MOVEMENT CONTROL OF AMPHIBIOUS ROBOT USING IMC BASED PID CONTROLLER WITH FUZZY LOGIC OPTIMIZATION

Gargi Phadke, Shamal Salunkhe, and Supriya Bhuran
Department of Instrumentation Engineering, Ramrao Adik Institute of Technology, India

Abstract

For the Amphibious bot movement control, this study provides an Internal Model Control (IMC) tuned PID controller using fuzzy logic optimization method. IMC approach is used to tune the PID controller parameter as per the robot movements for robust control. Fuzzy logic is used to optimize the input error for controlling output. The proposed control approach, which is based on an accurate robot model, resulted, design of the stable and robust control system. The proposed method produces better outcomes than the present methods. It is measured against performance indices. Comparative results show a significant improvement in the system's overshoot, rising time, and settling time. It is also performing better and better robustness against disturbances.

Keywords:

Movement Control, Ambiguous Robot, PID Controller, IMC, Fuzzy Logic, Time Domain Analysis

1. INTRODUCTION

In the paper IMC tuned PID controller with Fuzzy logic optimization and its implementation for amphibious robot has discussed. The issue of how to control the amphibious robot has several facets. The circumstance, which is denied by a huge number of disruptions, is the most difficult part. Controlling an amphibious spherical robot is complicated by the effects of several types of disturbances, as well as unanticipated events. When employing typical approaches to create the controller of an amphibious spherical bot, the consequent performance does not meet the expectations. The linear process model is mostly controlled by traditional PID control. Establishing a mathematical model is difficult or impossible because, conventional PID control cannot deliver strict control for such applications. Fuzzy control, on the other hand, does not require the development of a mathematical model; itis particularly beneficial for complex robots for which accurate mathematical models are difficult to construct. In addition to PID if dynamics of robot movements are known then it facilitates control action. IMC can predict low impact disturbances and then deliver a respective signal to the PID controller [1]. The IMC PID controller decreases overshoot and settling time when disturbances and uncertainty are present [2].

Authors proposed IMC-PID controller for uncommon unstable system. It is an inverse-response second-order time delay system. To check robustness of controller, ITAE criteria is used. An overshoot is eliminated with a set-point weighting parameter [3]. In the paper [4] authors proposed IMC PID controller with new design is used to improve disturbance rejection and good transient response. Shahab Abdulla et al [5] proposed PID using IMC to control anesthesia dose variations. The simulation showing good disturbance rejection and setpoint tracking. He has mapped patients' demography and drug tolerance as pharmacokinetics (PK), and pharmacodynamics (PD). Based on these parameters they build up IMC model. Liu Li-Ye et al [2] proposed a better performing, SOPDT process-based control system. They have modified TDF Smith control structure with IMC-PID controller. For integrating processes, Ranganayakulu et al. developed an IMC-PID controller based on a fractional IMC filter designed. Raval et al. [6] proposed PID control for level of tanks. Higher order fractional IMC eradicates the set point weighting and helps to minimizethe overshoot. Ujjwal Nath et al [7] worked on online switching using IMC-PID controller using fuzzy logic. Mohammed Alshaboti et al. [8] proposed fuzzy logic control for multiple tasks for robot. The proposed switching algorithm is effective for real-time application.

The following is an overview of the article's structure: The information in section 2 is about amphibious robot model identification and depiction. IMC PID is discussed in section 3. section 4, Simulation results of IMC PID optimized with fuzzy logic technique are presented. In section 5, conclusion of paper is presented.

2. MODEL IDENTIFICATION AND REPRESENTATION OF AMPHIBIOUS ROBOT

Robots of many kinds now populate our planet, and they are used for a variety of purposes. Robots are often thought to be a 20th-century invention, yet their origins are much older. Greeks and Egyptians created mechanical machines in the prehistoric era, approximately 270BC, to perform simple tasks. Automated toys now amuse children, and ever more intricate technology is being developed.

As computer technology advanced at a rapid pace, scientists became increasingly interested in building intellectual machines that could eventually have some logic to work for themselves. A comparison of two off-line identification approaches to the nonlinear models. An integral technique is a type of non-linear multivariate model that used to a wide range of models and has outstanding numerical performance. Both strategies are contrasted when it comes to determining the dynamic model of the URIS UUV.

2.1 TYPES OF ROBOTS

Robots now perform a wide range of duties in a wide range of industries, and the number of occupations assigned to robots is steadily increasing [9]. As a result, dividing robots by their application is one of the most effective ways to categorise them. The following are examples of these:

Industrial robots: Robotics in the workplace Robots employed in industrial manufacturing are known as industrial robots. These are usually articulated arms designed expressly for welding, material handling, painting, and other uses. This category could potentially include some automated guided vehicles and other robots if we assess solely since applicability.

Domestic or household robots: Robots that are employed in the home are referred to as domestic or household robots. These are usually articulated arms designed expressly for painting, placing the objects, welding, material handling, and other uses. Some automated guided vehicles may cover under this category and other robots if we assess solely based on applicability.

Medical robots: Robots worked for medicine sector and medical institutions are known as medical robots. Surgery robots are first and foremost very important. Additionally, there may be some automated guided vehicles and possibly lifting aids. Robots that do not fit into any of the other categories due to their purpose. These could be data collection robots, technology demonstration robots, research robots, and so on.

Military robots: are robots that are employed by the military. Bomb disposal robots, various transportation robots, and reconnaissance drones are examples of this sort of robot. Robots designed for military objectives are frequently utilized in police enforcement, search and rescue, and other disciplines. Robots that are utilized for amusement are known as entertainment robots. This is an extremely broad classification. It starts with toy robots like Robosapiens or the running alarm clock and progresses on to professional robots like articulating robot arms used as motion simulators.

Space robots: This category of robots utilized in space operations. They are utilized in International Space Station. Can adarm, which was used in Shuttles, and Mars rovers and other space robots, fall into this category. Hobby and competitive robots - These are robots that you build yourself. Popular robots such as line followers, robots built for amusement, sumo bots, and robots built for competitiveness are all examples of robots.

Agriculture Robots: Articulated robots' flexibility, agility, and reach make them excellent for jobs that needs more power and time, such as machine tending. Articulated robots can enter into machine compartments with obstacles and then perform a task. Articulated robots excel in both clean and filthy situations thanks to sealed joints and protective sleeves. The ability to install an articulated robot on any surface allows for a wide range of working possibilities.

2.2 AMPHIBIOUS SPHERICAL BOT'S OPERATION

Amphibious spherical bot can move land as well as water. The effort to analyse and control the system is to develop the model of mathematical equations, which is a crucial approach and precondition [10]. If we wish to achieve precise underwater robot motion control, we must first understand its model.

2.3 DESCRIPTION OF MOVEMENT CONTROL SYSTEM

Amphibious spherical bot has different controlling parameters [11]. The water-jet propeller swings forward and backward by servomotor. Changing the PWM signals enables the spherical robot to walk at variable speeds [10].

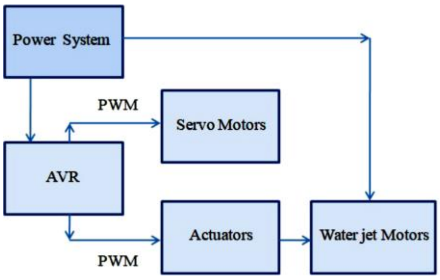

Fig.1. Description of Movement Control System Amphibious Spherical Robot

The Fig.1 shows the control system for an amphibious spherical bot. The CPU of the system for the robot is an AVR micro unit. To drive water motors, servo motors with the 4 actuation units, generates PWM signals. PWM signals are used to adjust movement of bot in water [12],[13]. The design of depicted in Figure1.Single water-jet motor, servo motors, also stainless-steel water jet thrusters are included with each unit. Four water jet thrusters propel the amphibious spherical bot around the room. PWM signals are used to control the motor's movement. The servo motor can turn 180 degrees. Another motor attached to a water-jet thruster which is controlled to travel vertically at the same time [16]. Each actuating unit can use servo motors to implement two degrees of freedom movement. The rotations of these thrusters are controlled by eight servomotors. Actuating modules, each with two DOF, are used as legs while the amphibious spherical robot walks on land. The quadruped bot is made up of four driving legs. The PWM signals may be adjusted to allow the botto walk and rotate on land. The robot can also move with water propellers that produces thrust under water. Each water-jet propeller's spray angle can be adjusted by changing the PWM signals of the servo motors, allowing for degree of freedom motions such as going forward, spinning, floating up down. The proposed controller is described in the next section.

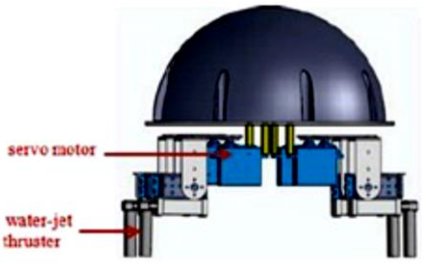

Fig.2. Generalize Design of Amphibious Spherical bot [14]

The bot is shown as in Fig.2 depicts general design of an amphibious spherical bot. An upper hemispheroid is sealed transparent, may be opened, and 4 actuation parts make up the amphibious bot [14]. A two servo motors and water-jet propeller make up each unit [15]. They are vertical to each other. The control components such as power supply and sensors are kept in the waterproof upper hemispheroid structure. The water jet propeller helps the amphibious spherical robot to float up and down. In addition, by modifying the propeller thrust, we may change the robot's speed. Figure1 depicts the design of the amphibious spherical robot. The robot has two modes of operation: quadruped walking and waterjet propulsion Actuating System The amphibious spherical bot includes four actuating components, as depicted in Fig.1. Single water-jet motor, servo motors, also stainless-steel water jet thrusters are included with each unit. Four water jet thrusters propel the amphibious spherical bot around the room. PWM signals are used to control the motor's movement. The servo motor can turn 180 degrees. Another motor attached to a water-jet thruster which is controlled to travel vertically at the same time [16]. Each actuating unit can use servo motors to implement two degrees of freedom movement. The rotations of these thrusters are controlled by eight servomotors. Actuating modules, each with two DOF, are used as legs while the amphibious spherical robot walks on land. The quadruped bot is made up of four driving legs. The PWM signals may be adjusted to allow the bot to walk and rotate on land. The robot can also move with water propellers that produces thrust under water. Each water-jet propeller's spray angle can be adjusted by changing the PWM signals of the servo motors, allowing for degree of freedom motions such as going forward, spinning, floating up down. The proposed controller is described in the next section.

3. BLOCK DIAGRAM OF PROPOSED METHOD FUZZY LOGIC OPTIMIZED IMC-PID CONTROLLER

The Fig.3 shows proposed method steps in details. IMC is used for tuning the PID controller [15]. As robotic movement should be predicted as per disturbances. IMC works better for low impact disturbance prediction. Fuzzy logic control is does not need mathematical model is suitable for the complex bot. It is used for input optimization. Step input is given for simulations. Proposed method is validated using time responses and performance index. For robustness testing disturbances is added. Next section explains fuzzy logic optimization method in detail.

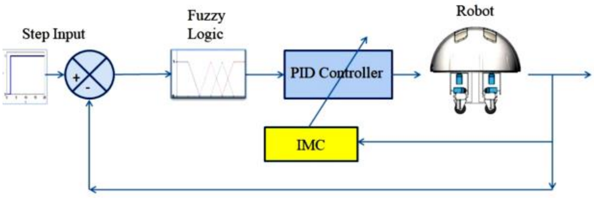

Fig.3. Block Diagram of Proposed Fuzzy-IMC-PID Controller

3.1 FUZZY LOGIC MODEL FOR OPTIMIZATION

Fuzzy Logic is a problem-solving control system paradigm that may be used in a wide range of systems [17]. The Fuzzy Logic approach to problem solving is based on how a person would make decisions, but it is considerably faster. The selection of a controller and the tuning of its settings are both part of the synthesis of a control system. To improve the control system's performance, the type of controller used in some circumstances may be more complicated or general. The tuning problem must be solved satisfactorily in all circumstances. Fuzzy Control, on the other hand, has enabled the construction of intelligent control. However, in proposed method Fuzzy logic is used with inputs of IMC-PID controller for optimization purpose. The output of a fuzzy logic analytic is summarized in terms of its input variables. This initial optimization has been tested in MATLAB Simulation.

Adaptive techniques are utilised to reduce the problem and offer an acceptable solution for bot movement control. When there is a disturbance in the amphibious spherical bot, solving the control complex problem of an amphibious spherical bot is challenging. Input is improved for robust controller design using a fuzzy logic paradigm. I/O variables to represent Fuzzy state and obtain control rules are established based on experience and perceptive reasoning. Therefore, development of a Fuzzy logic-based control input and output variables along with the control rules are as follows [18].

The MATLAB model of membership function for input variable is symmetric triangular "Error" is shown in in Fig.4. Control rules are developed for the Fuzzy model optimization using MATLAB environment and are as mentioned:

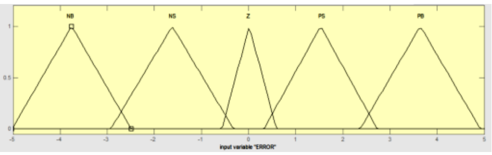

Fig.4. "Error" as an input variable

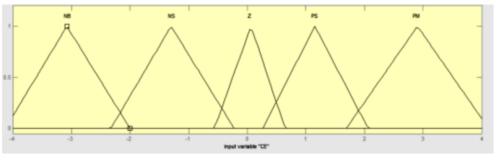

Fig.5. "Rate of Change of Error" as an Input variable

The motor's speed output is used to start or stop running motors, so deviation *e* is large, allowing the response time to be accelerated and the value of k_p to be improved. At the same time, the kd takes medium to avoid differential supersaturation. To avoid a huge overshoot because of the motor's speed, we normally omit the integral action, making $k_i = 0$.

Amphibious spherical bot's motors are functioning at a typical nominal speed, deviation e and deviation rate e_{in} medium size, e_c in intermediate number, to make the motor rotation speed to has a small overshoot, k_p tends smaller; the values of k_i should be medium, and the k_d value should be huge.

Motors speed constant, the error *e* is minor, the k_p and k_i values should be increased at the same time to ensure that the bot's performance is stable. The value of k_d is crucial for avoiding oscillation phenomena in the amphibious bot around the set value, improving the robot's anti-interference performance. In general, if e_c is lower, k_d grows larger, and if e_c is higher, k_d shrinks.

The Table.1 shows a Fuzzy model control rules based on the preceding analysis. Next section explains PID tuning using IMC in detail.

Table.1. Fuzzy PID inference rules to optimize the IMC-PID input error

ec,e	*NB*	*NS*	*ZE*	*PS*	*PB*
NB	PB,VB,VB	PB,VB,VB	PB,B,B	B,M,M	B,M,M
NS	PB,VB,B	B,B,B	B,B,B	B,M,M	B,M,M
ZE	B,B,B	B,B,B	B,M,M	M,S,S	M,S,S
PS	B,B,B	B,M,M	M,S,S	M,S,S	M,S,S
PB	B,M,M	M,S,S	M,S,S	M,S,S	M,S,S

3.2 INTERNAL MODEL CONTROL (IMC) MODEL

This section gives details of IMC model design. Both input tracking and disturbance rejection responses can be configured with the controller Some model inaccuracies could be easily overcome by an IMC based PID controller while this is not achieved in a conventional PID system. The result of simulation shows that IMC based PID is better [19]. Here is the IMC tuning method [2], Lambda tuning is another name for it. It is a reliable and stable alternative to other methods, such as the well-known Ziegler-Nichols method, is used for speed at the expense of stability. IMC model is explained in Fig.7. As shown in $G_C(s)$ is the controller, assume $\bar{G}_p(s)$ is the model of $G_C(s)$, The model inverse of the process is equal $G_C(s)$.

$$G_C(s) = \bar{G}_p(s)^{-1} \tag{1}$$

If $G_C(s)=\bar{G}_p(s)$ that mean the model is an exact representation of the process. it indicates set point is equal to output. In Fig.6, $D(s)$ is disturbance affecting the system, $U(s)$ is desired input. Proposed method compared with different methods. Comparative analysis is given in next section.

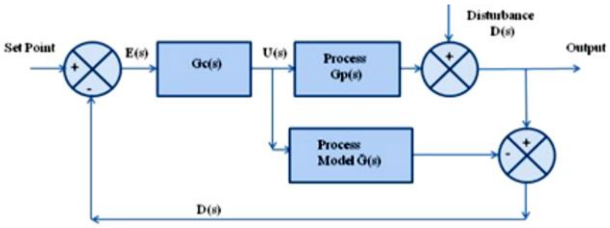

Fig.6. Block Diagram of design model of IMC [2]

4. RESULT AND DISCUSSION

The general goal of the proposed method is to control movement of a robot which can manoeuvre in sea and on land. The idea is to have a limited number of control techniques (that has been fixed to two), which can be used to control a variety of models. In this paper, the robot model is designed using forces and moments of Hydrodynamic which causes of damping is considered [14]. We use a numerical value for robot parameters using transfer function given in,

$$G(s) = 1/(61.84s^2+6.128s+3.265) \tag{2}$$

Proposed method is compared with PID controller [9]and IMC controller [5]. It is compared using time domain parameters analysis. The Fig.7 shows step response of proposed method with other existing methods PID and IMC-PID controller. The Fig.7 shows PID overshoot and steady state error is more, to reduced it PID tuned with IMC but, Rise time and settling time increased drastically. Proposed method reduced overshoot and settling time. Proposed method works better than other methods. The Fig.8 shows comparison of errors, proposed method has less error than other existing methods.

Error means the measured process variable differ from desired set point. It is continuously calculates using PID controller. Error is minimized using by adjusting of a control variable, such as the position of a robot, motor speed etc. Robustness of controller is tested by adding disturbance. It should handle disturbance and reduce the error.

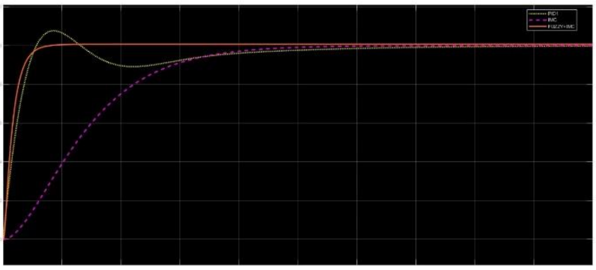

Fig.7. Comparative results: Proposed method with IMC and PID controller using Step response

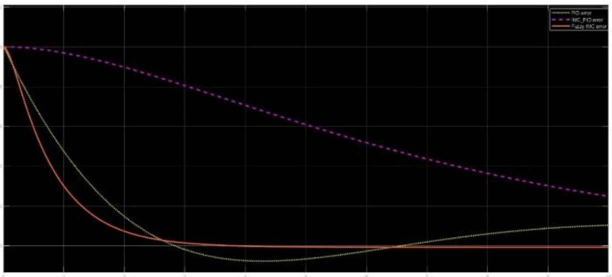

Fig.8. Comparative results: Proposed method with IMC and PID controller using Error

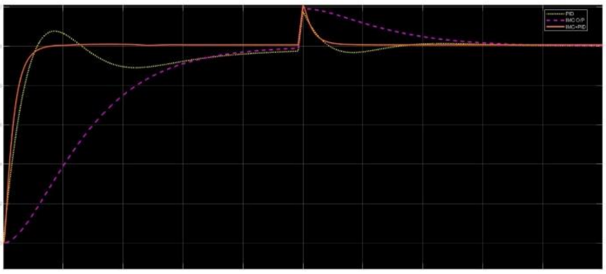

Fig.9. Comparative results: Proposed method with IMC and PID controller using Error with disturbance

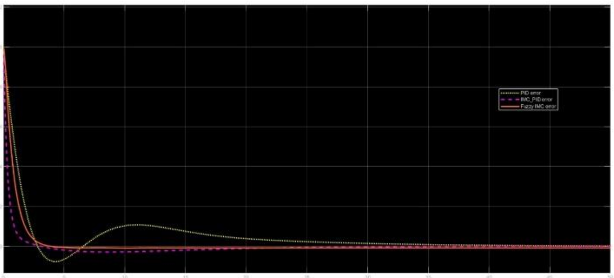

Fig.10. Comparative results of proposed method with Fuzzy with IMC and PID controller with disturbance

The Fig.9 shows proposed method handles disturbance better than other methods. The Fig.10 shows error comparison when disturbance is added. Though the disturbance is added proposed method works properly.

4.1 QUANTITATIVE ANALYSIS

Time domain parameters and performance index errors are used for analysis of proposed method. In this paper transient response Peak overshoot Rise time, and steady state response settling time and steady state error parameters are used for comparison. For error comparison Root mean square error (RMSE), Integral of Time multiply Absolute Error (ITAE), IAE, ISE are used. RMSE is calculated as given in equation,

$$R_e = \sqrt{\frac{\sum_{t=0}^{n}\left(x - y_t\right)^2}{n}} \tag{3}$$

where, x is set point, y is output of controller, t is time.

Integral of Time multiply Absolute Error (ITAE) is the absolute error multiplied by the time over time [14]. It is given as:

$$ITAE = \int_0^{\infty} t\left|e\left(t\right)\right| dt \tag{4}$$

The Integral of Absolute Error (IAE) integrates the absolute error over time. It is given as:

$$IAE = \int_0^{\infty} \left|e\left(t\right)\right| dt \tag{5}$$

The Integral of Squared Error (ISE) measure of system performance oven fixed interval of time, as given in:

$$ISE = \int_0^{t} \left|e\left(t\right)\right|^2 dt \tag{6}$$

All values should be low for better performance. The Table.2 shows comparative result. The proposed method performs better than other existing method. Better results are in bold numbers. The Table.3 shows comparative results of proposed method with disturbance for robustness test. Proposed method performs better than other existing method in disturbance condition.

Table.2. Comparison using Time Response parameters and performance indices of Proposed Method

Method	**T_r (s)**	**Overshoot**	**T_s (s)**	**ess**	**RMSE**	**ITAE**	**IAE**	**ISE**
PID	2.023	8.153	2.085	0.1037	0.1037	25.07	2.615	0.748
IMC	-	-	12.06	0.2486	0.2486	4.16	7.40	4.62
FuzzyIMC	1.624	0.485	1.455	0.0071	0.0071	9.504	1.15	0.47

Table.3. Comparison using Time Response parameters of Proposed Method with Disturbance

Method	**T_r (s)**	**Overshoot**	**T_s (s)**	**ess**	**RMSE**	**ITAE**	**IAE**	**ISE**
PID	2.062	7.164	15.276	0.1037	0.1037	30.15	2.7	0.7
IMC	-	-	4.656	0.2486	0.2486	83.83	8.805	4.803
FuzzyIMC	1.644	0.249	4.462	0.0071	0.0071	13.82	1.31	0.49

5. CONCLUSION

This paper proposed a design of control system for the movement control of amphibious robot. After comparison with a Conventional PID, IMC model proposed method perform better. Proposed method is Internal Model Control (IMC) tuned PID controller with fuzzy logic optimization method for the Amphibious Robot movement control. IMC approach is used to tune the PID controller parameter as per the robot movements for robust control. Overshoot is present with less settling time than Conventional PID but rise time is too more. Fuzzy logic control is used to optimize the input to IMC-PID reduce the error and perform better. It has reduced the Settling time. comparative results of proposed method with disturbance for robustness test. Proposed method performs better than other existing method in disturbance condition. Proposed method improves the deficiency of the original control strategy and has good robustness.

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