Review on Auto-Depth Control System for an Unmanned Underwater Remotely Operated Vehicle (ROV) using Intelligent Controller

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***Abstract*—This paper presents a review of auto-depth control system for an Unmanned Underwater Remotely operated Vehicle (ROV), focusing on the Artificial Intelligent Controller Techniques. Specifically, Fuzzy Logic Controller (FLC) is utilized in auto-depth control system for the ROV. This review covered recently published documents for auto-depth control of an Unmanned Underwater Vehicle (UUV). This paper also describes the control issues in UUV especially for the ROV, which has inspired the authors to develop a new technique for auto-depth control of the ROV, called the SIFLC. This technique was the outcome of an investigation and tuning of two parameters, namely the break point and slope for the piecewise linear or slope for the linear approximation. Hardware comparison of the same concepts of ROV design was also discussed. The ROV design is for small-scale, open frame and lower speed. The review on auto-depth control system for ROV, provides insights for readers to design new techniques and algorithms for auto-depth control.**

***Index Terms*—Auto-Depth Control; Remotely operated Vehicle; Artificial Intelligence Controller; Single Input Fuzzy Logic Controller**

I. INTRODUCTION

Recently, the world has been shocked by the missing aircraft MH 370 from Malaysia to Beijing, China. Based on expert analysis, this aircraft has ended in Hindi Ocean, the third deepest with an average depth of 3000 m. Exploring the underwater environment for long duration of time and depth has been difficult since the maximum depth human can dive is very limited. This situation has motivated the rapid development of Unmanned Underwater Vehicle (UUV), especially the Autonomous Underwater Vehicle (AUV), Remotely Operated Vehicle (ROV), Underwater Glider, Underwater Bottom Crawler and etc. This review focuses on the ROV using auto-depth control because of its high ability to maneuver. Further, it is faster and easier to set up since it is operated by a person on board of a vessel. The ROV is suitable for pre-planned missions over large areas such as rescue for MH 370. However, the design of AUVs is complicated because it involves many sensors and manipulators, and it is very expensive depending on the task and depth of operation.

The k-chart^{TM} has been used to identify the focus and aim of this research so that they are aligned with the research objectives. The k-chart^{TM} of the research is presented in Figure 1. As highlighted in the chart, the focus of this work mainly deals in the area of control input for the ROV. In order to design any UUVs, especially the ROV, it is essential and compulsory to have strong background knowledge in terms of its fundamental concepts and theory about the physical laws governing the ROV in its environment and the current issues of the ROV. Thus, the objective of this paper is to conduct some reviews to get an idea to design and control of the ROV. With regard to the ROV, factors such as buoyancy, stability, hydrodynamics and pressure are taken into consideration in the design of the ROV. Basically, a combination of electrical and mechanical factors must be considered in order for the overall design of the ROV to be successful.

The problem statement was found after investigations were carried out in the literature reviews and case studies. In this research, the major problem considered is in the design of the ROV 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 includes 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, the other problems will not be discussed further except on the recommendation for future work. The aim of this project is more on controlling method of ROV for the depth control.

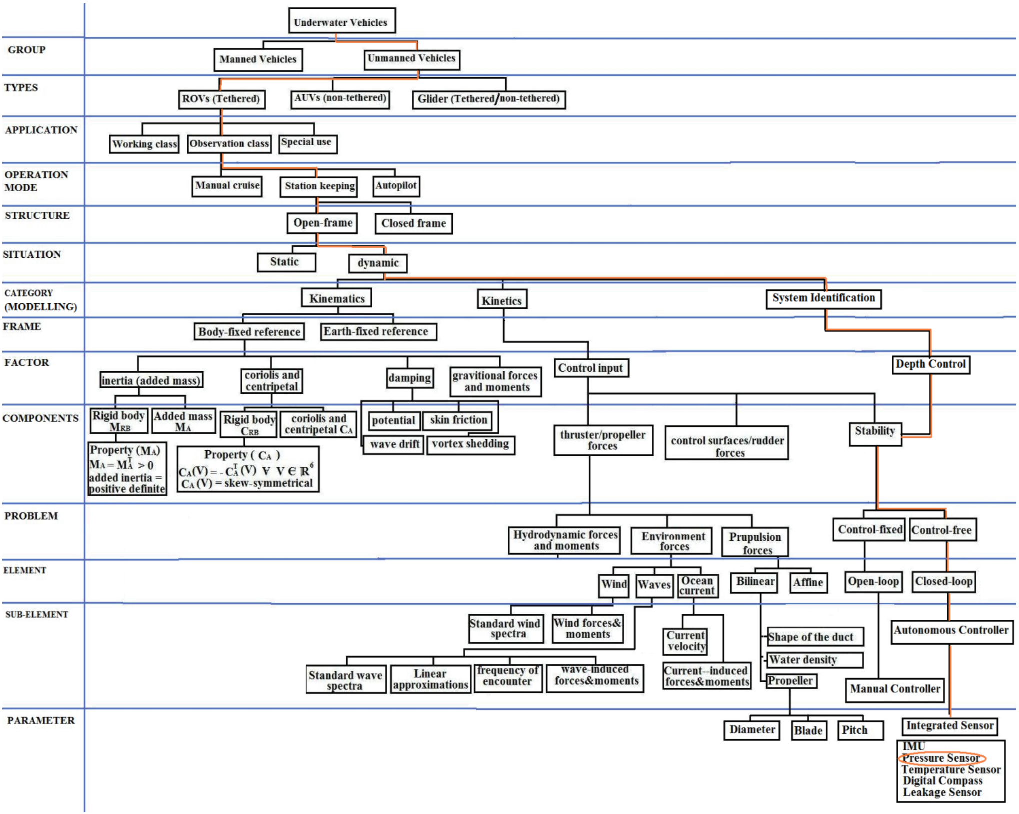


Figure 1: The k-chart™ of the research

II. DEPTH CONTROL OF UNMANNED UNDERWATER VEHICLE

A summary of key papers in depth control of UUV is listed in Table 1.

Table 1
Other relevant works in Depth Control of UUV fields

AUTHOR (YEAR)	TITLE	IMPORTANT RESULT/FINDINGS
Shahriar Negahdaripour, Sohyung Cho, Joon Young Kim (2011)	Controller design for an autonomous underwater vehicle using nonlinear observers	The authors designed the control system of AUV for depth control and heading angle. The controller used is a sliding mode control using estimated hydrodynamics coefficients were estimated employing conventional nonlinear observer techniques such as sliding mode observer and extended kalman filter. This control algorithm make the control system stable and accurately follow the desired depth in presence of parameter uncertainty.
Faruq, Amrul, Abdullah, S. S., Fauzi, M., (2011)	Optimization of depth control for Unmanned Underwater Vehicle using surrogate modeling technique	The authors explained the method to tune the scaling factors of Fuzzy Logic Controller (FLC). This method namely a radial basis function metamodel for depth control of UUV. Authors also did comparison between genetic algorithm (GA) and metamodeling where showed using metamodeling approach much a shorter time compared with GA.
Maria Letizia Corradini, Andrea Monteriu, Giuseppe Orlando (2011)	An Actuator Failure Tolerant Control Scheme for an underwater Remotely Operated Vehicle	The authors used the ROV in the exploitation of combustible gas deposits at great water depths. The authors used fault-tolerant control scheme for an underwater ROV. The actuator failure tolerant scheme is composed by the usual modules detection, isolation, and accommodation of faults by control reconfiguration. The fault identification module is based on sliding mode control.
K. Ishaque, S.S. Abdullah, S.M. Ayob, Z. Salam (2010)	Single Input Fuzzy Logic Controller for Unmanned Underwater Vehicle	The authors used Single Input Fuzzy Logic Controller (SIFLC) to control heave motion of Deep Submergence Rescue Vehicle Model (DSRV). The SIFLC offers significant reduction in rule inferences and simplify the tuning of control parameters. Practically it can be easily implemented by a look-up table using a low cost microprocessor due its piecewise linear control surface. The result indicates that SIFLC requires very minimum tuning effort and its execution time is in the orders of two magnitudes less than CFLC.
Zhijie Tang, Luojun, and Qingbo He (2010)	A Fuzzy-PID Depth Control Method with Overshoot Suppression for Underwater Vehicle	The authors used fuzzy-PID controller method based on overshoot prediction to control the ROV for depth control. This method where fuzzy controller calculates the PID controller parameters, and then the underwater vehicle completes the fast and non-overshoot depth control of the ROV. The simulation results shows that the method is effective and feasible.
Wallace M. Bessaa, Max S. Dutra, Edwin Kreuzer (2008)	Depth control of Remotely Operated Underwater Vehicles using an Adaptive fuzzy sliding model controller	The authors designed the control system of ROV for depth control using Adaptive Fuzzy Sliding Mode Control (SMC) approach. The authors used SMC and enhanced by an adaptive fuzzy algorithm for the depth control of Remotely Operated Underwater Vehicles.

Sergio M. Savaresi, Fabio Previdi, Alessandro Dester, Sergio Bittanti, (2004)	Modeling, Identification, and Analysis of Limit-Cycling Pitch and Heave Dynamics in an ROV	The authors the ROV dynamics as dynamic gray-box model is developed and its uncertain parameters are identified from real data. The Proportional Controller used on the Gaymarine Pluto–Gigas ROV. The analysis of such a model shows that the nonlinear dynamics of the ROV contains a limit cycle. This discovery explains the observed oscillatory behavior. An interesting aspect of this limit-cycling behavior is that it is not due (as usual) to saturation effects of the actuators, but is intrinsic in the ROV dynamics.
Silvia M. Zan oli, Guiseppe Conte (2003)	Remotely Operated Vehicle Depth Control	The authors designed the control system of the ROV for depth control. The authors used Proportional Integral and Derivative (PID) Controller and Fuzzy techniques to Depth Control of the ROV. This author also showed the results has the reduction of overshoot in the depth response.
Gianluca Antonelli, Stefano Chiaverini, Nilanjan Sarkar, Micheal West (2001)	Adaptive control of an Autonomous Underwater Vehicle : Experimental Results on ODIN	The authors designed the control system of the AUV. The authors used 6DOF for AUV. The control algorithm is adaptive in the dynamic parameter where this controller has been successfully implemented and experimentally validated on Omni-directional intelligent navigator (ODIN) and the experimental results showed the good performances of the adaptive controller within constraints of the sensory system.
Edwin Kreuzer, Fernando C. Pinto (1996)	Controlling the position of a remotely Operated Underwater Vehicle.	The authors designed the control system of the ROV for position control. The authors implies the robust control system through the use of sliding mode or variable structure controllers. This author also model the hydrodynamics effects model on the vehicle and on the umbilical cable.

III. CONTROL SYSTEM OF ROV

To control of unmanned underwater vehicles (UUV) is not easy and simple, and it is mostly due to the nonlinear dynamic motion and coupled characters of plant equations. The difficulties are also due to the lack of accurate models of UUV hydrodynamics and uncertainty parameters, as well as the appearance of environmental disturbances such as wave, current and wind [1]. For the controller design, simple models of UUV mass and drag, generally yields unacceptable performances [2] but acceptable for depth control. The common control methods used in UUVs are given in Table 2. There are a large number of projects that used this controller.

Table 2
Control Method with Limitations

Control Method	Limitations
PID	Cannot dynamically compensate for unmodelled vehicle's hydrodynamics forces or unknown disturbances Parameter configuration contradictory between response speed and overshoot control.
Sliding Mode	Could easily lead to system jitter and effect control accuracy
Fuzzy Logic	Hard to tune the fuzzy rules. Overshoot prediction time should be smoothed
Neural Network	Cannot meet the requirement of rapid response Complex for real time application

A control system for the ROV adopts the same concepts as other UUV, where it is complicated because of the unknown parameter and uncertainties, nonlinear hydrodynamic effects, and environmental disturbances where it is complicated to calculate approximately and precisely. The common problem of ROV control system design includes a variety of nonlinear and modelling parameter uncertainties. Additionally, the problem that need to be considered includes hydrodynamic nonlinear, inertial nonlinear, and problems related to coupling between the Degrees of Freedom (DOF). Many of the researchers have to ignore some uncertainties in the parameters to reduce the difficulty in designing the controller. The assertion that the dynamic equation of ROV is the most excellent approach has been used by many researcher as stated in the previous section.

A Proportional-Integral-Derivative controller (PID) is a simple control technique that has been universally used because of the simplicity of its implementation. A PID controller for tracking has been implemented successfully on the UUV [3 - 6]. Simple Linear Quadratic Regulator (LQR) controllers have also been developed [4]. Regardless of the existence of these simple controllers, other more artificial intelligent control techniques have also been recently utilized for UUVs. Even though ROV is easier than the other UUVs, it still needs an intelligent controller to do automatic task such as auto-depth control. One of common and simple, intelligent controller used is Fuzzy Logic Controller (FLC). FLC is widely implemented on electrical appliances in the year 1980s. However, recently, many methods have used a combination between two controllers to get better performances. In [5 - 6], the authors have proposed and implemented the FLCs on ROVs and it performed well in terms of system response analysis. When an empirical or mathematical model of the ROV is not well-known, the control solution of this system is recommended to the FLC. As a result, implementing an intelligent controller on the ROV model using FLC can evade the need for complex hydrodynamic nonlinear modelling of the vehicle. Yet, the drawback is that the execution of the FLC controller itself creates its own level of difficulty. As a result, FLC execution demands for fast and high-performance processors and this will be discussed in the next section. Subsequently, to decrease a level of difficulty a new technique based on FLC will be introduced. The Single Input Fuzzy Logic Controller (SIFLC) is introduced and applied to control system for the auto-depth control of the ROV. Based on the results in [7], the simulation results showed that the SIFLC has superb performance, and it exactly looks like conventional FLC in terms of its system response. The most important improvement of SIFLC is the reduction of the system from Multiple Input Single Output (MISO) or Multiple Input Multiple Output (MIMO) system to Single Input Single Output (SISO) system. Nevertheless, up to this point, the SIFLC has never been investigated on an actual UUV especially for the ROV.

Adaptive control has also been used in UUV [8]. Obviously, the advantage of this type of control is due to the changing dynamic parameter of UUVs in the ocean. In this case, the adaptive controller can adapt itself to varying ocean disturbance such as current, wave and wind or to a different vehicle density, when the ballast tank system for depth control are used. Adaptive controller is also useful because the UUVs especially the ROV are usually refitted with new equipment such as manipulators or vision system and adapted for different missions [9]. The changing of components in the ROV will change their static and dynamic characteristics. Most of UUVs are normally designed with specific tasks and all equipments are fitted, hence there are very limited space to add some equipments or sensors. Another technique that has been commonly used to control the UUV are the Sliding Mode Controller (SMC). In [10], the SMC control scheme. The dynamics within the system are altered by the application of high-speed switching control. The system, in essence, is constrained in such a way to exhibit desirable characteristics. This proves that it is practical in the linearization and hence, better controlling of UUV dynamics.

Nowadays, the most frequently control techniques have been used to control the UUV or in combination with each other, such as the Neural Network combined with Fuzzy Logic, which is called as the Neuro-Fuzzy or the Fuzzy Logic is combined with particle swarm optimization (PSO) algorithm, called as Fuzzy-PSO. For example, a Neuro-Fuzzy controller has been developed by [11] for modelling approach control for the ROV. This involved using a combination of neural networks and fuzzy logic as explained above. Alternatively, in [12], a SMC combines with Adaptive control that is called as a sliding mode adaptive control system was implemented for controlling the ROV. The improvement of the robustness and fault tolerance of the overall controller performances is the main advantage of combining the useful properties of the different control techniques. In this paper, we also describe the literature review that summarizes several existing works in the controlling of the UUVs, which is presented in the next section. To control these UUVs at various aspects, the control schemes that have been studied for years and can be used to stabilize the motion of the ROV as auto-depth control are discussed.

The example of the ROV control system and the structure of the control system for the ROV is shown in Figure 2. The control systems are divided into two elements. One is the thrust control system, and the other is the vehicle control system. The dynamics of the thrusters lead to the control difficulty and it should be correctly measured to achieve excellent performances. Thrusters are an electromechanical device equipped with a motor and propeller that generates thrust to push the ROV. Thrusters' control and modelling are the important parts of the ROV control system and for simulation. This is because the thruster control and modelling is the low control loop of the system; hence, the system would benefit from precise modelling of the thrusters. The input to the system called control signal is the desired vector of propulsion forces and moments.

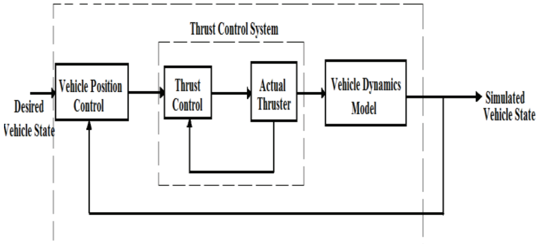
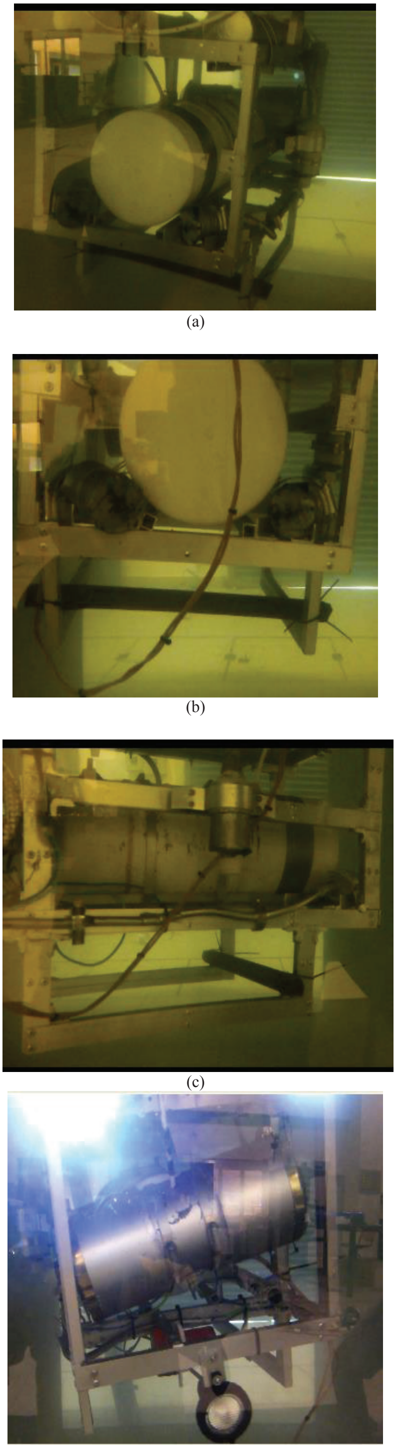


Figure 2: Unmanned Underwater Vehicle Control system

Under actuated conditions is defined as one having fewer control inputs than degrees of freedom. The lack of actuation on certain directions or position can be interpreted as constraints on the acceleration, which is also defined as the under actuated systems. In the case of ROV situation, under actuated condition means the malfunction of one or more thruster. The capability to sustain a certain direction or path in its following tasks is initially setup by the use of two thrusters. For example, for depth control, if one of the thrusters malfunctions, the second thrusters will take over the mission to control the following tasks of the ROV. For illustration, the tasks of the ROV should go to the depth at 5 meters. At the beginning, the two thrusters are moving with the supply of 8 V for submerging at a certain depth (5 meters), and then if one of the thrusters malfunctioned such as coil broken, propeller dislodged, cable convolution or etc, another thruster will take over the action to control the depth by increasing the supply to 12 V to follow the set point.



(a)

(b)

(c)

(d)

Figure 3: The thruster configuration for the depth control.

The configuration of the thruster for the depth control is shown in Figure 3 (a). As explained before, the ROV is set to depth operation for a certain set point using two thrusters (Thruster 1 and 2 as shown in Figure 3 (a) and (b)) supplied by a 8 V DC motor. The ROV will submerge following the set point. Then, unexpectedly, one of the thrusters is broken due to loses connectivity, propeller missing or problem occurred based on the external factors. As shown in Figure 3 (c), one of the thrusters is having a problem to function well and because of the present wire is hooked to the propeller, it can rotate as usual. Another thruster will take the action to control the depth by increasing the supply amount to 12 V to achieve a certain depth but, unfortunately the angle of ROV will be changed, skewed to the x-axis direction as shown in Figure 3 (d).

The thrusters operated based on pressure sensor output signals. If the ROV is set to the depth at 5 meters, the thrusters will move vertical direction (submerge) until it reached the set point and tries to maintain the set point using on-off thrusters. The stability of ROV may be uncontrollable, but it is still submerged at a certain depth. This means that the angle of ROV will skew to the x-axis direction or horizontal angles (pitch angle) as shown in Figure 3 (d). The location putting the pressure sensor also can be considered as a problem. The pressure sensor is fixed to the center between the two thrusters so that it can balance their speed of thrusters based on the signal output from the pressure sensor. The most excellent solution is that every thruster must have their own encoder to derive its speed of thrusters. So, the speed of thrusters can be identified. Theoretically, both thrusters will obtain the same speed. If the thrusters' rotations obtained different speed, the ROV will be unbalanced.

Critical Review of the ROV Depth Control from Existing Works

From the review of existing works, it seems that a lot of work in depth control of ROV has been done. However, based on the understanding of the non-linearity of the dynamics of an ROV, its optimum controller parameters should be different at different operating conditions. For depth control, there seems to be very few existing works that look at optimising ROV controller parameters at different operating conditions that derive an adaptation law for the ROV to allow automatic change of optimum sets of parameters depending on different situations. For instance, in [13], a standard PID controller was used whereby its parameters was only tuned once using MATLAB® PID tuner algorithm and only for one set point. In another example [14], they used an adaptive PID controller on an AUV (not ROV). However, they did not optimize their PID on the different set points to be used by the AUV. Instead, their adaptive rule comes from a complicated 3-input 1-output fuzzy controller. This may affect their algorithm implementation, which they did not study. Therefore, at this point, one motivation of this research will be in the areas of optimisation and adaptation of controller parameters, focusing on the simplified intelligent for fast real time application. 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.

IV. FUZZY LOGIC CONTROLLER

As mentioned ealier, the advantage of the FLC is that it recommends a control solution when a mathematical model of the ROV is not well-known, but some issues still exist for the control of complex systems. For example, there are no general stability analysis tools that can be applied to FLCs. The fuzzy rules are a large amount of a higher-order system and the parameters of membership functions affect the performance from the FLCs system. Further, appropriate membership functions can only be acquired through an extensive time-consuming and a trial-and-error procedure [15]. Hence, many researchers spend much effort to investigate the above three problems to overcome these formidable tasks. Control performances of FLCs are significantly influenced by a number of rules. In common, the more the number of rules is applied to an FLC, the accurateness of the control performances is improved [16]. On the other hand, a large set of rules needs more execution time. Consequently, FLC implementation demands for fast and high-performance processors [17]. To ease the problem, a simple yet efficient FLC is proposed for this work. One of the methods to overcome this problem was the introduction of Single Input Fuzzy Logic Controller (SIFLC).

V. SINGLE INPUT FUZZY LOGIC CONTROLLER

The technique was originally proposed by [18]. Later, [19] and [20] applied this idea to control the DC to DC converters followed by inverter control by [21]. However, so far, no reports have described the application of the Signed Distance method for the underwater vehicle system. Based on [22], the authors proved that the SIFLC is proven to be absolutely stable if the SIFLC operates as the general nonlinear controller. In addition, the authors stated that the control performance was nearly the same as of the existing FLCs, which is discovered through computer simulations using two nonlinear plants such as inverted pendulum system and the magnetic-levitation system. The authors analyzed the stability in the case that the SIFLC operates as the general nonlinear controller. That is, they assumed that the relationship between input and output of the SIFLC is nonlinear.

Based on [23 - 25], the authors claimed that the SIFLC control with a higher number of input shaper modes provides a higher level of sway reduction as compared to the cases using lower number modes. However, with a lower number of modes, the speed of the response is slightly improved at the expenses of the decrease as the level of sway reduction. That is, the adaptability is still deficient. The authors proposed a new design a single-input direct adaptive FLC (SDAFLC). In the Adaptive FLC (AFLC), some parameters of the membership functions which characterize the linguistic terms of the fuzzy rules are adjusted by an adaptive law. The SDAFLC is designed by a stable error dynamics. The authors prove that its closed-loop system is globally stable in the sense that all signals involved are bounded and its tracking error converges to zero asymptotically. They performed computer simulations using a nonlinear plant and compared the control performance between the SIFLC and the SDAFLC.

Based on [7], the authors reported that the application of the SIFLC on Deep Submergence Rescue Vehicles (DSRV) was first reported using SIFLC on UUV. The SIFLC is then applied to control the depth of DSRV. The system is simulated using MATLAB/Simulink, and all parameters of DSRV obtained from [26]. The simulation divulges the SIFLC that gives the best performances, and it exactly resembles the CFLC in terms of its response. In addition to the new method of SIFLC, there are two parameters to be tuned, namely the break point and slope for the piecewise linear or slope for the linear approximation. Unfortunately, the parameters still need to be tuned manually.

VI. HARDWARE COMPARISON

A lot of small scale ROV have been designed for observation purposes. In this work, five small scale, low-cost and open frame ROVs have been selected as a comparison to the one designed here. For observation purpose, the weight of ROV must not be too heavy compared to the working class ROV which is normally very heavy and has complex control systems. Since the focus of this work is not on hardware design, the detail hardware comparison between the ROV constructed in this work and the other existing ROVs can be found in Table 3 and Table 4.

Table 3
Comparison Design

Parameter	Design 1 ACE ROV	Design 2 CCC ROV	Design 3 Hornet II
Size	0.25m x 0.4m x 0.3m	0.4m x 0.45m x 0.35m	0.45m x 0.6m x 0.45m
Material	PVC	PVC	PVC
Stability	Square and center stability. Thruster mounting center of ROV.	Additional foam	Syntactic foam to offset the stability
Propulsion	1100 GPH Bilge Pump motor	4 Bilge Pump 5678 LPH	4 Brushless DC-Motor add on nozzles go around the propeller.
Computer Control System	Arduino Control Board	PIC	PIC Controller, PIC18LF877, PIC16C876,
Tether	Length 50m	Length 25m	100m
Depth	20m	20m	30m - 90m
Camera	2 Waterproof, Navroute Neptune EZ, Fixed direction	1 Camera	Color camera, Infrared LED
Sensor	Sonar, Depth sensor,	-	Depth sensor, compass, temperature sensor, hydrophone.

Table 4
Comparison Design 2

Parameter	Design 4 Latis II	Design 5 Seaweed	My Design UTeRG ROV
Size	0.5m x 0.9m x 0.6m	0.4m x 0.6m x 0.46m	0.3m x 0.6m x 0.45m
Material	PVC, Acrylic	Aluminum	Aluminum
Stability	Pressure Hulls Box design	Tendency to make slightly buoyant and operated positively buoyant	Frame Design, Ballast Tank position.
Propulsion	6 BTD-150 Seabotix thrusters, 3 Sabertooth motor	4 Motors Brushless DC motors	4 motors Brushless DC Motors.
Computer Control System	Compact RIO controller, Analog sensor board	PIC	PSC28A PIC
Tether	45m	50m	50m
Depth	5m	5m	5m
Camera	3 camera (2 external, 1 internal mounted)	Video Camera MB-1050C	1 Video camera
Sensor	Temperature and humidity sensor board, OMEGA Thermostat, Hydrophone	Pressure sensor, compass	Leakage Sensor, Depth Sensor, Pressure Sensor. Seabed Mapping

A. Design 1- Aquatic Cave Exploration Remotely Operated vehicle (ACE ROV) [27]

ACE ROV was designed with the purpose of an exploration of flooded cave systems, as shown in Figure 4. In order to pass through places inside flooded caves, which cannot be performed by humans, ROV needs to be set as a miniature size. ACE ROV was 400mm long, 300mm wide and 250mm tall. ACE-ROV frame design was built with polyvinyl chloride (PVC). This design is fairly hydrodynamic due to the cylindrical cross-section of the piping. From the maneuver system, it was powered by an external power source in order to reduce weight. It was powered by a five 12-volt bilge pump motors. The power consumption can hold until 30 minutes operation, a reasonable time to conduct observation within a 50m tether. It was also equipped with a camera video, depth sensor, magnetic compass and range finder or sonar.

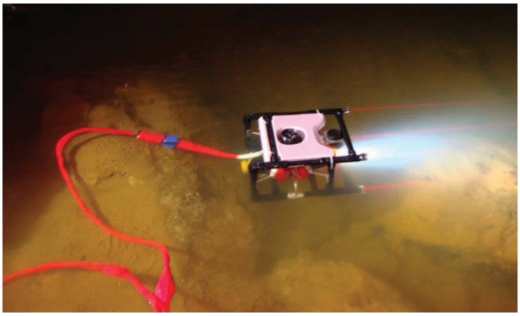


Figure 4: ACE ROV design

B.Design 2- CCC ROV Project (Clatsop Community College) [28]

This CCC ROV design was fairly simple but efficient. After completing two tasks, they decide to use the first ROV because it is attached with more powerful motors and the design has been improved on the test environment. The body was made of 1.9cm Polyvinyl Chloride (PVC) pipe, lightweight and hollow in purpose to float, otherwise PVC price is cheap. The design was powered with 5678 LPH bilge pumps that is attached for vertical and horizontal movement as shown in Figure 5. The interesting part is when they installed metal claw in front of ROV that will be used to grasp and hold the connector until it is released. The 12V power supply delivered through 25m tether and a 25A fuse are installed as safety. The camera was pointing directly at the claw arm to allow for precise insertion of the connector. The second camera also has been attached underside of the ROV to assure a stable attachment to the module.

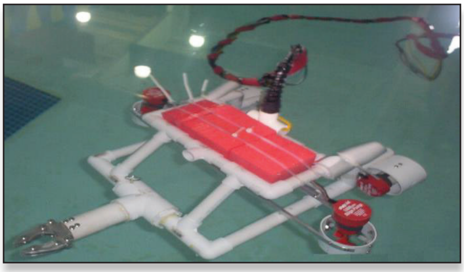


Figure 5: CCC ROV project.

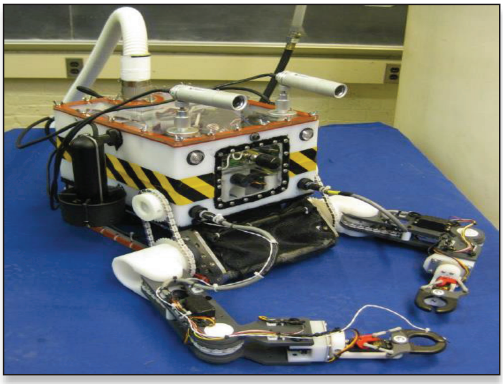
C. Design 3- Hornet II by Mikhail Dembicki and Margaret Boshek [29]

The hornet II project is an extension from Hornet I project as shown in Figure 6. This ROV was an improvement from the first design and many features have already been added to it. The concept of the frame of the Hornet II is the use of PVC. This ROV is attached with four separate motors to power the ROV. Hornet II targeting depth of 300 feet and the PVC coupling was designed to withstand rough 150psi of underwater pressure. Hornet II is controlled by using four-axis joystick. The advantage of Hornet II is the embedded sensors such as depth sensor, temperature sensor and hydrophone.

Figure 6: Hornet II during pool testing.

D. Design 4- Latis II Underwater Remotely Operated Vehicle [30]

Latis II was categorized as a work-class ROV as shown in Figure 7. It was built purposely to participate in the 2010 MATE International ROV competition. The mission included tasks such as sensing and measuring sound waves, accurately measuring fluid temperature, navigating through an underwater cave and collecting crustaceans to the surface. This ROV was built with two identical four Degree of Freedom (DOF) arm with open and close grippers. There are six static thrusters providing six DOF control, three cameras and a holding net. The power supply box consists of power converters, video converters, fuses, switches, camera and power connectors. They split the power to 24V, 12V and 5V for the ROV.



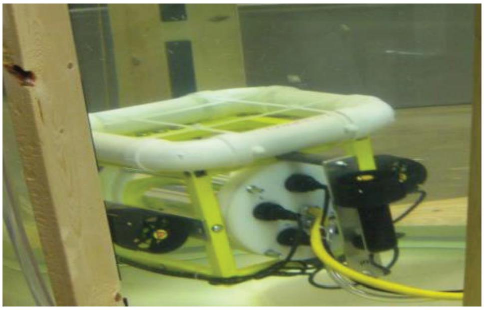


Figure 7: Latis II

E. Design 5 - The SeaWeed Remotely Operated Vehicle [31]

The ROV of this project was classified as observation class ROV which is used to research, visual inspection, and minimal data collection. Sea Weed features an instrument package that includes a depth sensor, temperature sensors and a compass. Other than that, it also includes a color camera to capture video that will be displayed on a monitor mounted in the topside control box. The frame of this ROV was fully designed by using aluminum. One of the advantages of Aluminum is the material was antirust and it is not affected when undergoing subsea. For maneuver system, they used four motors Molded Brushless DC motors to produce thrust in forward, backward, left and right as shown in Figure 8. This ROV uses a power supply converted through an AC-DC Front End converter from the 110V AC to 300V DC. This 300V sent down the tether into the bottom side of the DC converter that converts it to 5V and 12V DC to power the ROV. In order to control the ROV buoyancy and stability, they used Syntactic Foam.

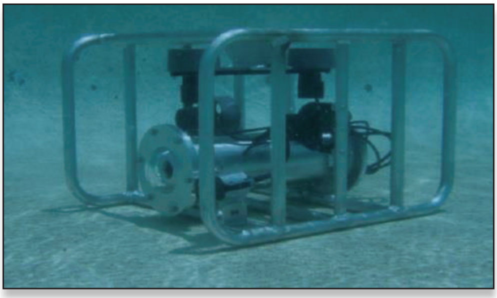


Figure 8: Seaweed ROV

Table 5 shows a list of the most common control strategies used on UUVs. This table was taken from [32], which contains the complete list of references for each of the controllers/UUV pairs. There are, however, many other control strategies which have been successfully implemented on UUVs (a list of them can be seen in Table 4). In total, Table 5 and 6 cover 56 different UUV/controller combinations, which represent a large section of the research-based AUV field. Details of the control systems for commercial AUVs are not widely available. Of the 56 listed, only 19 have been fully implemented and tested on a UUV.

Table 5
Main Types of Controller Used on UUVs [32]

TYPE OF CONTROLLER	UUV
PID (and variations)	ARCS, ICTINEU, KwaZulu-Natal AUV, OBERON, ODIN, ORCA, REMUS, SPARUS, Subjugator, THETIS, ARIES, Phantom S2, UTM
Sliding Mode (and variations)	Benthos RPV-430, Hamburg ROV, Subjugator, OEX-C, EAVE, JASON, MUST, REMUS
Adaptive (and variations)	ODIN, Manta-Ceresia, Taipan 2, R2D4

Table 6
Alternative Controllers for UUVs [32]

TYPE OF CONTROLLER	UUV
Disturbance Compensation Scheme	NPS Phoenix
Nonlinear Gain Scheduling	INFANTE
Formation Control	SERAFINA
S-Surface/S-Plane	EAUV-XX, MAUV-II, OID-1
Lyapunov-based Tracking	Simulation only
HPSO-based Fuzzy Neural Network	National Key Lab AUV
Smith Control Scheme with LQG/LTR	ARGO
State-dependent Riccati Equation	REMUS
H2/H∞	Simulation only
Fuzzy	ARPA UUV
Robust Cascade	RRC
Cross-track Controller	C-SCOUT
Receding Horizon Tracking Control	Simulation only
Multivariable Control using LQG/LTR	Simulation only

VII. CONCLUSION

This paper provides a thorough explanation of auto-depth control system for an Unmanned Underwater Remotely operated Vehicle (ROV) using Artificial Intelligent Controller Techniques focusing on the use of Fuzzy Logic Controller (FLC) for the auto-depth control system of the ROV. The recently published papers for auto-depth control of an Unmanned Underwater Vehicle (UUV) are also described. A new technique for auto-depth control of the ROV called as the SIFLC resulting from the investigation and tuning of two parameters, namely the break point and slope for the piecewise linear or slope for the linear approximation are introduced. The hardware comparison of the same concepts of ROV design is also discussed. This review provides valuable insights for reader to design a new technique and algorithms for auto-depth control. This review on SIFLC, ROV and Depth control also provides a new approach for readers to conduct further exploration in this field of research.

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