Stabilizing and Controlling the Altitude and Attitude of Remotely Operated Underwater Fishing Drone

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Abstract

Fishing is one of the most intense and time-consuming occupations. Sometimes it's hard to find a healthy fish population and fishermen to travel far offshore for this purpose and it's sometimes dangerous in bad weather conditions. The study focuses on controlling and stabilizing the altitude and attitude of the fishing drone. This manuscript designs dual control based on model adaptive control (MAC) with Proportional integral derivative (PID). It also uses an integral as the feedback. MAC deals with the disturbances and PID tunes the systems adaptive gain. Furthermore, the Lyapunov stability criterion helps in maintaining the stability of the system. The feedback removes the steady-state error and improves the convergence rate. The simulation results verify the accuracy and effectiveness of the designed scheme. The designs scheme shows high convergence, low steady-state error, and better robustness.

Keywords—Remotely operated underwater vehicle, Adaptive controller, PID controller, Stability

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1 Introduction

1.1 Motivation

As the year passes the usage of underwater vehicles swiftly increases [1]. These vehicles play an essential role in the inspection of resources underwater. It helps for under-water observation, construction, and maintenance of the sub-sea project as well as to assist commercial fishing [2-3]. The underwater drones could have a typical fishing operation from the perspective of efficiency, fuel use, revenue, and cost. Unmanned underwater robots (UUV) are commonly categorized into two categories include Autonomous underwater vehicles (AUV) and Remotely Operated Vehicles (ROV) [4]. The main center of attraction is ROV and it is an empty submerged robot, inter-connected with link transmit charge and control motions between the administrator and the ROV, allowing remote route of the vehicle. ROV submerged vehicle, sometimes used for submerged observations. It can also be used for underwater photography, videography, fish detecting, and fish luring [5]. Designing an under-water drone is inherently more intricate than one for the sky as factors like waterproofing, pressure, stability of ROV under-water with buoyancy and have to face a variety of other challenges so its body needs to be designed more accurately, explicit, precise. [6-8] The motivation is to design a fishing drone and dual controller for its stability. Still, there are plenty of things that remain unexplored under the water. The upcoming era mainly focused on developing the stabilizing algorithm for the underactuated or actuated system.

1.2 Related Work

In reference to [9] the study proposes the PID controller based on a neural network. The NN plays an important role in estimating the set of PID gains which help in attain g the stability of the system. It also regulates the controller gains that attains low tracking error. The system in this study is underactuated ROV. The simulations results show the accuracy and effectiveness of the proposed scheme. Similarly, in [10] the fuzzy logic controller that deals with the non-linearity combined with PID. The controller makes ROV capable to be balanced while maneuvering and diving. It also helps in attaining the response with the disturbances in attitudes and depth. The simulation results show that the proposed scheme solves all the problems and shows effective results during the test. About [11] the study designs a dual controller. 1) PID controller

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2) Single input fuzzy logic controller (SIFLC). This manuscript also presents the comparison among the different techniques. It also deliberates the modeling of the designed underwater vehicle and tuning of SIFLC to attain the best transient response. It also analyzes the steady-state error, overshot, settling time, and rise time. The computational experiment shows the precision and effectiveness of the proposed scheme. Lastly, in [12] the study focuses on the controlling of the underwater vehicle having overshoot, settling, and rise time minimized. This study proposes an adaptive logic controller that can stabilize the system according to the surrounding. The MATLAB software verifies the accuracy of the algorithm. Then, it was tested on the actual prototype of the designed ROV. Results show the accuracy, efficiency, and control of the vehicle.

1.3 Contribution

The main contribution of this manuscript is to design the dual control algorithm based on the model adaptive controller (MAC) and Proportional integral derivative (PID) along with the feedback. In this control algorithm, PID tunes the system's gain and the other one helps in the dynamic stability of the system. Similarly, the feedback loop cancels all the steady-state errors and external disturbances. Lastly, the stability of the system is dealt with by the Lyapunov stability standard.

1.4 Organization

The whole manuscript is organized as follows. Section 1 defines the introduction comprised of motivation, related work, contribution, and organization. Section 2, defines the problem statement and proposed solution. State of the art is defined in section 3. Section 4 defines the mathematical model of the designed ROV. Section 6 explains the design of the control scheme. Section 7 defines the simulation and section 8 defines the conclusion.

2 Problem Definition & Solution

Many researchers designed the structure of underwater vehicles for different types of applications. This study focuses and applies the vehicle to the area of fish catching [13-14]. The main focus is to design and construct the vehicle which falls in the category of a fully actuated system. The main problem faced is to maintain maneuverability and stability of the vehicle during the operation. It's only due to the hydrodynamic effects and pressure of the underwater environment. For this, along with the perfect control strategy, the design will also be the best, and the system is fully actuated as in this manuscript. This study designs the dual controller to control all responses of ROV. The controller attains (MAC), (PID), and integral for the feedback. The MAC deals with the moments and disturbances while PID tunes the adaptive gains.

3 State of the Art

This section of the manuscript explains the recent trends in this field. In reference [15] ROV is designed namely 'Findev' which attains the capability of performing visual imaging and fish tracking. This study also applies the principle of hydrostatic to achieve equilibrium. The dimensions of the vehicle (535.5x304.2x248 mm). It also can operate at the depth of 20 m and is stable at the pressure of 200 MPa. Bilge pumps help in the movement with the physical properties of 1100 GPH. The simulation results verify the effectiveness of the whole system. In [16-17] ROV provides the solution of monitoring the quality of water in the farms of fish. The system comprises a camera for capturing and sensors to measure the environmental data. The study implements algorithms based on computer vision for inspecting the fish farms. The vehicle helps in capturing the underwater images and determining the net patterns of the fish cage. This system is evaluated in real conditions. The data of ROC demonstrate the accuracy of the proposed scheme. Lastly, the simulation results verify the accuracy and effectiveness of the designed scheme. Similarly, in another reference [18] the study focuses on designing the control strategy combining fuzzy PID with dynamics compensation. Firstly, the hydrodynamic analysis had done to attain the relationship between the velocity and water. Also, the field experiments help in removing the dynamics error. Secondly, the controller based on fuzzy PID tunes the parameters of the controller with the help of fuzzy rules. The computational experiments show the accuracy of the control strategy. The design fully meets the requirement in the practical application of the vehicle. The contribution of this manuscript is to design and combine the fuzzy PID with the dynamics equation. Lastly in [19] the study designs the lateral line system (LLS) for the perception of field, removing disturbances, and stability. All sensors faced the challenge of the signal to noise (SNR) during the operation. The study proposes the fusion method to solve all these issues. Firstly, LPF was applied to data and then mapped on the angle of attack. The efficiency of the designed scheme is evaluat-ed by comparing the scheme with other designed schemes. The study provides the method of attitude controlling of underwater vehicles by fusing the data of sensors.

4 Mathematical Modeling

This section of the manuscript defines the mathematical model of ROV which helps in its construction as well as in the designing of the controller. The two coordinate systems 1) Body fixed frame 2) Earth fixed frame define the vehicle movement in 3-D space [20]. The designed ROV attains six actuators to control the longitude and latitude of the vehicle and six degrees of freedom (6-DOF). The system is fully actuated due to the equivalent number of actuators and DOF. The figure below shows the model of the designed underwater vehicle. The table below defines the notations of ROV.

$$\eta = \begin{bmatrix} \eta_1 \\ \eta_2 \end{bmatrix}^T ; \eta_1 = \begin{bmatrix} x \\ y \\ z \end{bmatrix}^T ; \eta_2 = \begin{bmatrix} \phi \\ \theta \\ \psi \end{bmatrix}^T \tag{1}$$

η represents position and orientation vector whereas η_1 defines the position and η_2 defines the orientation. As given in table 1 position is denoted by the vector $[xyz]$ and orientation is denoted by the vector of $[\phi\theta\psi]$.

$$\nu = \begin{bmatrix} \nu_1 \\ \nu_2 \end{bmatrix}^T ; \nu_1 = \begin{bmatrix} u \\ v \\ w \end{bmatrix}^T ; \nu_2 = \begin{bmatrix} p \\ q \\ r \end{bmatrix}^T \tag{2}$$

Velocities are denoted by ν_1 and ν_2 whereas ν_1 is a linear or translational velocity and ν_2 is angular or rotational velocity.

$$\omega = \begin{bmatrix} f \\ m \end{bmatrix}^T \tag{3}$$

$$f = \begin{bmatrix} Y \\ Z \end{bmatrix} \tag{4}$$

$$O = \begin{bmatrix} Y' \\ Z' \end{bmatrix} \tag{5}$$

The force and movement are denoted by ω in which f denotes force and O denotes movement. Both force and movement respective vectors are displayed in Equations 8 and 9. Now, the figure below shows the earth-fixed and body-fixed coordinate systems. The designed ROV attains six actuators and rach provides force f. Table 2 and 3 define the movement and the turning on/off of the actuators for the precise movement simultaneously. Table 3 explains the direction attained by the actuators (1-6) and the location on the designed ROV. Actuators 1 & 2 move in the clockwise direction for forward and 3 & 4 move in an anti-clockwise direction for backward. Similarly, 5 & 6 helps in moving the body up and down.

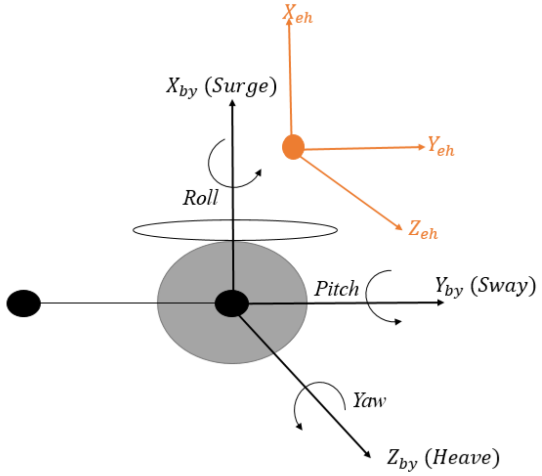


Fig. 1: Body & Earth fixed coordinate system

5 Designing of the Controller

The stabilization of the dynamics of the underwater vehicle and the controlling is a very difficult mission. It's only due to the hydrodynamic properties and non-linearity. In the past decade many researchers design ROV with any number of actuators to stable it. The designs failed due to the high pressure and unstable maneuvering. The design of ROV in this manuscript attains six actuators. The article designs a dual controller based on model adaptive control (MAC) and PID responsible for feedback loop regularity and fine-tuning of the gain of the system simultaneously. The control laws of MAC stables the dynamic system. In the system model, the uncertainties and non-linearity of the system are not included. The specification of hydrodynamic attains improbability coefficient σ. The augmentation of the ROV model and state equation produces the below system.

$$\begin{cases} L_s(t) = P_s(t)L_s(t) + Q_s(t)\sigma C(t) \\ M_s(t) = R_s(t)L_s(t) \end{cases} \tag{6}$$

Whereas, $L_s(t)$ defines the system state variable, $M_s(t)$ defines the system output, $P_s(t)$, $Q_s(t)$ and $R_s(t)$ denotes the matrix variables of the system, $C(t)$ denotes the input control signal, and σ denotes the unknown matrix.

$$[P_a(t), Q_a(t)] = [P_s(t), Q_s(t)] \tag{7}$$

Whereas,
$L_a(t) \in U^{m*1}$; $P_a(t) \in U^{m*m}$; $Q_d(t) \in U^{m*r}$; $C_a(t) \in U^r * 1$, the anticipated system state is denoted by $P_a(t)$ and $Q_a(t)$. Integral feedback with MAC is commonly used in the intelligent system with the designed algorithm. In an integral state, response builds up and is adjusted with the PID controller. It also helps in

Degree of freedom (DOF)	Position and Euler angles	Linear and rotational velocities	Forces and moments
Motion in x-direction	x	u	X
Motion in y-direction	y	v	Y
Motion in z-direction	z	w	Z
Rotation about the x-axis	ϕ	p	X'
Rotation about the y-axis	θ	q	Y'
Rotation about the z-axis	ψ	r	Z'

TABLE 1: Notations of a 6-DOF ROV

Actuators					
1	2	3	4	5	6
Forces					
f_1	f_2	f_3	f_4	f_5	f_6

TABLE 2: Actuators and forces of ROV

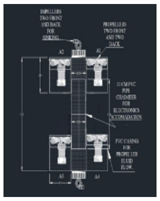
	Actuators	Movement
	1/2	Forward
	3/4	Backward
	2/4	Left
	1/3	Right
	5 & 6	Up/ Down

TABLE 3: Forces and actuators for movement

canceling the noise. The tracking error of the system concerning integral feedback is given as

$$E_i(t) = \int_0^t M_s(t) - cfM_a(t) \tag{8}$$

Whereas, the system actual and anticipated output is represented by $M_s(t)$ and $M_a(t)$ simultaneously. The controller imposes $M_s(t)$ to follow $M_a(t)$. The state vector can be written as

$$L(t) = [\dot{E}_i(t)R_s(t)E_i(t)]^T \tag{9}$$

The equation below denotes the comprehensive open loop from equation (6) without external torque.

$$\begin{cases} \dot{L}_s(t) = P(t)L(t) + Q(t)\sigma C(t) + Q_a(t)M_a(t) \\ M(t) = R(t)L(t) \end{cases} \tag{10}$$

Actuators	
Size (Meters)	0.54x0.45x0.34
Body Weight (kg)	18

TABLE 4: Physical properties of the designed ROV

The equation below defines the extended form of the system.

$$L(t) = E_i^q(t)L_s^q(t)^T \tag{11}$$

The augmented state-space matrix is expressed as follows,

$$\begin{cases} P(t) = \begin{bmatrix} 0 & R_s(t) \\ 0 & P_s(t) \end{bmatrix};\ Q(t) = \begin{bmatrix} 0 \\ Q_s(t) \end{bmatrix} \\ M_s(t) = \begin{bmatrix} 0 & R_s(t) \end{bmatrix};\ Q_s(t) = \begin{bmatrix} -I \\ 0 \end{bmatrix} \end{cases} \tag{12}$$

The augmented matrix can be controllable when the condition in the equation below satisfy.

$$det \begin{bmatrix} P_s(t) & Q_s(t)\sigma \\ R_s(t) & 0 \end{bmatrix} \neq 0 \tag{13}$$

The designed controller follows the output state and anticipated response in the accessibility of the uncertainty in the system. Then, $P_a(t)$ combines with the diagonal of σ. The following matrix calculates the output of the anticipated system.

$$P_a(t) = P(t) + Q(t)\sigma\delta^e \tag{14}$$

Substituting Equation 14 in Equation 10,

$$\dot{L}_s(t) = P_a(t)L(t) + Q(t)\sigma(C(t) - \delta_x^e L(t)) + Q_a(t)M(t) \tag{15}$$

The designed algorithm consists of MAC and PID. So, the control signal is the sum of both controllers.

$$C(t) = C_MAC(t) + C_PID(t) \tag{16}$$

Whereas,

$$C_{MAC}(t) = \hat{a}_x^e(L_s(t)) \tag{17}$$

$$C_{PID}(t) = -[N_pE_i(t) + N_i\int_0^t E_i(t) + N_a(E_i(t)\frac{d}{dt})] \tag{18}$$

$P_a(t)$ helps in attaining the $P(t)$ and σ matrix. The only PID controller cannot meet the required performance due to the disturbance effects. Therefore, the dual controller is designed to meet the required performance. MAC controller handles the disturbance, predicts the behavior, and stabilizes rendering to conditions. Now, the equation (15) can be rewritten as,

$$\dot{L}_s(t) = P_a(t)L(t) + Q(t)\sigma(\delta_x^e L(t)) + Q_a(t)M_a(t) \quad (19)$$

The below equation defines the desired system on behalf of equation (8).

$$\dot{L}_a(t) = P_a(t)L_a(t) + Q_a(t)M_a(t) \quad (20)$$

The tracking error is expressed as,

$$E(t) = L(t) - L_a(t) \quad (21)$$

The dynamics error is expressed as,

$$\dot{E}(t) = P_a(t)E(t) + Q(t)\sigma(\gamma_x^e L(t)) \quad (22)$$

Now, the Lyapunov candidate function is applied for the merging of all errors in the system. It can be articulated as,

$$b(E(t)) = E^e(t)A_aE(t) + trace(\Delta\delta_x^e \rho_x^{-1} \sigma \Delta\delta_x) \quad (23)$$

Whereas ρ_x denotes the adaptation rate and trace represents the operator matrix. The diagonal matrix A_a must be equal to $A_a^e > 0$. Neglect all the deviations to measure the Lyapunov candidate function resolution, i.e. $P_a^e(t)A_a + A_aP_a(t) = -B$. Where B denotes the positive matrix and equals to $B^e > 0$. Equation 15 can be rewritten as,

$$\begin{aligned} \dot{b}(E(t)) = -E^e(t)BE^e(t) + 2trace(\Delta\delta_x^e\{a_x^{-1}\dot{\delta}_x \quad (24) \\ + L(t)E^e(t)Q(t)A\}\sigma) \quad (25) \end{aligned}$$

The two-dimensional vectors $P(t)$ and $Q(t)$ in terms of 'trace' can be written as $P^e(t)Q^e(t) = trace(P^e(t)Q^e(t))$. The equations below represent the adaptive law.

$$\dot{\delta}_x = -\sigma_x L(t)E^e(t)Q(t)A(t) \quad (26)$$

$$\dot{b}(E(t)) = -E^e(t)B(t)E(t) \leq 0 \quad (27)$$

Equation 26 approves the stability of the system.

6 Experimental Results

This section provides the experimental results of the designed ROV. The system performs according to the expectations under a certain environment. Firstly, the stability of the vehicle is evaluated that meet all requirements. As the system is the prototype, the next step is to examine its movement and control underwater. The system travels a long distance to help fishermen where there is no possibility of reaching. The results show that the system attains higher reliability and accuracy. Figure 2(a-b) shows the movement of ROV while catching fish. The experiment took place in the swimming pool bearing the dimensions (30x20) ft. The joystick works as the input controller of the designed vehicle. It is also equipped with a camera which helps in the visualization of the underwater environment and fish. Similarly, figure 3 (a-b) shows the vehicle when the fish is caught. As the results show, the system attains higher reliability, stability, control, and accuracy.

The experimental video of the above research is uploaded in the following URL: https://youtu.be/BcVjCF7Cc98.

7 Conclusion

This study designs the underwater fishing drone. It also aims towards stabilizing and controlling of vehicle by using a designed dual controller based on MAC and PID. The designed vehicle attains six actuators with six DOF. The system falls in the category of a fully-actuated system. The experimental results verify the effectiveness of the designed scheme. It also attains a good response along with better robustness. The designed vehicle performs according to the requirement and is easy to use for underwater applications such as this one. Lastly, the field experiments verify the controlling and stabilization of the vehicle.

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(a) (b)

Fig. 2: ROV while chasing fish

(a) (b)

Fig. 3: ROV caught fish

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