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Type-1 Fuzzy-PID Depth Control-Based Simulation and Analysis of Underwater Vehicles

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Abstract *— To address the limitation of conventional PID controllers in underwater vehicle depth control, where fixed gains cannot balance rapid response and overshoot suppression, this work takes the depth channel of an underwater vehicle as the research subject. A mathematical model for vertical motion is established, and the corresponding depth control transfer function is derived. A type-1 fuzzy PID controller with online parameter self-tuning is developed. The controller uses depth error and its rate of change as inputs, and adjusts proportional, integral and derivative gains in real time via fuzzy inference. Simulation models are constructed in the MATLAB/Simulink environment. Control performances of the conventional PID and the type-1 fuzzy PID are compared, sinusoidal continuous depth variation, ocean wave disturbance and sensor time delay. Simulation results reveal that the type-1 fuzzy PID converges faster after disturbance removal for step inputs, and its settling time under sensor time delay is less than half that of the conventional PID. The proposed type-1 fuzzy PID effectively suppresses overshoot while maintaining favourable response speed, and exhibits better adaptability and robustness against wave disturbances and sensor time delay.*

Keywords *—* ***underwater vehicle, depth control, type-1 fuzzy PID, ocean wave disturbance, sensor time delay***

I. INTRODUCTION

The exploitation of marine resources has raised growing demands for the autonomous operation of underwater vehicles. Widely adopted in marine resource surveying, underwater environmental monitoring, submarine pipeline inspection and military reconnaissance, these vehicles rely heavily on depth control to maintain steady depth-keeping, hovering and depth-changing maneuvers. The quality of depth control largely governs whether a mission can be completed successfully[1]. Unfortunately, underwater vehicles represent strongly coupled, nonlinear and time-varying systems. Subject to uncertain disturbances such as waves and ocean currents, they rarely allow an accurate dynamic model to be obtained, which places stringent requirements on the robustness of control schemes[2].

Thanks to its simple structure, clear physical interpretation and easy implementation, the PID controller remains the dominant option in industrial control. Nevertheless, the depth channel of an underwater vehicle features large inertia and weak damping. When fixed PID gains are adopted, a large proportional gain is generally required to pursue fast response, which inevitably introduces noticeable overshoot and oscillation. Reducing the proportional gain can suppress overshoot, yet it slows down the system response considerably. Such a trade-off between rapidity and overshoot suppression is hard to resolve[3], and becomes even more prominent under external disturbances and measurement delays.

Type-1 fuzzy control does not require an accurate mathematical model of the plant. It encapsulates practical operational knowledge from experts into linguistic rules and copes well with parameter

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variations and external disturbances. By integrating type-1 fuzzy inference with conventional PID, a type-1 fuzzy PID controller can tune PID gains online, making it possible to balance fast response and satisfactory dynamic performance. This strategy has already outperformed standard PID in many applications, including liquid level regulation, temperature control, speed regulation of conveying systems and dissolved oxygen control[4-7]. It has also been validated for attitude and position control of underactuated multirotor platforms such as quadrotors and hexarotors[8].

As for simulation tools, MATLAB/Simulink offers a graphical modular framework for control system development. It conveniently accommodates nonlinearities, time delays and external disturbances, and has become a standard testbed for validating control algorithms. Reference[9] built open-loop and closed-loop simulation models for DC-DC converters in Simulink, while reference[10] constructed dynamic models for complex electromechanical systems from transfer functions. Both studies demonstrate that transfer-function-based modelling clearly reveals how system parameters shape dynamic responses and supports controller tuning.

For underwater vehicle depth control, reference[1] proposed a type-1 fuzzy PID controller and validated it under step commands only. Although the controller achieved better overshoot and settling time than conventional PID, the tests covered limited operating scenarios and ignored practical conditions such as continuous depth tracking, wave rejection and sensor time delay. Following the depth channel model and controller architecture from this work, this paper carries out further simulations in MATLAB/Simulink. Three additional test cases are introduced: sinusoidal depth tracking, wave disturbance rejection and robustness tests with sensor delay. A systematic comparison between the two controllers is presented, with the aim of offering useful insights for the practical deployment of depth controllers on underwater vehicles.

II. MATHEMATICAL MODEL OF DEPTH MOTION FOR THE UNDERWATER VEHICLE

To characterise the spatial motion of an underwater vehicle, two coordinate systems are defined: the inertial frame O-xyz attached to the Earth, and the body-fixed frame Ob-xbybzb rigidly connected to the vehicle. The inertial frame is used to describe the position and attitude of the vehicle, while the body-fixed frame serves to resolve forces and moments acting on the hull. Neglecting Earth's rotation and curvature, the vector governing equation for the six-degree-of-freedom motion of the underwater vehicle can be expressed as[1]:

$$M\dot{\nu} + C(\nu)\nu + D(\nu)\nu + g(\eta) = \tau \qquad (1)$$

where v denotes the vector of linear and angular velocities resolved in the body-fixed frame, with components [u, v, w, p, q, r].

Here, u, v and w represent the surge, sway and heave velocities respectively, while p, q and r are the angular rates about the three body axes. η stands for the position and attitude vector defined in the inertial frame. M is the inertia matrix including added mass, C(v) the Coriolis and centripetal matrix, D(v) the damping matrix, g(η) the restoring force vector arising from gravity and buoyancy, and τ the control force and moment vector generated by thrusters and control fins.

Depth control essentially targets the heave motion of the vehicle, so only the heave component from Equation (1) needs to be considered. Roll and yaw coupling are neglected, and cross-coupling terms other than thrust, hydrodynamic damping and net buoyancy along the depth direction are assumed small. Under these assumptions, the vertical motion equation can be derived from Equation (1):

$$m(\dot{w} - uq + vp) = Z \qquad (2)$$

where m represents the vehicle mass, and w is the heave velocity. u and v are the horizontal velocity components, while q and p denote the pitch and roll angular rates, respectively. Z stands for the total vertical force acting on the vehicle, which covers thruster thrust, vertical hydrodynamic forces, and the net force between gravity and buoyancy.

Eq. (2) is nonlinear and difficult to apply directly for controller design. Small-disturbance linearization is performed around the equilibrium point of Eq. (2). The vertical velocity w and depth z are selected as state variables, where depth is the time integral of vertical velocity, $z=\int w\,dt$. Laplace transformation is carried out on the linearized equations under zero initial conditions. After eliminating the intermediate variable w and rearranging the terms, the transfer function of the depth control channel for the

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underwater vehicle studied in this work can be obtained as follows:

$$G(s) = \frac{0.3559s^2 + 5.226s + 35.2459}{s^4 + 10.0997s^3 + 8.3879s^2} \quad (3)$$

The denominator of the above expression is factorized as:

$$\begin{aligned} s^4 + 10.0997s^3 + 8.3879s^2 \\ = s^2(s^2 + 10.0997s + 8.3879) \\ = s^2(s + 0.913)(s + 9.187) \end{aligned} \quad (4)$$

It can be seen from Eq. (4) that the controlled plant has two repeated poles at the origin. These poles arise from the physical nature that depth corresponds to the double integration of vertical acceleration, which also endows this channel with prominent large-inertia characteristics. The other two poles of the plant are −0.913 and −9.187, both lying in the left half of the s-plane. This indicates that the controlled plant contains no unstable poles except for the double integrator at the origin. Nevertheless, owing to the double integrator at the origin, the open-loop system cannot track constant depth commands. Feedback control with properly arranged zeros is therefore required to improve its dynamic behaviour. Eq. (3) serves as the mathematical basis for subsequent controller design and Simulink modelling.

III. SIMULATION

The conventional PID controller takes the error e between the depth reference zd and the measured depth z as the input. It performs proportional, integral and derivative operations on this error signal, and the weighted sum of the three terms is taken as the control output. Its block diagram is shown in Fig. 1. The continuous-time PID control law is written as:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt} \quad (5)$$

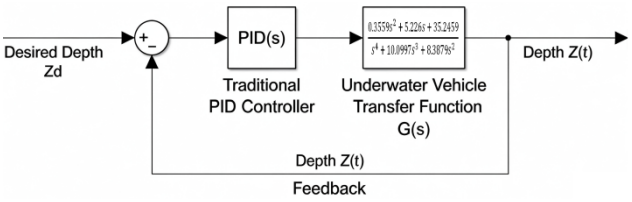


Fig 1. Block diagram of the conventional PID depth control system for the underwater vehicle.

The corresponding controller transfer function is:

$$G_c(s) = K_p + \frac{K_i}{s} + \frac{K_d s}{T_f s + 1} \quad (6)$$

where K_p 、K_i 、K_d denote the proportional, integral, and differential gains, respectively; T_f represents the low-pass filter time constant for the derivative term, which suppresses the amplification of high-frequency measurement noise induced by derivative computation. In the PID Controller block of Simulink, this filter is specified by the derivative filter coefficient $N = 1/T_f$, and the default value N = 100 is adopted in this work. As indicated by Eq. (5), the three gains of the conventional PID controller remain fixed once tuned during operation. Consequently, its control performance degrades significantly when the operating condition of the controlled plant varies or external disturbances occur.

To address the limitation of fixed parameters in conventional PID control, this work adopts a fuzzy inference scheme to adjust PID gains online. The structure of the designed type-1 fuzzy PID controller is illustrated in Fig. 2. Built upon a standard PID framework, the controller takes the depth error e and its rate of change ec as two inputs to the type-1 fuzzy logic unit. The fuzzy controller generates three correction terms ΔK_p 、ΔK_i 、ΔK_d, which are added to predefined baseline values to yield the real-time PID gains applied at each instant.

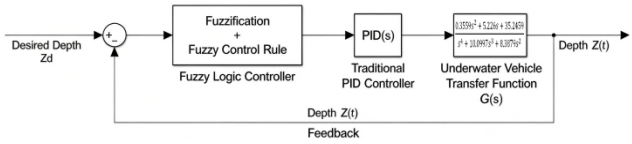


Fig 2. Structure of the designed type-1 fuzzy PID depth control system.

In the implementation, the two inputs of the type-1 fuzzy controller are the current error e and the error rate ec. The three output correction terms are added to the baseline values K_{p0} 、K_{i0} 、K_{d0}, respectively, to obtain the current gains K_p 、K_i 、K_d. These three gains act on the proportional, integral, and derivative paths of the error, and the control output u is obtained by summing the three paths and then sent to the controlled plant.

To verify the performance of the designed controller, a simulation model of the depth control system for the underwater vehicle is established in the MATLAB/Simulink environment, as shown in Fig. 3.

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The model consists of five components: command input, controller, controlled plant, disturbance channel and measurement unit. The command input module generates the depth reference signal; the controller is configured as either conventional PID or type-1 fuzzy PID; the controlled plant is implemented using transfer function blocks according to Eq. (3). The disturbance channel introduces wave interference, while the measurement unit simulates sensor time delay.

The conventional PID and type-1 fuzzy PID branches are arranged in parallel within the model. Both branches receive identical input signals, and their outputs are sent to the scope for comparison. This setup ensures that the two controllers are tested under identical reference and disturbance conditions, and allows direct comparison of their response curves in the same coordinate frame.

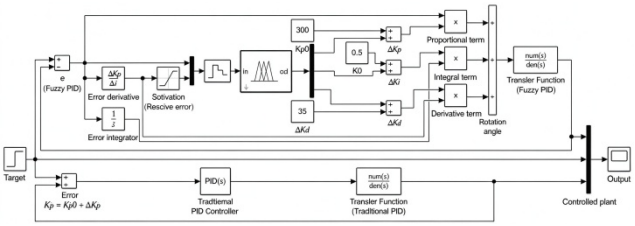


Fig 3. Structure of the type-1 fuzzy PID depth control system for the underwater vehicle.

The model includes four simulation cases, which correspond to the four operating conditions considered in this work. In the basic case, the depth command is a step signal that changes from 0 to 1 m at t=1 s. In the sinusoidal continuous diving case, the depth command is replaced by a sinusoidal signal with an amplitude of 1 m. In the sea-state disturbance case, an equivalent disturbance torque with a duration of 1 s is injected at t=4 s based on the basic case. In the sensor time-delay case, a Transport Delay block is added in the depth feedback loop. The Simulink models for the four cases are presented in the respective sections.

The type-1 fuzzy PID subsystem is implemented using a Fuzzy Logic Controller block, where the inputs are the error e and the error rate ec, and the outputs are ΔK_p、ΔK_i、ΔK_d. After the error rate is obtained through a derivative action, it is limited by a Saturation block to prevent abnormal changes caused by noise from affecting the inference results. The fuzzy inference system is constructed in the Fuzzy Logic Toolbox according to the membership functions and rule table determined in Section 2. The Mamdani inference method is adopted, and the center of gravity method is used for defuzzification.

For comparison against the results reported[1], the gains of both controllers adopt the validated values from that reference. For the conventional PID controller, K_p=20、K_i=0.5、K_d=15. For the type-1 fuzzy PID controller, the baseline gains are set to K_{p0}=300、K_{i0}=0.5、K_{d0}=35, which are adjusted online via fuzzy inference. The derivative filter coefficient N=100 is identical for both controllers. It can be observed that the baseline proportional and derivative gains of the fuzzy PID controller are substantially higher than those of the conventional PID controller, enabling a faster response during the initial phase with large tracking errors. The depth command is set to 1m, and the simulation runs for 10s. The variable-step ode45 solver is employed to accurately capture the system dynamics.

Simulations are carried out using the above model and parameters to obtain depth responses of the two controllers under the four operating conditions. For consistent comparison, performance indices are calculated with the instant of step or disturbance injection taken as the starting time. The overshoot is defined as the percentage by which the peak depth exceeds the setpoint, while the settling time refers to the time required for the response to enter and remain within the ±2% error band of the reference depth. Fig. 4 presents the depth responses of the two controllers under the step command. In this plot, the orange curve denotes the conventional PID response, the yellow curve corresponds to the fuzzy PID response, and the blue curve represents the depth reference.

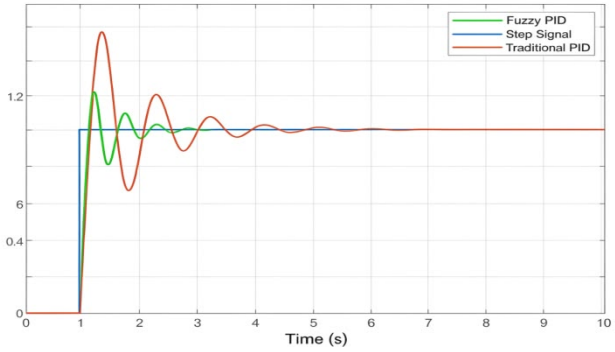


Fig 4. Comparison of step disturbance response between traditional PID and type-1 fuzzy PID.

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It can be observed from Fig. 4 that both controllers track the 1 m depth step command with zero steady-state error, and their steady-state errors converge to nearly zero. This suggests that the two schemes offer equivalent steady-state performance. Their differences mainly emerge in the dynamic response: the conventional PID produces considerable overshoot and persistent oscillations around the peak, requiring a long period to settle within the ±2% error band. In contrast, the type-1 fuzzy PID reduces both overshoot and settling time by roughly 60%, while presenting a smooth response free of prominent oscillations.

A closer inspection shows that the type-1 fuzzy PID reaches its peak value slightly earlier than the conventional PID. After the peak, its response drops back rapidly toward the reference without secondary oscillations. For the conventional PID, the three fixed gains keep a strong proportional action during the overshoot stage, which repeatedly amplifies the error and triggers sustained damped oscillations. For the type-1 fuzzy PID, the three gains are adjusted instantaneously based on e and ec. The control effort adapts to the evolution of error convergence, so oscillations are attenuated much faster.

It should be noted that despite the marked improvement in overshoot achieved by the type-1 fuzzy PID under step excitation, the overshoot magnitude is still non-negligible for the depth precision demands of depth-keeping navigation. This is attributable to the adoption of baseline gains[1] to maintain consistency with the benchmark results.

The simulation model for this case is illustrated in Fig. 5. Compared with the basic test case, the depth setpoint is modified from a step signal to a continuous sinusoidal command with an amplitude of 1m and a period of approximately 12s. This setup mimics continuous depth-changing maneuvers of the vehicle during depth-keeping cruise. Under such operating conditions, the controller is required not only to eliminate tracking error but also to maintain favorable tracking performance for continuously varying references.

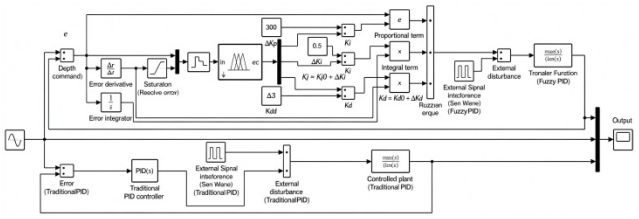


Fig 5. Top-level simulation structure of the type-1 fuzzy PID control system for depth tracking.

The tracking responses of the two controllers under the sinusoidal depth-varying command are plotted in Fig. 6.

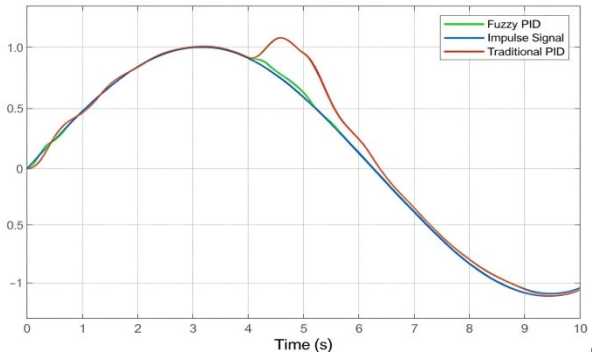


Fig 6. Comparison of sinusoidal disturbance response between traditional PID and type-1 fuzzy PID.

It can be seen from Fig. 6 that the response of the conventional PID exhibits obvious amplitude attenuation and phase lag relative to the reference sinusoidal profile, with the largest tracking error occurring near the peaks and troughs of the command. By contrast, the response of the type-1 fuzzy PID nearly overlaps the reference curve. Compared with the conventional PID, the type-1 fuzzy PID achieves roughly a 90% reduction in maximum tracking error and an 80% reduction in root-mean-square error.

The amplitude attenuation and phase lag of the conventional PID stem from its limited proportional gain, which is set to a low value to suppress overshoot under step excitation. This results in a narrow system bandwidth. As the command frequency increases, the effective gain drops further and fails to deliver sufficient control effort. The type-1 fuzzy PID, however, adjusts its gains online according to the error and error rate. It maintains strong control action throughout the tracking process when persistent error and large error rates are present, thereby achieving superior tracking accuracy. This finding demonstrates that the type-1

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fuzzy PID is better suited for applications requiring high-precision trajectory tracking, such as continuous depth-changing maneuvers of underwater vehicles.

Ocean waves represent one of the dominant disturbance sources for underwater vehicles in practical operations, introducing periodic or impulsive torques on the vehicle body. The simulation setup for this test case is shown in Fig. 7. On the basis of the basic case, a wave disturbance is introduced at t=4 s. This disturbance is implemented as an equivalent torque with an amplitude of 2 and a duration of 1s, which is applied to the input of the controlled plant via the External Signal Interference block.

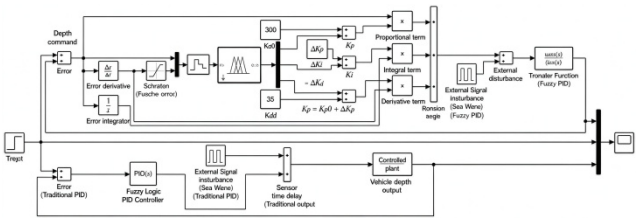


Fig.7. Simulation structure of the underwater vehicle depth control system with external wave disturbance.

The depth responses of the two controllers after wave disturbance injection are presented in Fig. 8.

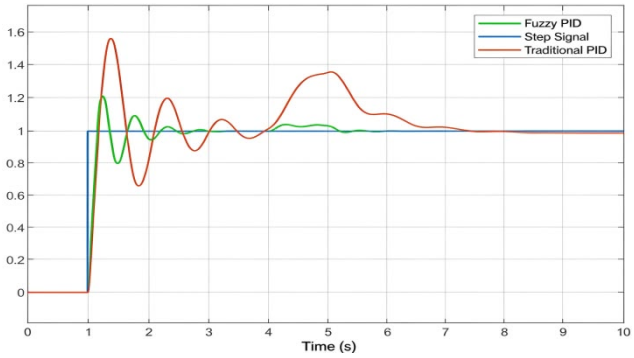


Fig 8. Comparison of wave interference disturbance response between traditional PID and type-1 fuzzy PID.

It can be observed from Fig. 8 that both controllers have stably tracked the 1m depth setpoint before disturbance injection. After the disturbance is applied, the depth under conventional PID control rises evidently and undergoes prolonged oscillation. It takes a considerable time after the disturbance vanishes before the response fully converges to the reference depth. In contrast, the depth controlled by the type-1 fuzzy PID only rises slightly under the disturbance, and its dynamic deviation is roughly one-tenth of that of the conventional PID. Once the disturbance disappears, the depth quickly falls back and settles near the setpoint with minor residual oscillation.

This result demonstrates that the type-1 fuzzy PID offers substantially better disturbance rejection capability. When a depth deviation arises from external disturbance, the fuzzy inference yields a large ΔK_p, which raises the open-loop gain of the controller. A stronger control effort is therefore generated at the early stage of disturbance to counteract its effect. Meanwhile, a large ΔK_p increases the system damping, enabling the depth to decay rapidly back to the reference without sustained oscillation after the disturbance is removed. With fixed gains, the conventional PID relies solely on pre-tuned compromise parameters to handle disturbances, which leads to larger dynamic deviation and longer recovery time.

In practical systems, the depth sensor introduces a certain delay between the detection of depth variation and the availability of valid measurements. Latency also arises from algorithm computation and actuator response. Time delay forces the controller to make decisions based on outdated information, which effectively reduces the phase margin of the system and may even induce instability under severe conditions. To evaluate the robustness of the two controllers against time delay, a Transport Delay block with a time constant of 0.02s is inserted into the depth feedback loop. The simulation model for this scenario is shown in Fig. 9.

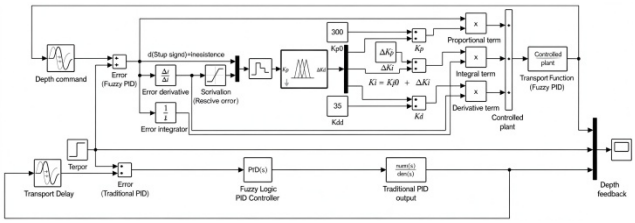


Fig.9. Simulation structure of the depth control system with sensor time delay.

The depth responses of the two controllers after introducing the time-delay element are shown in Fig. 10.

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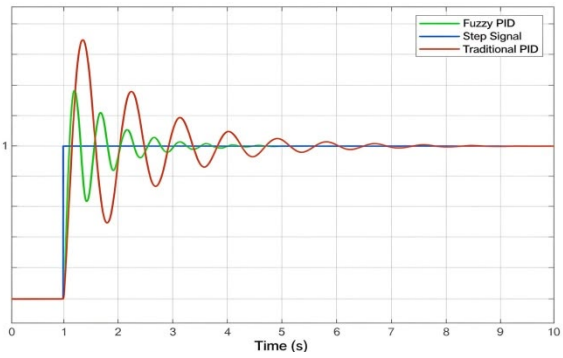


Fig 10. Comparison of sensor time delay response between traditional PID and type-1 fuzzy PID.

It can be observed from Fig. 10 that the dynamic performance of the conventional PID degrades markedly after time delay is introduced. Its overshoot rises further, oscillations become more severe, and the settling time increases substantially. The type-1 fuzzy PID is also affected by the delay, with higher overshoot and longer settling time, yet its performance metrics remain considerably better than those of the conventional PID.

Quantitative comparisons reveal that the settling time of both controllers grows by approximately 50%–60% under the delay, confirming the adverse impact of time delay on both schemes. In terms of absolute values, however, the settling time of the type-1 fuzzy PID remains less than half that of the conventional PID, and its overshoot is roughly half the value obtained with conventional PID. This indicates that the performance advantage of the type-1 fuzzy PID is well preserved even with feedback delay. The underlying mechanism is that measurement errors induced by delay increase the error rate ec, which triggers the fuzzy inference to generate a large ΔK_d. This effectively raises system damping, improves phase margin, and prevents oscillations from growing. Such adaptive tuning of controller parameters according to operating conditions cannot be achieved by fixed-gain PID, which verifies the stronger robustness of the type-1 fuzzy PID against sensor time delay.

The comparisons across the four test cases demonstrate that the type-1 fuzzy PID controller outperforms the conventional PID under all considered scenarios. For step commands, both overshoot and settling time are reduced by approximately 60%. For sinusoidal continuous depth-varying commands, the maximum tracking error drops by around 90% and the root-mean-square error by roughly 80%. Under wave disturbances, the dynamic deviation is cut by nearly 90%, and the controller recovers rapidly toward the reference depth once the disturbance vanishes. In the presence of sensor time delay, its settling time remains less than half that of the conventional PID. These results suggest that the advantages of the type-1 fuzzy PID are not limited to the step condition examined[1]. It also delivers prominent performance gains under more practical operating conditions, including continuous depth tracking, external disturbance rejection and measurement delay.

IV. CONCLUSION

This work focuses on the depth control of underwater vehicles. A mathematical model for the depth channel is developed, and a type-1 fuzzy PID controller is proposed and tested through simulation. The transfer function of this depth channel is derived, where the double integrator at the origin leads to significant inertia. The open-loop system cannot track steady depth commands, which makes feedback control necessary and lays the groundwork for the controller design. The proposed type-1 fuzzy PID takes depth error and its rate of change as inputs, and adjusts PID gains online by adding correction terms to preset baseline values. The fuzzy rule table is built from practical PID tuning experience, with Mamdani inference and centroid defuzzification adopted.

Simulation tests across different scenarios reveal the advantages of the proposed controller. Compared with conventional PID, the type-1 fuzzy PID reduces both overshoot and settling time by around 60% under step depth commands. For sinusoidal continuous depth variation, the maximum tracking error drops by approximately 90% and the root-mean-square error is reduced by 80%. When ocean wave disturbances are applied, dynamic deviation is lowered by nearly 90%, and the system returns to steady state quickly once the disturbance disappears. Even with sensor time delay, its settling time remains less than half that of the conventional PID controller.

It should be acknowledged that the baseline gains adopted here are directly taken[1] without extra optimisation. As a result, the overshoot under step response can still be further reduced. Future efforts may use intelligent optimisation approaches such as

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genetic algorithms and particle swarm optimisation to tune the baseline gains and scaling factors. Integral separation and derivative pre-action can also be incorporated into the fuzzy inference logic, so as to further improve the dynamic performance of depth regulation.

ACKNOWLEDGEMENTS

An acknowledgement section may be presented after the conclusion, if desired.

REFERENCES

[1] Luo Xiaoling, Wang Zihan (2020). Research on motion control of underwater vehicle based on fuzzy PID. Electronic Measurement Technology, 43(19), 141-145.

[2] Wang Bingyu (2024). Simulation and experimental research on anti-sway device and dynamic characteristics of ship-mounted crane. Journal of Mechanical & Electrical Engineering, 41(12), 2163-2174.

[3] Chen Yuanwei (2024). Research on balance car control system based on PID algorithm. Instrumentation Technology, (1), 64-65.

[4] Li Ya, Li Gao (2019). Design of liquid level control system for double-capacity water tank based on fuzzy PID. Digital Technology and Application, 37(7), 11-12.

[5] Wang Chunrong, Wang Bo, Lv Hongwei, et al. (2024). Design and research of heating furnace double cross limiting fuzzy PID temperature control system based on Simulink. Mechanical and Electrical Technology, (3), 19-24.

[6] Du Bowen, Huang Kehua, Zhang Lijie, et al. (2022). Research on control strategy of thick-thin combined conveying system based on MATLAB. Cotton Textile Technology, 50(10), 68-72.

[7] Han Tianfeng, Hou Xiaozhu, Wang Na, et al. (2024). Adaptive fuzzy PID control of dissolved oxygen for freshwater carp aquaculture. Journal of Anhui Science and Technology University, 38(6), 47-53.

[8] Feng J H, Luo Y H, Huang Z X, et al. (2024). Fuzzy PID controller analysis for the hexacopter aircraft using Simulink simulation. International Journal of Advanced Engineering Research and Science, 11(11), 1-9.

[9] Zou Yao, Bao Jiaming, Chen Liang, et al. (2019). Modeling and simulation of Buck DC-DC converter based on Simulink. Electronic Design Engineering, 27(21), 151-155.

[10] Xia Yue, Zhang Hongfei, Chen Ying, et al. (2024). Research on dynamic modeling method of doubly-fed wind power generation system based on transfer function analysis. Proceedings of the Chinese Society for Electrical Engineering, 44(12), 4759-4774.

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