ADAPTIVE SIMPLIFIED FUZZY LOGIC CONTROLLER FOR DEPTH CONTROL OF UNDERWATER REMOTELY OPERATED VEHICLE

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DEDICATION

This project is dedicated to my mom, Mariam binti Mahat, my lovely wife Norzaima binti Zainal Badri and my sons Ammar Zulqarnain, Adam Zahirulhaq and Annas Zulqairy and not forgets to my friends who have always sincerely pray for my success and glory.

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ABSTRACT

A Remotely Operated Vehicle (ROV) is one class of the unmanned underwater vehicles that is tethered, unoccupied, highly manoeuvrable, and operated by a person on a platform on water surface. For depth control of ROV, an occurrence of overshoot in the system response is highly dangerous. Clearly an overshoot in the ROV vertical trajectory may cause damages to both the ROV and the inspected structure. Maintaining the position of a small scale ROV within its working area is difficult even for experienced ROV pilots, especially in the presence of underwater currents and waves. This project, focuses on controlling the ROV vertical trajectory as the ROV tries to remain stationary on the desired depth and having its overshoot, rise time and settling time minimized. This project begins with a mathematical and empirical modelling to capture the dynamics of a newly fabricated ROV, followed by an intelligent controller design for depth control of ROV based on the Single Input Fuzzy Logic Controller (SIFLC). Factors affecting the SIFLC were investigated including changing the number of rules, using a linear equation instead of a lookup table and adding a reference model. The parameters of the SIFLC were tuned by an improved Particle Swarm Optimization (PSO) algorithm. A novel adaptive technique called the Adaptive Single Input Fuzzy Logic Controller (ASIFLC) was introduced that has the ability to adapt its parameters depending on the depth set point used. The algorithm was verified in MATLAB® Simulink platform. Then, verified algorithms were tested on an actual prototype ROV in a water tank. Results show it was found that the technique can effectively control the depth of ROV with no overshoot and having its settling time minimized. Since the algorithm can be represented using simple mathematical equations, it can easily be realized using low cost microcontrollers.

ABSTRAK

Kenderaan Operasi Kawalan Jauh (ROV), adalah salah satu daripada kenderaan dalam air tanpa manusia, mempunyai kabel dan mudah dikendalikan oleh jurumudi daripada platform di permukaan air. Bagi kawalan kedalaman ROV, sekiranya ia terlajak daripada had ketetapan kedalaman yang dikehendaki, maka risikonya adalah sangat berbahaya. Jelas sekali, sekiranya ia melebihi had kedalaman yang ditetapkan, kerosakan pada ROV atau pada struktur yang hendak diperiksa boleh berlaku. Penstabilan posisi ROV skala kecil di kawasan kerjanya adalah satu tugas yang sukar, terutamanya apabila ada arus dalam air dan ombak, walaupun dikendalikan oleh jurumudi ROV yang berpengalaman. Projek ini memberi fokus kepada reka bentuk pengawal ROV bagi memastikan ianya stabil dan mengikut kedalaman yang telah ditetapkan tanpa wujudnya lajakan, dengan memiliki masa naik dan masa pengenapan yang pantas. Projek ini bermula dengan permodelan matematik dan empirikal bagi mewakilkan keadaan dinamik sebuah ROV baru dengan diikuti oleh reka bentuk pengawal pintar bagi kawalan kedalaman ROV. Pengawal pintar yang digunakan adalah berdasarkan Pengawal Logik Kabur Satu Masukkan (SIFLC) dimana faktor-faktor yang mempengaruhinya seperti jumlah aturan, penggunaan persamaan linear dan penambahan model rujukan telah dikaji. Parameter yang optima bagi SIFLC telah ditentukan menggunakan algoritma Pengoptimuman Kumpulan Zarah (PSO). Satu kaedah pengawal mudah suai baru telah diperkenalkan iaitu Mudah Suai Pengawal Logik Kabur Satu Masukkan (ASIFLC) yang mempunyai kebolehan menyesuaikan parameternya bergantung kepada nilai kedalaman yang ditetapkan. Pelaksanaan pengawal baru ini telah disahkan menggunakan perisian MATLAB® Simulink. Algoritma ini kemudiannya diuji pada prototaip sebenar ROV di dalam tangki air. Keputusan membuktikan bahawa teknik ini berjaya mengawal ROV dengan berkesan dengan tiada lajakan dan dengan masa pengenapan yang singkat. Oleh kerana algoritma pengawal ini dapat diwakilkan menggunakan persamaan matematik yang mudah, ianya boleh direalisasikan dengan menggunakan pengawal mikro kos rendah.

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LIST OF SYMBOLS

B	–	Vehicle's buoyancy
C	–	Matrix of the Coriolis and centripetal forces
D	–	Vector of forces on vehicle due to drag
g	–	Vector of forces on vehicle due to gravitational effects
Ix, Iy, Iz	–	Moments of inertia around the vehicle's x-,y-, and z- axes respectively
J	–	Euler angle transformation matrix
K, M, N	–	Moment about the vehicle's x-,y-, and z- axis respectively
K_D	–	Derivative gain, a tuning parameter
K_I	–	Integral gain, a tuning parameter
K_P	–	Proportional gain, a tuning parameter
L_{NS}	–	Diagonal line of Negative Small membership function
L_{NL}	–	Diagonal line of Negative Large membership function
L_{PS}	–	Diagonal line of Positive Small membership function
L_{PL}	–	Diagonal line of Positive Large membership function
L_Z	–	Diagonal line of Zero membership function
L	–	Vehicle length
m	–	Vehicle's mass
N_1	–	The minimum costing horizon
N_2	–	The maximum costing horizon
Nu	–	The control horizon
p	–	Roll rate [rad/s]
q	–	Pitch rate [rad/s]
r	–	Yaw rate [rad/s]
$S(t)$	–	Set point trajectory

Tref	–	Speed response
Ts	–	Sampling interval
U	–	Surge speed [m/s]
V	–	Sway speed [m/s]
w	–	Heave speed [m/s]
X, Y, Z	–	Forces parallel to the vehicle's x-,y-, and z- axes respectively
x_B, y_B, z_B	–	Position of vehicle's centre of buoyancy
x, y	–	Horizontal position of vehicle with regard to earth-fixed coordinates
y(k)	–	Plant output
x_G, y_G, z_G	–	Position of vehicle's centre of mass
ym	–	Predicted output of the neural network
yr	–	Reference trajectory
z	–	Depth [m]
η	–	Vector of global vehicle coordinate
Φ	–	Vehicle global roll angle [rad]
Θ	–	Vehicle global pitch angle [rad]
Ψ	–	Vehicle global yaw angle [rad]
λ	–	Main diagonal line slope
µ	–	Degree of membership
ρ	–	The control input weighting factor

LIST OF ABBREVIATIONS

AUV	–	Autonomous Underwater Vehicle
ARX	–	Autoregressive with Exogenous Input
ARMAX	–	Auto-Regressive Moving Average with Exogenous Input
ASFLC	–	Adaptive Simplified Fuzzy Logic Controller
BPFPSO	–	Binary Priority-based Fitness Particle Swarm Optimization
CFLC	–	Conventional Fuzzy Logic Controller
CI	–	Confident Interval
D	–	Derivative
DOF	–	Degree of Freedom
DSRV	–	Deep Submergence Rescue Vehicle
FLC	–	Fuzzy Logic Controller
HUV	–	Hybrid Underwater Vehicle
I	–	Integral
MUV	–	Manned Underwater Vehicle
MIMO	–	Multiple Input Multiple Output
MPC	–	Model Predictive Controller
NL	–	Negative Large
NM	–	Negative Medium
NNPC	–	Neural Network Predictive Control
NS	–	Negative Small
P	–	Proportional
PL	–	Positive Large
PM	–	Positive Medium
PS	–	Positive Small
PD	–	Proportional-Derivative

PI	–	Proportional-Integral
PID	–	Proportional-Integral-Derivative
PSO	–	Particle Swarm Optimization
PFPSO	–	Priority-based Fitness Particle Swarm Optimization
ROV	–	Remotely Operated underwater Vehicle
SIFLC	–	Single Input Fuzzy Logic Controller
SISO	–	Single Input Single Output
SNAME	–	Society of Naval Architects and Marine Engineers
UG	–	Underwater Glider
UUV	–	Unmanned Underwater Vehicle
UV	–	Underwater Vehicle

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Underwater vehicles (UV) can be classified into two basic categories: manned underwater vehicles (MUV) and unmanned underwater vehicles (UUV). UUV is the term referring to unmanned vehicles for underwater application (e.g. remotely operated vehicles (ROV), autonomous underwater vehicles (AUV), underwater glider (UG), and hybrid underwater vehicles (HUV). The classification of UUV is shown in Figure 1.1. These types of UUVs normally have complex vehicle control systems [1- 4]. These UUVs have existed for over 100 years and have been known as an interesting area for researchers and industries, especially for underwater tasks and works [5]. UUVs can bring an important tool in pilot-free underwater operations due to the increased operating range and depth [6]. Typical applications of UUVs today include surveying, monitoring, searching, surveillance, reconnaissance, inspection, recovery, repair maintenance, and construction [7]. Predominantly, in the offshore industry, UUVs have become very important for underwater works [8].

The ROV is tethered and sometimes called as unmanned underwater robot and sometimes can be called a remotely operated underwater vehicle to distinguish it from remote control vehicles operating on an underwater platform. ROVs are unoccupied, highly manoeuvrable and operated by a person aboard ship or on an underwater platform [9]. They are linked to the platform by a tether, sometimes referred to as an umbilical cable, a group of cables that carry electrical power, video, and data signals back and forth between the operator and the ROV. They are commonly used in deepwater industries (e.g. oil and gas exploration, telecommunications, geotechnical investigations, and mineral exploration) [9].

Modern ROV systems can be categorized by size, depth capability, inboard horsepower, and whether they are all-electric or electro-hydraulic. In general, ROVs can be grouped as in Table 1.1. Small ROVs include the majority of low-cost ROVs, most of which are typically all electric and nominally operate in water depths up to 300 meters as shown in Table 1.1. The term *low cost* refers to the pricing range class of RM 30,000 to over RM 300,000 [10]. These ROVs are used primarily for monitoring, inspection, observation tasks, surveying, and bottom profiling such as piping or ship inspection. Working class ROV is normally for heavy-duty work for underwater applications that include an important tool for doing a given task (e.g. welding, cutting or drilling). Special use ROV is ordinarily for defence and military applications.

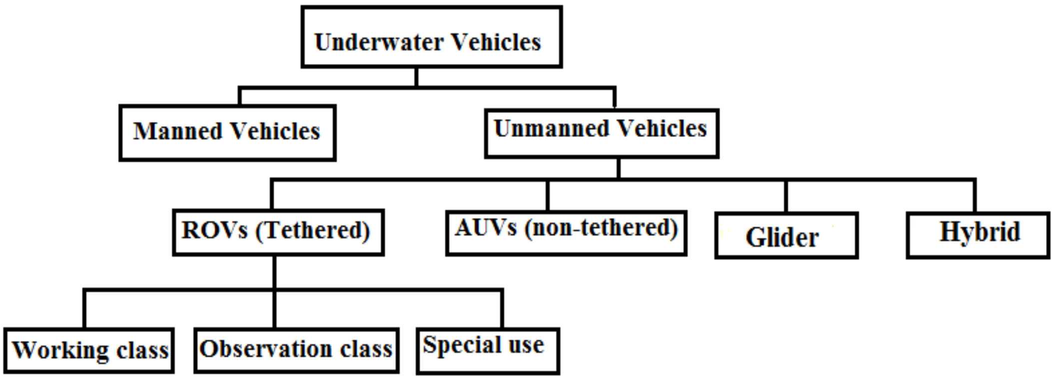

Figure 1.1: Classification of underwater vehicles

Table 1.1: Categories of ROV [11]

Class	**Application**	**Depth (Meters)**	**Power (HP)**
Low cost small ROV/ mini ROV	Observation	<100	<5
Small ROV (Electric)	Observation	<300	<10
Medium (Electro/ Hydraulic)	Light/ Medium Heavy Work	<2,000	<100
High Capacity Electric	Observation/Light Work	<3,000	<20
High Capacity (Electro/ Hydraulic)	Heavy work/Large Payload	<3,000	<300
Ultra-Deep (Electric)	Observation/Data Collection	>3,000	<25
Ultra-Deep (Electro/Hydraulic)	Heavy Work/Large Payload	>3,000	<120

The advantages and disadvantages of the ROV system in general are highlighted below. Some of the advantages of the ROV are as follows:

- No time constraints because power is supplied from other platform on the surface of the water such as from boats or ships.
- Able to cover wide areas relative to the capability of human divers.
- Mobility allows close-up inspection of the sea bed. Several models are able to collect benthic samples which are the ecological region at the lowest level of a body of water such as an ocean or a lake.
- Deployment areas less controlled than towed video, and can be used in areas with obstacles.

The drawbacks of ROV include:

- Depth range is limited by the length of the umbilical cable.

- Equipments and sensors need a platform to operate. The ROV may be unable to access very shallow water.
- Equipments or sensors for underwater are very expensive and not widely available.
- It may be difficult to employ in areas with strong water currents or big waves.
- Areas for observation are selected by the operator.

1.2 Research Background

The control system of an ROV is an interesting and challenging problem. This is primarily due to the difficult and unpredictable environmental conditions that existed underwater [12]. During operation, the ROV undergoes a complex multi-axis motion trajectories that are highly nonlinear because the subsystems in the ROV are ill-defined and strongly coupled with one another [13]. Furthermore, the ROV dynamics can change considerably with the changes in surrounding conditions and external disturbances (e.g. wind velocity, ocean currents and waves) [14]. The hydrodynamic coefficients are difficult to measure or predict accurately [15]. Effective control schemes require relevant signals in order to accomplish the desired positions and velocities for the ROV. Designing a suitable controlling method of the ROV is challenging due to the unpredictable nature of underwater dynamics and difficulty in measuring ROV parameters [16]. In this research, the focused area was controlling an ROV in a heave-axis motion trajectory sometimes called depth motion to maintain its desired position. The function of heave-axis motion is to maintain the ROV position at a specific depth and ensuring its stability, which is also called station keeping or auto-depth control. This auto- depth control approach is used to maintain a position in relation to other moving ROV as it tries to remain stationary at a certain depth in automatic control after this depth is set by the operator.

For vertical trajectory, overshoot in the system response will be one of the factors to be measured because overshoot is particularly dangerous in the ROV vertical trajectory and may cause damages to both the ROV and the inspected structure (e.g. operating in cluttered environments). To limit the overshoot, a first possibility is to pre-filter the input signal [17]. In [18 - 19], they proposed a station keeping method based on *direct method* to compute the ROV motion directly from spatio-temporal image derivatives. In [20], methods to stabilize underwater ROV movement's parameter under the presence of environment disturbance are highlighted. The design of the controller is to keep the amplitude of the overshoot in the system response drastically limited to a depth set point change, while keeping the system response time reasonably contained. Reasons for that are, as already pointed out, the necessity of assuring ROV integrity while operating near to bottom or in proximity of submersed installations and the need to prevent possible cable stress (for ROV), without compromising the system efficiency.

The control system of an ROV can be divided into two different groups as shown in Figure 1.2. The first group is focused on thrusters control system design and modelling. The second group is based on overall ROV control system design and modelling. In this work, the modelling of these two different groups of control systems will be by using system identification technique. The model will then be compared with its mathematical model derived from fundamentals. There are two types of the controller scheme to be investigated in this research: conventional, followed by an intelligent control scheme. The conventional approach considered PI and PID techniques, and optimal control linear-quadratic regulator (LQR) approach. While the intelligent one will focus on adaptation of Fuzzy Logic Controller (FLC) to control the overall system dynamics. The control algorithm was implemented and simulated using MATLAB® Simulink.

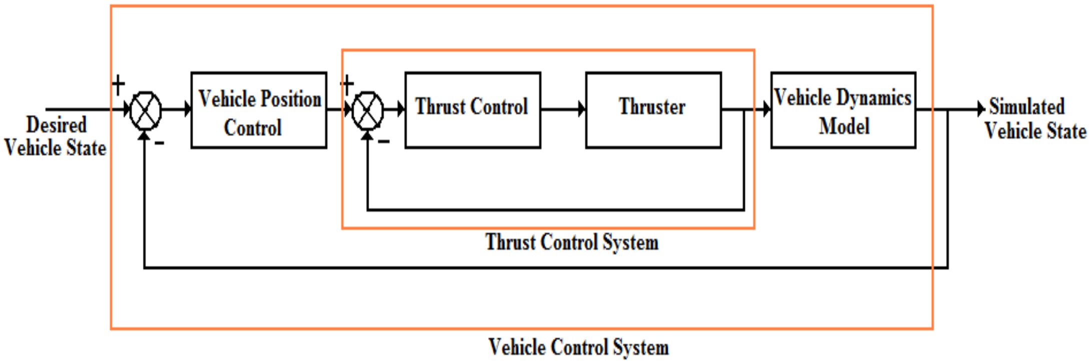

Figure 1.2: Unmanned Underwater Vehicle Control system

Single input fuzzy logic controller (SIFLC) adaptation from the conventional fuzzy logic controller (CFLC) was used for auto depth control of underwater ROV in this research. The advantage of SIFLC is that the number of tuning parameters is greatly decreased [21]. Hence, tuning of rules, membership functions, and scaling factors are much easier than CFLCs using two or more input variables. The control rule table for SIFLC consists of a 1-D rule table, and the computational complexity is reduced because the number of control rules has been considerably decreased. The SILFC will be improved based on the number of rules, using a linear equation to represent its lookup table, optimisation of the slope of the linear equation, and utilizing a model reference. The details of SIFLC will be elaborated in this research. The optimum parameters for the scaling factors of the SIFLC, tuned using the PSO techniques is one of the contribution of this research. Here, an improved PSO approach based on a priority-based fitness and binary priority-based fitness approach was implemented to find the optimal SIFLC parameters. Based on the optimum parameter obtained by PSO for every changing set point, a novel method called Adaptive Single Input Fuzzy Logic Controller (ASIFLC) design for underwater ROV was introduced in this research.

1.3 Problem Statement and Significance of the Research

The problem statement was found after a lot of investigations done in recent and existing works and several case studies based on journals, conference papers, thesis, books and other literature. In this research, the major problem considered in the ROV is in designing its depth control system. All UUV faced the same problem when controlling the vehicle since underwater environment is unexpected and unpredictable. The list of problems for ROV control include pose recovery or station keeping, under actuated condition, coupling issues and also communication technique. As the scope of study is limited to the control system for station keeping (depth control), the other problems will not be discussed further except in future work's recommendation. The aim of this project is more on controlling an ROV to maintain its depth.

In most ROV, its pitch and roll motion are stabilized through the inherent hydrostatic characteristic of the construction itself. The control system should deal only with the depth, *z-axis*, the Cartesian positions *x*- and *y-axis*, and with the yaw angle. In general the uncontrolled angles for roll and pitch motions remain small and the depth can be decoupled from the other coordinates [22]. Maintaining the position of the small scale ROV within the working area is a difficult task especially in the presence of underwater currents, wave and wind even for experienced pilots [22]. ROV has been designed to be passively stable in pitch and roll (its centre of gravity is below the centre of buoyancy). For this reason, rolling and pitching motion of the ROV are very small, and therefore better results are obtained with a similarity motion model.

The function of depth control is to maintain the ROV position at a specific depth and ensuring its stability, which is also called station keeping mode. For depth control, overshoot in the system response will be one of the issues occurred because overshoot is particularly dangerous for the ROV in its vertical trajectory and may cause damages to both the ROV and the inspected structure. Overshoot reduction is actually achieved at the expense of increased rise time [23]. In general, the control objective is to obtain a limited or no overshoot in system response without penalizing the rise time. This is difficult to achieve since normally, the limitation of overshoot in system response can be obtained but the rise time will be slower. From the review of existing works, there seems to be very few literatures that look at optimizing ROV controller parameters at different operating conditions and then derive an adaptation law for the ROV to allow automatic change of optimum sets of parameters depending on different situations (see Section 2.3). One main motivation of this research is in the areas of optimization and adaptation of controller parameters. Adapting the optimized ROV controller parameters at different set point conditions may very well improve its performance in terms of reducing its overshoot and response time for depth control. This seems a problem worthy of further investigation.

The derivation of mathematical model of a UUV is a complex problem. It is difficult to delimitate or calculate many parameters, which has to be well known to solve the dynamic equations of UUV movement. Accurate dynamic model are crucial to the realization of ROV simulators, precision autopilots and for prediction of performances. Control of underwater vehicles is not easy, mainly due to the nonlinear and coupled characters of plant equations and also the lack of precise models of underwater vehicle hydrodynamics and uncertainty parameters, as well as the appearance of environmental disturbances [24] such as wind, current and wave. Many of the researchers have to ignore some uncertainties in the parameters to reduce the difficulty in designing the controller. The assumptions on the dynamics of ROV in deriving its mathematical model are the most common approach. Implementation of the controller on the ROV using FLC itself poses its own level of complexity. Consequently, implementation of FLC also demands for fast and high-performance processors. For SIFLC approach, there are many parameters to be tuned manually in the literature [21]. Trial an error method will be used to find the optimum parameter. In [21], the parameters has been reduced to two, to be tuned manually using trial and error. Consequently, it will take more execution time to find the optimum parameters. Another issue is that the SIFLC has never been tested experimentally on any UUV.

1.4 Objectives of the Research

The objectives of this research are:

1) Development and modelling of thrusters for a prototype ROV using system identification technique for vertical trajectory. Then, the system identification model will be compared with its mathematical model derived using ROV fundamentals.

2) Designing an intelligent auto-depth control algorithm in the ROV vertical trajectory that can guarantee no overshoot in the system response and having faster rise and settling time.

3) Optimizing the parameters of improved SIFLC using PSO techniques based on Priority-based Fitness PSO (PFPSO) and Binary Priority-based Fitness PSO (BPFPSO) approach.

4) Designing an Adaptive Single Input Fuzzy Logic Controller (ASIFLC) for depth control of a newly fabricated underwater ROV to improve overall performance for different set points and test the algorithm experimentally.

1.5 Research Scopes

The k-chart™ of the research can be referred to in Appendix 1. From the k-chart™, the focus and aim to of this research can be identified so that they are aligned with research objectives as explained in the previous section. The focus of this work has been highlighted in this chart which mainly deals in the area of control input for ROV. In this project, the focus was in controlling an ROV in a heave-axis motion to maintain its desired position. The objective was to develop an intelligent controller that can guarantee the suppression or at least the limitations of overshoot in the system response. This project identified an empirical model of a newly designed ROV and then developed an intelligent controller to stabilize the ROV. This project began with mathematical and empirical modelling to illustrate the dynamics of the underwater vehicle followed by an intelligent controller design. Empirical modelling refers to any kind of computer modelling based on experimental observations rather than on mathematical describable relationships of the system. Mathematical modelling is a description of a system using mathematical concepts. Development of mathematical modelling of this research was based on several assumptions made by [15] on the dynamics equation of ROV to reduce the complexity and simplify the dynamics motion equation of ROV. The implementation phase was verified through MATLAB® and Simulink platform. The verified algorithms were then tested on the actual prototype ROV.

The emphasis of this project is on the aspect of controlling the ROV to investigate the problem of depth control system as mentioned before. The objective in modelling a depth controller is to develop an accurate model representing the actual system dynamics. The motion of the underwater vehicle consists of two movements; vertical and horizontal motion. However, the scope of this project is only concerned on the dynamics in the vertical motion considered in the auto-depth control approach. Open frame ROV design was developed because this configuration has been widely adopted by commercial ROV. This is because of its simplicity, robustness, easy to maintain, more stable compared with closed hull and cheaper. Although the hydrodynamics of the open frame vehicles are known to be less efficient than that of closed hull type's ROVs, the open frame ROV is suitable for applications that does not require movements at high velocities or travelling long distance. This open frame ROV design also focused on auto-depth control operation modes. This auto-depth control approach was used to maintain a position in relation to other moving ROV as it tries to remain stationary at a certain depth so that the ROV can do a task (e.g. monitoring pipe crack, welding, and pick and place) at a certain time. The ROV maintained a fixed position in relation to a fixed object. The depth of testing conducted is within the available water depth of 1-5 meter (e.g. lab test and pool test). For depth control, overshoot in the system response are particularly dangerous. Clearly an overshoot in the ROV vertical trajectory may cause damages to both the ROV and the inspected structure especially when operating in a cluttered environment. Control objective is to eliminate overshoot and reduce rise time and settling time in the system response.

1.6 Contribution of the Research Work

The contributions of this research are:

1) Development and modelling of thrusters and ROV using the system identification technique for vertical trajectory of a newly fabricated ROV. Validation between mathematical modelling and system identification of the prototype ROV has been done in simulation and in actual experimental works.

2) Designing an intelligent depth control algorithm for the ROV model in MATLAB. The focus was on an improved Single Input Fuzzy Logic Controller (SILFC). Investigations on the number of rules, lookup table, slope of the linear equation, and model reference to give best performances for ROV depth control having no overshoot in system response and faster rise time and settling time has been done.

3) Optimizing the SIFLC parameters using Particle Swarm Optimization (PSO) techniques. An improved PSO algorithm is based on a Priority-based Fitness PSO (PFPSO) and Binary Priority-based Fitness PSO (BPFPSO) approach is implemented for finding optimal SIFLC parameters.

4) Adaptive Single Input Fuzzy Logic Controller (ASIFLC) has been designed and tested to account for the different optimum parameters based on different depth set point. A method to dynamically combine the result of different optimized parameter settings obtained from PSO optimisation for different set point values has been suggested and tested. ASIFLC design for auto-depth control of the ROV was found to give better performance in system responses and can adapt to changes in the set point.

1.7 Organization of the Thesis

This thesis is organized into five chapters. Their contents are outlined as follows:

Chapter 1 provides an introduction to the ROV system and research background. In this chapter, the objectives, scopes and contribution of this research are provided. The problem statement of this study is also covered under this chapter.

Chapter 2 provides an extensive review of modelling and control techniques used to control the UUVs especially the ROV. The details of depth control of UUV are covered in this chapter which include a critical review of ROV depth control from existing works. In this chapter, the fundamentals of system identification techniques, fuzzy logic and the Single Input Fuzzy Logic Controller were discussed. Next, the stochastic optimization approach, namely the particle swarm optimization approach was discussed. Finally, the specification of the underwater platform used in this research will be explained briefly in this chapter.

Chapter 3 discusses the methodology of the project including the modelling of the thrusters and the ROV using system identification approach. The factors affecting the control design of ROV is covered within this chapter. It also contains the overview of the ROV system and the derivation of the mathematical model of system dynamics based on the several assumptions made of the dynamics equation of the ROV. In this chapter, the design of SIFLC and an improved SIFLC for ROV using MATLAB®/Simulink was also described. The focus is on improved SILFC where it investigates the effects of scaling factor tuning for SIFLC to improve the performances of system response for depth control. Also, the optimization method for tuning SIFLC by using Particle Swarm Optimization (PSO) approach is introduced for finding optimal SIFLC parameters. Furthermore, it includes the comparison of SIFLC with conventional PID controller and Output Feedback Observer tuning using Linear-Quadratic Regulator (LQR). The controller design focused on depth control of the ROV and performance evaluation is presented. Finally, a new method called Adaptive Single Input Fuzzy Logic Controller (ASIFLC) was proposed. The ASIFLC was designed for depth control of the ROV and this technique gives best performances in system response and can adapt to any changing values of set point. This chapter also includes the comparison with real time application and other ROV with the same class.

Chapter 4 analyze thoroughly the results based on the methodologies described and implemented in Chapter 3. The results of system identification and mathematical modelling were covered in this chapter. Also, the results of investigations in improving SIFLC and the parameters of SIFLC by tuning using priority based fitness PSO and binary priority based fitness PSO was reported here. Finally, the results of using a new method called the ASIFLC was discussed and found to give better performances in system response. The method is suitable to be implemented in real time system due to its reduced complexity and can easily be realized using a low cost microprocessor or microcontroller.

Chapter 5 concludes the work undertaken by summarizing the system, highlighting the results and contributions and providing several suggestions for future work.

1.8 Summary

This chapter gives an introduction of the ROV and also research background of the ROV in section 1.2. Also discussed a problem statement and significant of the research in section 1.3. In this chapter objectives, scopes and contributions of the research work was provided (section 1.4 -1.6).

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