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Enhancing Adaptability and Performance of Autonomous Underwater Vehicles through PID-Supported Evolvable Hardware

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Abstract
This work addresses the design of an Autonomous Underwater Vehicle (AUV) which utilizes a Proportional-Integrative-Derivative (PID) setup supported by evolvable hardware which provides numerous advantages. Evolvable hardware serves as a valuable aid for expediting parameter tuning in PID controllers. PID controllers are special due to their ability to maintain the desired values at a set point using proportional, integrative and derivative actions. The dynamic and unpredictable nature of AUV environments calls for adaptability, a quality enhanced by evolvable hardware. This technology empowers the PID controller to optimize its parameters in response to changing conditions dynamically, ensuring optimal performance in real-time. Moreover, evolvable hardware facilitates self-optimization, enabling automatic parameter adjustments based on predefined performance criteria. In the face of hardware or sensing system faults, the PID controller equipped with evolvable hardware demonstrates fault tolerance by reconfiguring itself.

Keywords:Autonomous Underwater Vehicles (AUVs), PID Control, Evolvable Hardware (EH), Self-optimization

1.INTRODUCTION

The enigmatic depths of our oceans, teeming with life and veiled in mystery, have captivated humanity for millennia. Today, Autonomous Underwater Vehicles (AUVs), these uncrewed robotic emissaries, play a critical role in unravelling the secrets of this vast underwater realm. This feedback mechanism ensures that the AUV maintains its desired course and depth, even in the presence of minor disturbances. However, the complexities of the underwater environment often extend beyond what a static PID controller can handle. Evolvable Hardware (EH) injects a revolutionary element into the control system, empowering it with real-time adaptation capabilities. This allows the control system to accept unforeseen environmental changes or equipment malfunctions, ensuring the AUV remains operational and achieves its mission objectives.

They evaluate different combinations of PID parameters within the EH framework, selecting the most effective ones based on their ability to maintain stability and performance in the current environmental conditions. This selection process is analogous to how organisms with favourable traits are more likely to survive and reproduce in nature. This research delves into this exciting interplay between PID control using evolvable hardware. We propose a groundbreaking framework that integrates EH functionalities within the PID control loop of an AUV This novel approach paves the way for a more robust and

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adaptable control system, capable of autonomously correcting errors, optimizing performance, and ensuring mission success even in the face of the ever-changing ocean environment. Invaluable tools for oceanographic research, search and rescue operations, and venturing into unexplored territories. However, the unforgiving nature of the underwater environment presents a unique set of challenges for these robotic explorers. Precise navigation and efficient operation are paramount for mission success, and these can be significantly hindered by unexpected faults or disturbances. At the core of an AUV's control system lies the PID controller. These ubiquitous controllers have earned their reputation for simplicity and effectiveness. By continuously adjusting control inputs based on the measured error between the desired and actual state of the AUV, PID controllers ensure efficient and reliable navigation. However, the underwater environment is anything but static. Unpredictable currents, sensor malfunctions, or unforeseen equipment failures can disrupt the delicate balance maintained by the PID controller. This disruption can lead to performance degradation, mission failure, and even endanger the AUV itself. This is where a transformative paradigm shift emerges, a symphony of control orchestrated by three powerful tools: PID controllers, and EH. This harmonious interplay holds the key to unlocking a new era of fault tolerance and adaptability in AUV control systems. PID controllers form the bedrock of this control strategy; their straightforward design, with tunable proportional, integral, and derivative terms, allows them to effectively handle a wide range of control problems. By continuously changing the difference between the desired and actual values of error, the PID controller adjusts control inputs to minimize this error over time. This feedback mechanism ensures that the AUV maintains its desired course and depth, even in the presence of minor disturbances. However, the complexities of the underwater environment often extend beyond what a static PID controller can handle. EH injects a revolutionary element into the control system, empowering it with real-time adaptation capabilities. EH systems possess the remarkable ability to modify their internal structure or behaviour in response to external stimuli. Imagine an AUV control system equipped with EH- not only can it detect faults, but it can also actively learn and adjust its PID parameters on the fly. This allows the control system to adapt to unforeseen environmental changes or equipment malfunctions, ensuring the AUV remains operational and achieves its mission objectives.

This novel approach paves the way for a more robust and adaptable control system, capable of autonomously correcting errors, optimizing performance, and ensuring mission success even in the face of the ever-changing ocean environment. The implications of this symbiotic collaboration are far-reaching. Enhanced mission success rates, improved data collection efficiency, and a deeper understanding of the enigmatic underwater world are just a few of the potential benefits. By harnessing the power of PID control, and evolvable hardware, we can unlock a new era of autonomous underwater exploration, pushing the boundaries of what's possible in the depths of the ocean.

2.Literature review

The quadcopter has been one of the most widely used forms of multirotor UAV [1]. Academic study on quadrotors has increased significantly in the past few years, probably as a result of their benefits, which include a straightforward mechanical design, hovering capability, and excellent mobility. As the demand for autonomous flight in varying environments continues to grow, controlling quadrotors remains a crucial task. There have been extensive studies on a variety of control systems aimed to enhance the accurate movement of such machines including, backstepping control, model predictive control, PID

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control, and sliding mode control. Quadcopters have received the most attention due to their specialized control in terms of both practical and theoretical perspectives. Parametric uncertainties, nonlinear behaviours, coupling effects, and external disturbances are some of the complications that come with quadrotor dynamics. To perform advanced control tasks, high-performance attitude control must be achieved. In real-life situations, a remote operator is usually in charge of positional control, while an onboard controller is usually in charge of UAV attitude stabilization. Roll, pitch, and yaw are the three main characteristics that define a quadcopter's motion. To define its orientation in three-dimensional space, Euler angles introduced by Leonhard Euler are commonly used. These angles define the orientation of a rigid body through a sequence of three elemental rotations. Since each movement may be expressed as a combination of these three basic rotations, the ZYX Euler angle convention is especially helpful for characterizing the relative orientation between reference frames. Ayelu Terefe Bayasa. A UAV is an aircraft that operates without a human pilot onboard. UAVs are increasingly utilized across various fields, including surveillance, environmental m, security, search and rescue, and traffic management. The quadrotor stands out as a Vertical Take-Off and Landing (VTOL) system among the various designs that have been developed as a result of advancements in UAV technology. It is an extremely adaptable aerial platform because of its ability to hover, execute vertical manoeuvres, and maintain low-speed flight. Furthermore, the miniaturization of UAVs made possible by recent developments in instrumentation technology has increased their variety of applications. To enhance UAV control the Kalman and PID controllers can be integrated [2]. The Kalman filter effectively eliminates noise, ensuring accurate signal processing, while the PID controller corrects static errors, which helps to simplify the system design. However, this method can only be used to control the forward and upward motion which is insufficient for autonomous UAV operations. In the proposed approach, the quadrotor model undergoes multiple iterations, evaluating attitude and elevation responses within a cost function. By fine-tuning the PID controller coefficients during these iterations, a suboptimal system response is achieved, HamedKharrati. Water covers approximately 71% of the Earth's surface. Given this vast aquatic expanse, underwater exploration plays a crucial role for both governmental and civilian purposes. However, because of the constantly shifting environmental conditions, human-led underwater operations are extremely risky and more likely to result in accidents. Underwater robots offer a practical substitute for performing a variety of jobs and missions to reduce these hazards. These robots can be employed for a wide range of applications, including underwater research, military activities, resource exploration, etc. A key aspect of underwater robotics is an effective control system that governs the robot's movement and positioning. In underwater situations, position control is crucial for stability and accurate navigation. The two main categories of underwater robots are AUVs and Remotely Operated Vehicles (ROVs). AUVs can perform activities on their own without direct operator involvement using controllers, in contrast to ROVs. Various studies [3] have been performed to explore the different ways to control the AUV, such as PID controller, self-adaptive Fuzzy-PID, Adaptive control Neural Network, Particle Swarm Optimization (PSO)-PID with derivative filter, and PID based on grey wolf optimizer. The efficiency of these controllers in AUV navigation, especially in depth control simulations, has been shown in several investigations such as [3]. Nevertheless, a lot of earlier research has only looked at simulation-based control systems, restricting their applicability to depth control. By employing both virtual and experimental AUV tests to assess navigation, positioning, and depth control using a PID controller, this study builds on earlier studies. Due to its simple structure and proven effectiveness across

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various systems, the PID controller remains a reliable choice for improving AUV performance. AUVs possess three degrees of freedom, and their subsystems exhibit strong coupling interactions. They can carry out missions autonomously without requiring any human intervention. Evolutionary algorithms have been extensively used in optimization to address a wide range of problem domains. A Genetic Algorithm (GA) paradigm for minimalist bridge-music production was previously used by Horner and Goldberg. Interestingly, a specific instance of Evolution Strategies is the Harmony Search (HS) algorithm, which draws inspiration from musical improvisation. The Harmony Memory Size (HMS) determines how many solutions are stored in the Harmony Memory (HM), which is initialized with randomly generated solutions at the start of the HS process. The Harmony Memory Considering Rate (HMCR) and the Pitch Adjusting Rate (PAR) are important factors that affect the creation of new solutions. This study has investigated another evolutionary optimization technique, the HS algorithm, which is intended to replicate the improvisation process in music composition. Similarly, AUV systems also must account for uncertainties in their operation and evolutionary algorithms like HS play a vital role in optimizing their control and navigation performance, Ankush Rathore.

Over the past few years, there has been an increased use of AUVs and ROVs especially in marine biology and underwater studies. Researchers have now been able to access hazardous regions and deep-sea habitats that would otherwise be too risky or unreachable for human divers because of these advanced machines. However, Traditional ROVs face considerable challenges when manoeuvring through confined or tight underwater spaces such as coral reefs or water-logged tunnels. Because most ROVs have less control over the degrees of freedom, precise movement in such environments has been challenging. Furthermore, their dependence on a tethered connection to a control station further restricts their mobility in confined spaces. AUVs, on the other hand, do not have to be tethered, but they struggle with navigation and onboard signal processing, which makes them more prone to be easily damaged from unintended impacts and less appropriate for interacting with delicate environments as found in Hudson et al [5].

Because of its adaptability and movement, AUVs have drawn a lot of interest for application in mobile data collecting in Underwater Wireless Sensor Networks (UWSNs). The work in [6] presents an innovative multi-modal AUV-assisted data collection system to address the increasing needs of diverse underwater data collection applications, including guaranteeing real-time data usefulness, protecting emergency event transmissions, and improving energy efficiency. The proposed methodology in [6] combines optical and acoustic communication technologies, taking advantage of their speed and range of data transfer. The Age of Information (AoI) of data packets, the energy needed for node transmission, and the power consumption of AUV movement are all important considerations in the suggested architecture. A balanced trade-off is made between these factors to ensure timely and reliable data retrieval. The ideal AUV motion trajectory is found by dynamically choosing the most appropriate communication mode using a Deep Reinforcement Learning (DRL) technique to attain optimal performance. To further reduce energy usage in various communication settings, an optimized angle steering algorithm is also created. The effectiveness of the suggested framework was assessed using extensive simulations, and the findings show that it considerably lowers both the weighted sum of AoI and overall energy usage. Gomathi et al. have investigated the use of evolvable hardware with genetic algorithms, demonstrating how adaptive computational techniques could improve system performance

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[7]. The research discusses the integration of genetic algorithms for optimizing hardware configurations, allowing autonomous systems to evolve based on environmental conditions. Research on improving autonomous systems, particularly in the domains of computer vision and adaptive hardware, has contributed significantly to the advancement of AUVs [8]. Kaniskaa et al. explore parallelization algorithms in computer vision for autonomous vehicles, highlighting the importance of computational efficiency in real-time decision-making. The work in [8] has emphasized how optimized algorithms improve the adaptability and responsiveness of autonomous systems.

Description and Dynamics of the AUV System

This section delves into the details of the proposed work, the AUV system; A comprehensive overview of its components, inputs, outputs, and the dynamics modelling approach are discussed in this section. The exploration of the underwater world hinges on the capabilities of this sophisticated robotic platform.

Building Blocks of the AUV

The AUV relies on a complex interplay between several key components. The propulsion system, with its thrusters, acts as the engine, generating thrust for movement. An Inertial Measurement Unit (IMU) sensor serves as the "inner ear", providing crucial information on orientation and motion. In Figure 1 the controller acts as the conductor. The controller receives data from various sensors, analyzes it based on the mission plan, and issues commands to the thrusters, ensuring the AUV follows its intended course. Some advanced AUVs even incorporate evolvable hardware, allowing the control system to adapt to unforeseen situations, much like a conductor improvising during a performance. These combined elements, along with a detailed system block diagram that considers factors like thruster dynamics and AUV motion, create a powerful tool for underwater exploration.

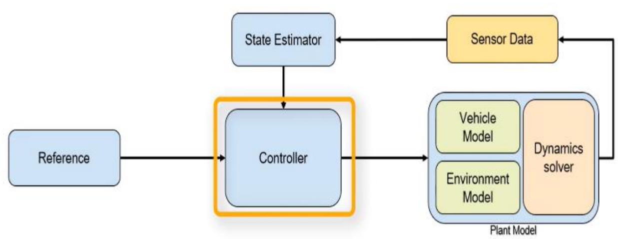

Figure. 1. System Block Diagram of the Proposed PID System for AUV

Propulsion: The Engine of Exploration

The propulsion system acts on the muscle of the AUV, responsible for generating the thrust necessary for movement. Thrusters, the workhorses of the system, convert electrical energy from batteries or fuel cells into thrust to propel the AUV through the water. The designed AUV utilizes five thrusters: (i) Two T200 thrusters, with high thrust capabilities to handle forward and backward propulsion. (ii) Two T100 thrusters facilitate precise lateral movements, allowing the AUV to navigate side-to-side with finesse. (iii) A single T200 thruster provides vertical control, which enables the AUV to ascend and descend in the water column. By strategically controlling these thrusters, the AUV can manoeuvre with precision in

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a three-dimensional underwater space. The specific propeller geometry of these thrusters, along with the overall dynamics of the AUV considering factors like buoyancy and drag, all play a crucial role in determining its manoeuvrability and efficiency. The control system communicates with each thruster using Pulse Width Modulation (PWM). This technique varies a digital signal's on-time pulse width to control the average power delivered to the thruster motor. A higher pulse width corresponds to a higher average voltage, resulting in increased motor speed and consequently, greater thrust generation. In Equation (1) the relationship between the PWM input signal (*ui*) and the generated thrust (*Ti*) of the *i*th thruster can be modelled using a first-order linear transfer function:

$$Ti(s) = K*ui(s)/(s+1) \quad (1)$$

Where *Ti(s)* and *ui(s)* are the Laplace transforms of thrust and PWM input signal for the in thruster, respectively. *K* is a positive gain factor that translates the PWM signal into thrust. Ideally, *K* would be the same for all thrusters, but in reality, there may be slight variations due to manufacturing tolerances. τ represents the motor bandwidth, which essentially indicates how quickly the thruster responds to changes in the PWM signal. A higher bandwidth signifies a faster response.s is the Laplace domain variable used in control system analysis.

PWM Input Range and Thrust Limits:
It's important to note that a PWM input of zero ($ui = 0$) corresponds to zero thrust, essentially turning the motor off. On the other hand, a PWM input of a specific value such as $ui=0.05$ represents the maximum thrust that the motor can generate. The control system must operate within these PWM input limits to ensure proper thruster operation and avoid exceeding their capabilities. By employing PWM and understanding the thruster dynamics, the control system can precisely regulate the thrust generated by each thruster. This allows for fine-tuned control of the AUV's movement, enabling it to navigate efficiently and precisely underwater.

IMU Sensor: The Inner Ear of the Machine

IMU acts as the AUV's internal sense of balance, much like the inner ear of a human. This compact sensor houses two key components: A three-axis accelerometer that measures the linear accelerations experienced by the AUV along each axis as surge, sway, and heave. A three-axis gyroscope that measures the angular rates of the AUV such as roll, pitch, and yaw, indicating how it's rotating around these axes. The continuous stream of data from the IMU provides vital information about the AUV's orientation and motion, which is crucial for maintaining stability and following a desired course.

Dynamics of AUV

An AUV navigates the underwater world through a complex interplay of forces and moments. Understanding these dynamics is crucial for designing and controlling effective autonomous underwater vehicles. Linear Motions are about 6 Degrees of Freedom. Surge refers to the forward and backward movement of the AUV along its longitudinal axis. The main propeller(s) primarily control surge, with factors like vehicle speed, buoyancy, and external currents influencing its behaviour. Sway signifies the lateral movement i.e. side-to-side of the AUV. While not directly controlled by the main thrusters, some lateral sway can thrust or external forces like duc uneven crosscurrents. Auxiliary thrusters or proper control algorithms can help mitigate this. Heave denotes the vertical movement i.e. up and down of the

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AUV. Changes in buoyancy or the action of vertical thrusters can cause heave. Maintaining a constant depth often requires precise control of heavy motion. Rotational Motions about 3 Degrees of Freedom describes the tilting of the AUV along its longitudinal axis, akin to rolling a ship from side to side. Auxiliary thrusters or rudders strategically placed can counteract roll and maintain a level orientation. Pitch represents the tilting of the AUV on the transverse axis, similar to raising or lowering the bow of a ship. Pitch control is crucial for manoeuvring the AUV up and down in the water column and maintaining the desired diving angle. Auxiliary thrusters or movable control surfaces can achieve pitch control. Yaw signifies rotation around the vertical axis of the AUV, essentially how it turns left or right. Rudder deflection or strategically placed vectored thrusters are typically used for yaw control, allowing the AUV to change its heading. Understanding these six degrees of freedom is essential for effectively modelling and controlling AUV behaviour. By considering factors like inertia, drag forces, and thruster capabilities, engineers can design AUVs with optimal manoeuvrability and stability for various underwater tasks.

Control System and Sensor Inputs To PID Controller

The AUV's control system acts as the brain and nervous system, interpreting sensor data, making critical decisions, and issuing commands to propel the AUV through the underwater world. Let's delve into the intricate workings of this control system, focusing on its role in maintaining heading and exploring the system block diagram. The IMU acts as the AUV's core sensor, providing a wealth of information about its motion and orientation. Figure 2 shows the three-axis accelerometer. This sensor measures the accelerations experienced by the AUV along its surge , sway ,and heave axes. These accelerations can be caused by thruster activity, external currents, or changes in depth. The processed data from the accelerometer is denoted as:

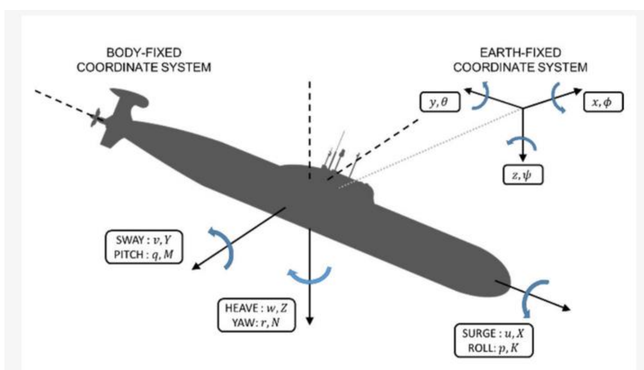

Figure. 2. Three-axis Accelerometer to Measure the Angular and Translational motion

Ameas = [Ax Ay Az]:

This 3x1 vector represents the measured accelerations along the surge, sway, and heave axes, estimated from the raw accelerometer data (*Ab*) after applying correction algorithms. These corrections aim to account for biases and noise in the raw sensor data, providing a more reliable representation of the actual linear accelerations experienced by the AUV. The Three-axis gyroscope sensor detects the AUV's angular rates, signifying how quickly it's rotating around each axis. For the heading control loop,

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the yaw rate which is the rotation around the vertical axis is particularly important. The processed data from the gyroscope is denoted as ω meas [wx wy wz]. This 3x1 vector signifies the measured angular rates around the roll, pitch, and yaw axes obtained after processing the raw gyroscope data (*w*). These processed values offer a more accurate picture of the AUV's rotational dynamics.

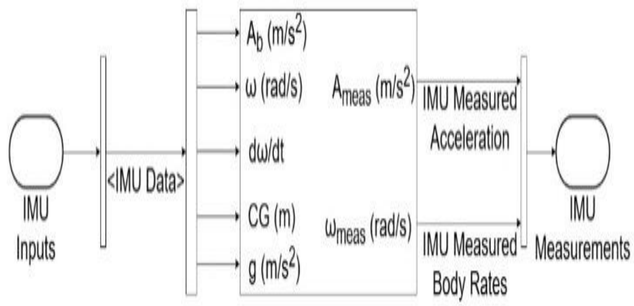

Figure. 3. 3-axis IMU : Ameas =[Ax Ay Az] , ωmeas=[ωx ωy ωz]

Understanding the Significance of Each Measured Value:

Ax, i.e. Surge Acceleration value indicates the linear acceleration along the AUV's forward axis. While not directly used in real-time heading control, it can be employed by the control system to understand the overall dynamics of the AUV, particularly during manoeuvres or when combined with other sensor data. For instance, a sudden increase in surge acceleration might indicate a change in thruster activity or the effect of an external current. Ay, i.e. sway acceleration value represents the linear acceleration along the AUV's side-to-side axis. Similar to surge acceleration, it doesn't directly contribute to heading control but can be valuable for understanding the overall motion. External factors such as cross-currents or manoeuvring can cause variations in sway acceleration. Az, i.e. heave acceleration value signifies the linear acceleration along the AUV's up/down axis. While not crucial for heading control in itself, heavy acceleration can be used by the control system to maintain depth or compensate for vertical movements caused by waves or currents. ωx, i.e. Roll Rate value represents the AUV's angular rate around the roll axis which is the rotation about the x-axis. While not directly used for heading control which focuses on yaw, roll rate can be used by the control system for stabilization purposes or to understand the overall rotational dynamics of the AUV. ωy which is the Pitch Rate value, signifies the AUV's angular rate around the pitch axis which is the rotation about the y-axis. Similar to roll rate, pitch rate doesn't directly contribute to heading control but can be valuable for stabilization and understanding the components.

The Role of Each Input in Heading Control

While the magnetometer directly measures the Earth's magnetic field for heading determination, the IMU data plays a crucial supporting role. In Initial Heading Estimation, the control system might use the initial roll and pitch information from the gyroscope (*meas*) to establish a rough estimate of the AUV's orientation before magnetometer data becomes available. In Filtering and Calibration, the gyroscope data (*meas*) can be used to filter out noise or biases present in the magnetometer readings, leading to a more accurate heading estimate. In Dynamic Compensation the accelerometers (*Ameas*) can provide information about external accelerations caused by currents or maneuvers. This information can be used

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by the control system to compensate for these disturbances and maintain a more precise heading, especially during dynamic manoeuvres. In Fault Detection and Isolation the comparison of the magnetometer data with the gyroscope and accelerometer data, the control system can potentially detect sensor faults or inconsistencies. This information can be used to isolate faulty sensors or activate backup control strategies. In essence, the IMU data acts as a complementary sensory stream that enriches the heading control loop. While the magnetometer provides the absolute heading reference, the IMU data helps refine the heading estimation, filter out noise, and compensate for dynamic effects, ultimately contributing to a more robust and accurate heading control system for the AUV.

PID Control

A Workhorse for AUV Navigation the PID controller is a ubiquitous tool in control engineering finding applications in everything from simple thermostats to complex robotic systems. In the realm of AUVs, PID controllers play a crucial role in maintaining heading, depth, and other vital aspects of navigation. This document delves into the workings of PID controllers for AUV control and explores the increasing need for evolvable hardware to support these systems. PID controllers are the standard tool in the current industrial automation experience thanks to their flexibility which makes the PID controller capable of being used in many situations. Many simple control problems can be handled very well by using PID control. The algorithm of the PID controller is shown as follows:

$$U(t) = K_p e(t) + \frac{1}{T_i}\int_0^{\tau} e(T)dT + K_d \frac{de(t)}{dt} \qquad (2)$$

$$U(t): Control\ Output\ (e.g., thruster\ command)$$

$$at\ time\ t. -u(t)$$

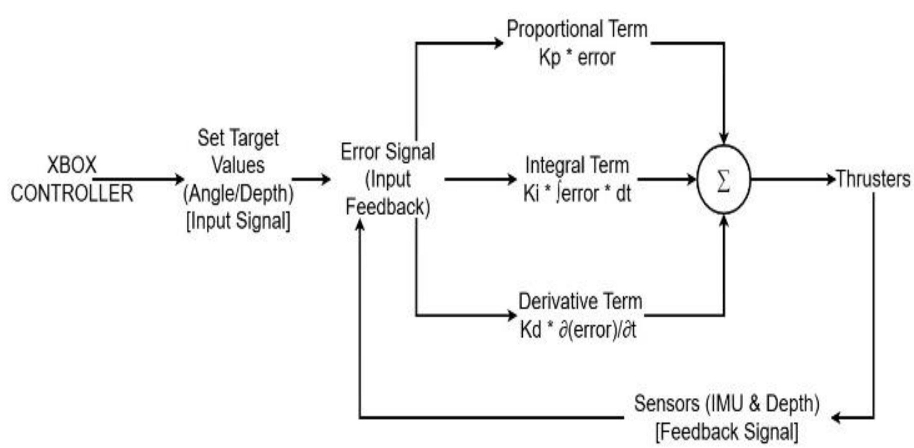

Figure. 4. PID Control Flow to Calculate the Total Proportional, Integral and Derivate errors

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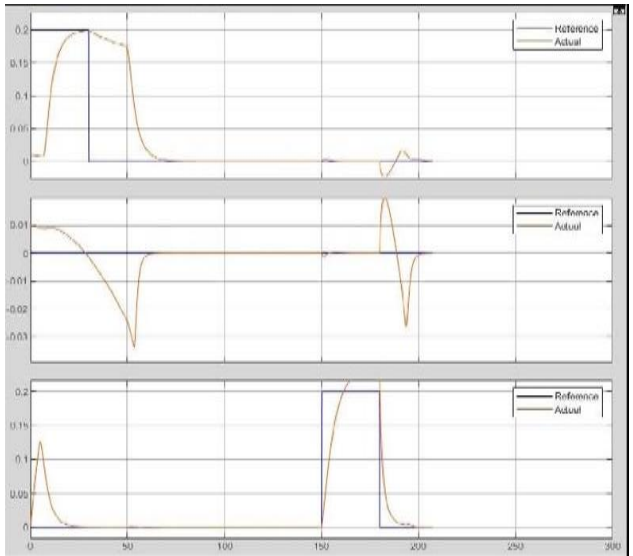

Figure. 5. Actual Velocity vs Reference Velocity before the implementation of evolvable hardware

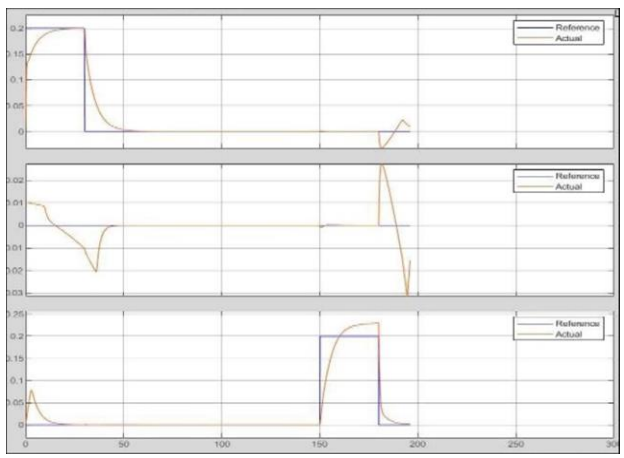

Figure. 6. Actual Velocity vs Reference Velocity after the implementation of evolvable hardware

Conclusions

Integration of PID-supported Evolvable Hardware (EH) with GA significantly enhances the adaptability and performance of Autonomous Underwater Vehicles (AUVs). By leveraging EH's ability to reconfigure hardware in real-time and GA's optimization capabilities, AUVs can dynamically adjust to unpredictable underwater environments. The inclusion of PID controllers ensures precise and stable manoeuvring, compensating for disturbances and nonlinearities in the aquatic domain. This hybrid approach enables AUVs to optimize control parameters autonomously, improving their responsiveness to environmental variations, reducing energy consumption, and increasing operational efficiency. The adaptability of the system ensures robust performance in diverse mission scenarios, such as ocean exploration, environmental monitoring, and underwater surveillance. Future research should focus on

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refining the interplay between EH, GA, and PID control to further enhance real-time adaptability, computational efficiency, and fault tolerance. Additionally, implementing machine learning techniques alongside evolutionary algorithms may offer even more sophisticated adaptive capabilities, making AUVs smarter and more resilient in complex underwater settings.

References

1. Ayele Terefe Bayisa "Controlling Quadcopter Altitude using PID-Control System." International Journal of Engineering Research and Technology, vol.8, no.12, pp. 2278 - 0181, 2019.
2. Hamed Kharrati and Hengameh Noshahri. "PID Controller Design for Unmanned Aerial Vehicle Using Genetic Algorithm." IEEE 23rd International Symposium on Industrial Electronics (ISIE) DOI:10.1109/ISIE.2014.6864613, 2014.
3. Albert Mario Alfarino, Iky Bayusari, et al. "Position Control System of Autonomous Underwater Vehicle using PID Controller." 8th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI), DOI:10.23919/EECSI53397.2021.9624231, 2021.
4. Ankush Rathore and Mahendra Kumar, "Robust PID Tuning of Autonomous Underwater Vehicle Using Harmonic Search Algorithm Based on Model Order Reduction." International Journal of Swarm Intelligence and Evolutionary Computation, DOI: 10.4172/2090-4908.1000127, 2015.
5. Fabian Plum, Jan-Henning Dirks,"SAUV—A Bio-Inspired Soft-RoboticAutonomous UnderwaterVehicle." Frontiers in Neurorobotics, DOI: 10.3389/fnbot.2020.00008,2020.
6. Fanfeng,HanjiangLuo,SukhsanaRuby,GuangjieHan."AUV-Aided Optical—Acoustic Hybrid Data Collection Based on Deep Reinforcement Learning." DOI.org/10.3390/s23020578, 2023.
7. Gomathi, B., Manimegalai, R., Noor Mohamamd, S.K., Jegan, G.V.S.R., Venkateshwaran, M. (2024). Evolvable Hardware Using Genetic Algorithm. In: Haldorai, A., Ramu, A., Mohanram, S. (eds) 6th EAI International Conference on Big Data Innovation for Sustainable Cognitive Computing. BDCC 2023. EAI/Springer Innovations in Communication and Computing. Springer, Cham. https://doi.org/10.1007/978-3-031-54696-9_5
8. MS, Kaniskaa & Rajkumar, Manimegalai & SK, Noor. (2023). Parallelization Algorithm of Computer Vision for Autonomous Vehicles. 1-6. 10.1109/ViTECoN58111.2023.10157031.
9. Amin R, Aijun L, Shamshirband S. A review of quadrotor UAV: Control methodologies and performance evaluation. International journal of automation and control engineering, 2016, vol. 10, no. 2, pp. 87–103.
10. Tofigh M A, Mahjoob M J, Ayati M. Dynamic modeling and nonlinear tracking control of a novel modified quadrotor. International journal of robust and nonlinear control, 2018, vol. 28, no. 2, pp. 552–567.
11. An S, Yuan S, Li H. Self-tuning of PID controllers design by adaptive interaction for quadrotor UAV in Proceedings of the 7th IEEE Chinese guidance, Navigation and Control Conference, August 2016, GNCC 2016, pp. 1547–1552.

https://doi.org/10.64151/PSGCARE-12

ISSN 2394 - 9554

12. Das A, Lewis F, Subbarao K. Backstepping approach for controlling a quadrotor using Lagrange form dynamics: Journal of intelligent & robotic systems, 2009, vol. 56, no. 1-2, pp. 127–151.
13. Lee D, Kim H J, Sastry S. Feedback linearization vs adaptive sliding mode control for a quadrotor helicopter. International journal of control, automation and systems,2009, vol. 7, no. 3, pp. 419–428.
14. Chamseddine A, Zhang Y, Rabbath C A, Fulford C, Apkarian J. Model reference adaptive fault tolerant control of a quadrotor UAV. USA, March 2011.
15. Chen F, Lu F, Jiang B, Tao G. Adaptive compensation control of the quadrotor helicopter using quantum information technology and a disturbance observer. Journal of the Franklin Institute, 2014, vol. 351, no. 1, pp. 442–455.
16. Salazar S, Romero H, Lozano R. Modeling and real-time stabilization of an aircraft having eight rotors. Journal of intelligent and robotic systems, 2008, vol. 54, no. 1-3, pp. 455– 470.
17. Ding L, Ma R, Wu H, Feng C, Li Q, Yaw control of an unmanned aerial vehicle helicopter using linear active disturbance rejection control. Proceedings of the Institution of Mechanical Engineers: Journal of Systems and Control Engineering, 2017, vol. 231, no. 6, pp. 427–435.
18. Jackson S, Tisdale J, Kamgarpour M, Basso B, Hedrick J K. Tracking controllers for small UAVs with wind disturbances: theory and flight results. Proceedings of the 47th IEEE Conference on Decision and Control, December 2008, pp. 564– 569.

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