic Controller (ASFLC). According to the research of D. Taylor Anderson (1993), navigation control of UUV which consist pitch angle and depth control is important due to the accurately and efficiently needed to collect data on the seabed and UUV must able to trace path smoothly at a variety of depths in the ocean. Thus, a high accuracy navigation control system is important in UUV in order to pass through each desired point underwater efficiently. Hence, this project will proposed an Adaptive Simplified Fuzzy Logic Controller (ASFLC) as UUV's depth and pitch control with carried out a study on the analysis of transient response of UUV in depth and pitch control by using ASFLC.

1.2 Problem Statement

Pitch angle is the angle of UUV's turning up or down while depth control is desired by the task of UUV. Controlling the depth and pitch angle of an UUV is important due to unknown hydrodynamics in the sea. Measurement of pitch angle and the error of angle can be interacted into the UUV's obstacle avoidance system along paths and waypoint along z-axis. Paths are determined by a path planner which figures a series of waypoints through which the vehicle must travel to complete an obstacle avoidance action. A depth control system in terms of pitch angle is necessary for the UUV to pass through each desired point smoothly and accurately.

This project is concerned with the development of an Adaptive Simplified Fuzzy Logic Controller (ASFLC) to control the pitch angle of UUV. Fuzzy Logic Controller (FLC) is an intelligent control that completed and performed with inference rules and membership function. Unmanned Underwater Vehicle (UUV) is a submarine-like robot device that can deploy for underwater tasks, such as deep sea survey and rescue operation, repair and maintenance for seabed petroleum gas pipeline.

Fuzzy Logic Controller has various efforts and advantages instead of linear (conventional) controller to control the depth and pitch angle of an UUV due to the ability of FLC to adopt the hydrodynamics uncertainties underwater. However, conventional fuzzy logic controller (CFLC) requires more computational power due to their Multi Input Single Output (MISO) method, complex processes and decision making that deal with rules based storage, membership function, fuzzification and de-fuzzification processes.

An ASFLC is proposed for depth and pitch angle control of an UUV, where ASFLC is a controller operate by using Single Input Single Output (SISO) method (K. Ishaque et al., 2011). ASFLC simplified the rules based storage and reduce the inputs for UUV's depth and pitch angle control parameters. Performance of proposed ASFLC is validated by simulation in Matlab/Simulink. As a result, the rise time and settling time of depth and pitch angle should faster and overshoot of the system is reduced.

1.3 Objectives

i. To propose an Adaptive Simplified Fuzzy Logic Controller (ASFLC) in depth and pitch angle control system of Unmanned Underwater Vehicle (UUV).

ii. To validate the feasibility of Single Input Single Output (SISO) method fuzzy controller using Matlab/Simulink.

iii. To analyze the transient response of ASFLC in UUV's depth and pitch angle control.

1.4 Scope of Project

The main scope of this project is to propose an Adaptive Simplified Fuzzy Logic Controller for depth and pitch control of UTeM UUV. The measurement unit for UUV's pitch angle is Inertial Measurement Unit (IMU) which is the combination of accelerometer and gyroscope. Controller design and simulation is done by Matlab R2011b. The parameters that will be discussed are transient response of the proposed controller which consists:

i. Rise time, *Tr*

ii. Steady state error, *Ess*

iii. Percentage of overshoot, *OS%*

iv. Settling time, *Ts*

v. Depth of UUV, *m*

1.5 Significant of Study

This thesis provided an Adaptive Simplified Fuzzy Logic Controller which not only reduced the overshoot percentage, but faster the rise time and settling time of UUV depth and pitch control. Further, this study would also be a review on present UUV's navigation control system. Data gathered will be the reference of UUV obstacle avoidance system in the future.

1.6 Contribution of Project

This thesis proposed one of the types of intelligence controller (ASFLC) for the depth and pitch control of Unmanned Underwater Vehicle (UUV) in University Teknikal Malaysia Melaka (UTeM). Furthermore, this study would be provide the necessary data navigation control and would be beneficial to the future UUV researcher in UTeM that understood and more convenience in order to assign mission which required complex pathway to their UUV, especially obstacle avoidance system in UTeM's UUV.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Unmanned Underwater Vehicle (UUV)

In the field of geophysics, marine and naval meteorology, dialysis of the ocean and the seabed is one of the important needed. Especially in clarification for estimate about earthquake or tsunami mechanism, investigate the global warming and the specific seafloor topography (Shojiro Ishibashi et al, 2007). An Unmanned Underwater Vehicle (UUV) which is completed with an autonomous navigation system is the one of the device or vehicle that can fulfill the needs of these dangerous underwater jobs.

2.2 Navigation System of UUV

According to the Pan-Mook Lee et al. (2001), the navigation system is one of the basic parts of an AUV. The navigation that provided by them is an integrated system that built by range sonar sensor, inertial unit and Doppler Velocity Log sensor. The main unit of that integrated navigation is acoustic sensor. The basic operation of this system is based on a strap down inertial measurement unit (IMU). So, the auxiliary navigation includes range sonar sensor, DVL sensor, magnetic compass and a depth pressure sensor.

The performance of the IMU-DVL navigation can be improved by additional range information according to the author. On an undersea station, the range sonar sensor can sense the distance and angle that produce by a transponder if this transponder as reference point. The disadvantage of DVL sensor is cannot detect the lower seabed reflection. So, the sonar sensor can be modelled to improve the algorithm of navigation. It will provide important information to the IMU-DVL, hence the estimation error can be reduced.

Shojiro Ishibashi et. al (2000) presents the pseudo long base line (PLBL) navigation algorithm and evaluates the convergence characteristics of initial position error. They suppose that a transducer is installed at a UUV and two acoustic transponders are installed at two reference stations on sea bottom or below surface. They also suppose initial position obtained by ultra short base line (USBL) can be transmitted to the UUV via an acoustic link. Figure 2.1 show the concept of PLBL navigation with two range measurement sensors. The navigation system consists of an SD-IMU mounted on the UUV and assisted with auxiliary navigation sensors, such as two ranges, depth, and heading sensors, excluding DVL. The transducer on the UUV transmits acoustic signal and the two reference stations respond with interrogation signals to the vehicle. The UUV can calculate two ranges by processing the travel time of acoustic signals from the stations. Using the two range measurements, the navigation system is able to improve the performance of conventional IMU-DVL navigation systems for long-time operation of underwater vehicles, and useful even without DVL information.

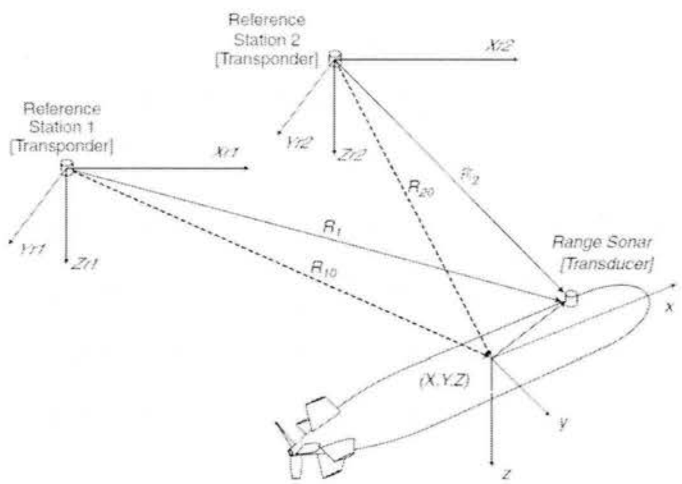

Figure 2.1: Coordinates of the range measurement of a UUV for two reference stations (Shojiro Ishibashi et. al, 2000).

2.3 PID Controller

PID controller is the most use at current technology, it was an essential element of early governors and it became the standard tool when process control emerged in the 1940s. According to the research of Karl Johan Astrom in 2002, 95% of controller in control loop is PID controller. Most loops are actually PI control.

PID controller normally combined with sequential, logic and function to build a complete system. The system of PID either stand-alone or contains few loops in a box. According to Karl research, PID control is an important ingredient of a distributed control system. The controllers are also embedded in many special-purpose control systems.

However, PID control is used at the lowest level; the multivariable controller gives the set points to the controllers at the lower level (Karl Johan Astrom, 2002).

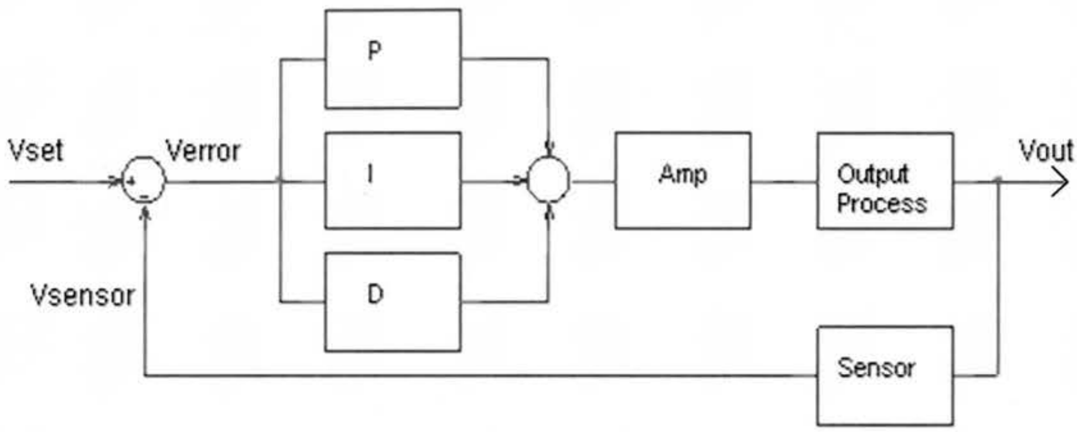

Figure 2.2: Block Diagram for PID Controller.

Figure 2.2 shows the basic configuration of PID controller. Basically, PID consists three main parameter which are Kp, Kd and Ki as table 2.1. Optimization of PID control system can be done by tuning the gain value of Kp, Kd and Ki. Hence, system overshoot, steady state error and system overshoot will be improved.

Table 2.1: Kp, Kd and Ki of PID controller.

Term	Math Function	Effect on Control System
P Proportional	KP	Typically the main drive in a control loop, KP reduces a large part of the overall error.
I Integral	KI	Reduces the final error in a system. Summing even a small error over time produces a drive signal large enough to move the system toward a smaller error.
D Derivative	KD	Counteracts the KP and KI terms when the output changes quickly. This helps reduce overshoot and ringing. It has no effect on final error.

2.4 Fuzzy Logic Controller (FLC)

Sujit S. Nerurkar (1994) described that in a conventional proportional, integral, and differential (PID) controller, what is modeled is the system or process being controlled, whereas in a fuzzy logic controller, the focus is the human operator's behavior. The system is modeled analytically by a set of differential equations, and their solution tells the PID controller how to adjust the system's control parameters for each type of behavior required. In the fuzzy controller, these adjustments are handled by a fuzzy rule-based expert system, a logical model of the thinking processes a person might go through in the course of manipulating the system.

This shift in focus from the process to the person involved, changes the entire approach to automatic control problems. The inference rules in the fuzzy expert system may take the form "if observed variable x is 'positive medium,' then change the control variable y by the amount 'negative medium." The model derives the designation "fuzzy" from its use of such terms as "positive medium," "positive large," and "no change," which in turn form a fuzzy subset of the associated measurement domain. As such, the system being controlled is formally viewed as a fuzzy system. This is why fuzzy controllers are simpler than conventional PID controllers.

Fuzzy logic works by accepting and processing analog input signals to judge or infer reliable conclusions from a combination of a few variable inputs, either calculated or received from an analog output device. It is best used in applications such as set point control (error nulling), discrimination (sorting), identification, and image processing.

Saflida Nor (2006) stated that fuzzy logic starts with the concept of a fuzzy set. A fuzzy set is a set without a crisp, clearly defined boundary. It can contain elements with only a partial degree of membership. Unlike classical set theory that classifies the elements of the set into crisp set, fuzzy set has an ability to classify elements into a continuous set using the concept of degree of membership. The characteristic function or membership function not only gives 0 or 1 but can also give values between 0 and 1. A fuzzy set is a set with fuzzy boundaries. In fuzzy logic, the truth of any statement becomes a matter of degree. Any statement can be fuzzy. A value between 0 and 1 represents the degree of membership, also called membership value.