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# Modeling and enhancing the performance of AGV actuation system using real-time advanced control techniques

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**Abstract.** In recent years, there has been a growing interest in Aerial Gliding Vehicles (AGVs) due to their versatile applications. The stability and maneuverability of AGVs depend on the control of their actuation systems, which necessitates an accurate model for controller design. However, some parameters of the system may be unknown, requiring the use of system identification techniques for parameter estimation. This study utilized the NI MYRIO1900 and LabVIEW platform to identify the parameters of the AGV actuation system by collecting input and output signals. The obtained model with estimated parameters was validated by comparing its response with the actual servo motor. Subsequently, two types of controllers were designed using the identified model: a traditional Proportional Integral Derivative (PID) controller and a Fuzzy PID (FPID) controller. Experimental results showed that the AGV under FPID control exhibited improved stability and accuracy, precise speed tracking, and reduced rise time, settling time, and overshoot compared to traditional PID control. The FPID controller was deployed on the embedded controller MY-RIO1900, and the real-time results were evaluated against the simulated results. The findings of this study provide evidence for the effectiveness of advanced control strategies such as FPID control in enhancing the performance of AGV actuation systems.

## 1. Introduction

Aerial gliding vehicles (AGVs) are adaptable airborne platforms that have become more well-known in recent years due to their numerous uses in both civil and military situations. AGVs are frequently referred to as "gliding unmanned aerial vehicles “or “gliders" in civil applications and as "smart bombs with wings" in military applications. [1] Aerial surveillance, delivery, and reconnaissance are some of the activities that AGVs are capable of performing. AGVs must have an accurate model of their actuation systems and employ efficient control strategies to assure their stability and maneuverability. [2] Because of this, system identification and control are essential elements in the development and use of AGVs.

The modelling of system dynamics using measured input-output data is a crucial focus of system identification in control theory. The objective of system identification is to determine, based on the information that has been gathered, the parameters of a mathematical model that accurately describes the system's behavior [3]. The initial stage in system identification is to gather an appropriate amount of input-output data from the system. This information ought to cover both the input signals used by the system and the corresponding output signals that were generated. It is necessary to select a model structure that accurately captures the system's underlying physical principles after the data have been gathered. The model can then be verified by contrasting its predictions with the actual measured data. If the model is a good fit for the data, it can be used for control design. It might be necessary to collect additional data, change the model's structure, or apply a different optimization technique, nevertheless, if the model does not suit the data well [4].

Traditional control methods, such as PID control, have been widely used for AGV actuation systems. PID control provides a simple and effective way to control the system, but it may not be suitable for systems with nonlinear dynamics or uncertain parameters[5].To address these challenges, advanced control strategies, such as fuzzy logic control and neural network control, have been proposed for AGV control. Fuzzy logic control provides a way to handle uncertainties and nonlinearities in the system, while neural network control allows for the identification of complex nonlinear dynamics. These

advanced control strategies have shown promise in improving the stability and accuracy of AGV control[7].
PID controllers are commonly used in control applications due to their simplicity and convenience [5]. However, PID controllers may not be effective in some systems with nonlinearities or time-varying characteristics [5]. One way to enhance the performance of PID controllers is to configure an auto-tuned fuzzy PID (FPID) controller using a fuzzy controller (FC) [6]. The auto-tuned FPID can dynamically adjust its settings in real-time by integrating the FC and PID controller, which improves control performance [7]. The auto-tuning process involves collecting data from the system initially and using it to train the fuzzy controller. After training, the FC can adjust the settings of the PID controller in real-time, improving control performance [8]. The robustness and accuracy of auto-tuned FPID have been demonstrated in various applications, including unmanned aerial aircraft control, temperature management, and motor control [9]. Using an FC to configure an auto-tuned FPID is a useful way to enhance the performance of PID controllers in challenging control systems [9].
In this paper,

- The system identification and control of the AGV are addressed, with a focus on developing an accurate mathematical model of the AGV's actuation systems and implementing effective control strategies.
- The system identification process involves collecting input-output data from the AGV and using this data to estimate the parameters of a mathematical model of the AGV actuation system.
- A (PID) controller is initially used, but it is improved using an FC to configure the auto-tuned FPID to achieve better control performance.
- LabVIEW and MYRIO 1900 embedded devices are used in the system identification process furthermore design and implementation of the controller, as well as in the testing of the control system in both a test environment and in real-time.

Overall, the work presented in this paper demonstrates the potential of using system identification and control techniques in the design and operation of AGVs.
The structure of this paper is as follows: The system under study and its components are clearly described in Section 2, along with the methodology for identifying the system, which includes the experimental setup, data collection, and analysis. The PID and FPID controller designs are covered in Section 3 while the performance evaluation of the system is covered in Section 4. Section 5 offering conclusions and suggestions for further research.

## 2. System Description and Identification.

The actuation system of Aerial Gliding Vehicles (AGVs) consists of four servo motors, each of which is connected to a moving fin as depicted in figure 1, representing a 3D CAD model of the AGV actuation system. In this study, only one of the motors was examined, as they are all identical.

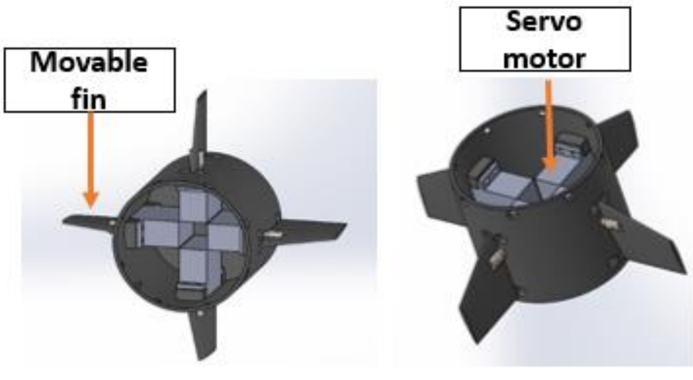



**Figure 1.** 3D CAD model of AGV actuation system.

LabVIEW and MYRIO 1900 embedded device are valuable tools in the field of system identification and control design. LabVIEW is a graphical programming platform that provides a user-friendly interface for designing, testing, and deploying measurement and control systems. It is widely employed in both industry and academia for its ease of use and its capability to interface with a wide range of hardware devices [10]. On the other hand, MYRIO 1900 is a compact, reconfigurable I/O (RIO) embedded device that integrates the processing power of a real-time microcontroller with the flexibility of FPGA technology [11]. As a result, MYRIO 1900 is an ideal platform for developing and testing control systems, including system identification and control design. The combination of LabVIEW and MYRIO 1900 provides a robust toolset for constructing and testing control systems in real-time, making it an essential tool for engineers and researchers in the field of system identification and control design. To initiate the system identification process, LabVIEW was utilized to generate a Pseudo Random Binary Sequence (PRBS) signal, which was transmitted to the servo motor via the NI MYRIO 1900 device. The servo motor is equipped with an internal feedback system in the form of an analog potentiometer, which provides readings from 0 to 3 volts according to angles ranging from 0 to 180 degrees. The feedback was obtained via the A/I channel in the MYRIO, while the PRBS signal was output from the PWM channel. The hardware setup for the system identification process and the procedures involved in the system identification process are illustrated in figure 2, which consists of host PC, MYRIO and AGV actuation system. figure 3. shows a sample of the input and output signals over a duration of 10 seconds.

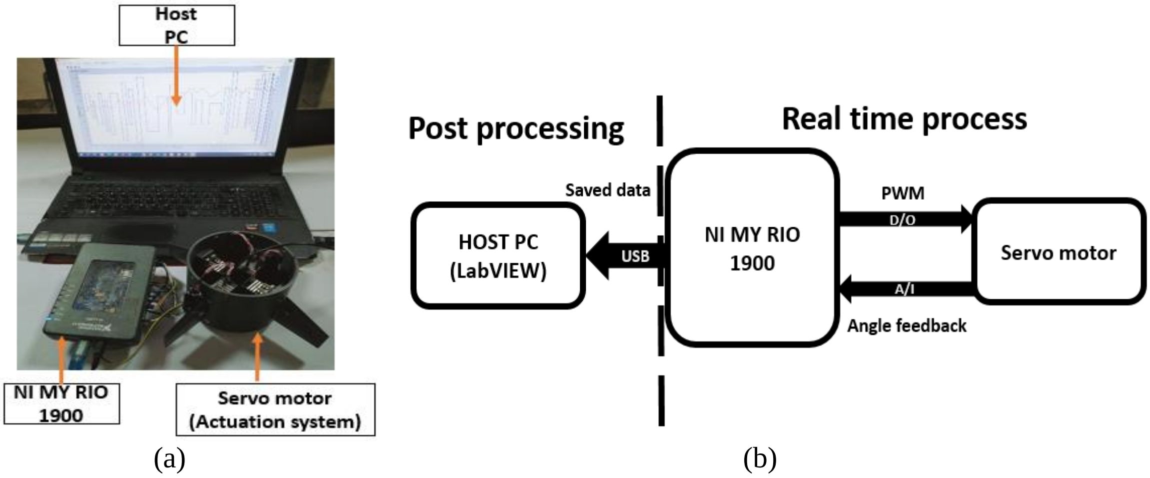



**Figure 2.** (a) Hardware setup (b) Block diagram of servo motor acquiring data.

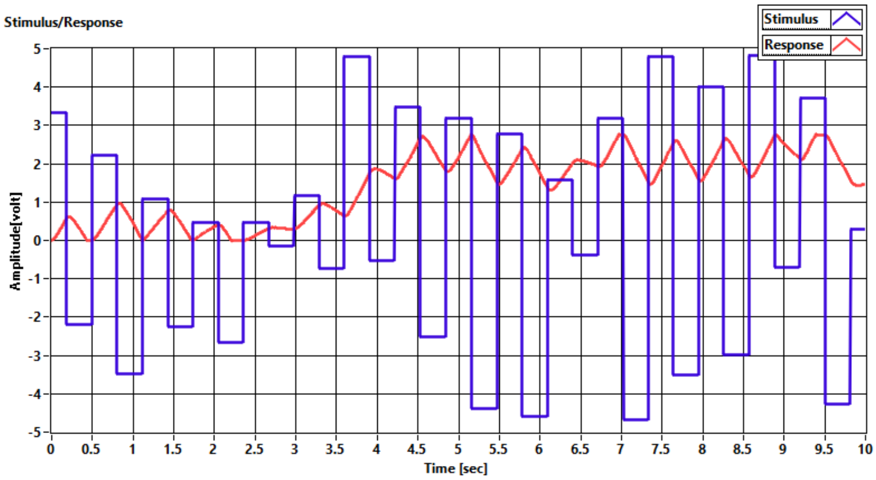



**Figure 3.** The input and output signals.

The Recursive Least Squares (RLS) algorithm is a popular technique that is widely used for estimating unknown parameters in a given system. In the present study, the RLS algorithm was employed through the LabVIEW system identification toolkit to effectively estimate the unknown parameters, making it a potent tool for system identification. This ultimately leads to the determination of the most appropriate transfer function to represent the system.
To compare the output of the first and second-order transfer functions, represented by equations (1) and (2), respectively, the system was analyzed. It was found that the second-order transfer function was more suitable, as it demonstrated a validation accuracy of 92% in contrast to the 87% obtained by the first-order transfer function, as shown in figure 4. The linear models were utilized to represent the system due to the absence of complexities. The transfer function derived from the system identification process was employed for control design, simulation, and prediction purposes. The identified transfer function exhibited a good fit for the system, and its predictions were authenticated via comparison with the measured data.

$$G(s) = \frac{0.503066}{1 + 0.642956\, s} \tag{1}$$

$$G(s) = \frac{0.151251\, s + 0.777289}{0.00497\, s^2 + 0.2307768\, s + 1} \tag{2}$$

After the system identification procedure, it was crucial to validate the findings in order to guarantee the correctness and dependability of the findings. Simulation and experiments in the test environment were two techniques utilized to accomplish this. The transfer function discovered during the system identification step was utilized to replicate the servo motor's response to the input signal during the simulation, which was carried out using LabVIEW. Following that, as depicted in figure 4, the simulation results for the first and second-order transfer functions were compared with the real results of the tests in the test environment.

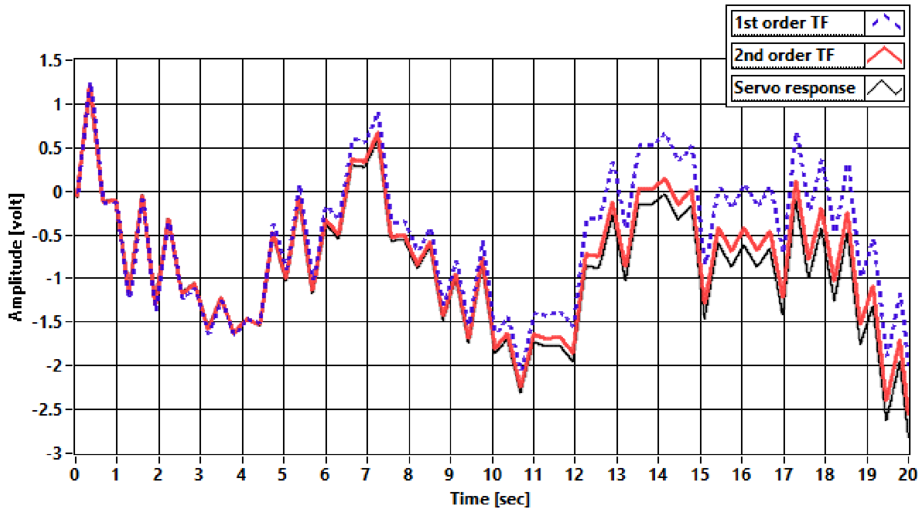



**Figure 4.** The responses from the real system and simulation models.

The results from the system identification process were validated by comparing the simulation results with the results from the experiments conducted in the test environment. This revealed a good level of agreement, demonstrating that the second-order transfer function derived through the system identification procedure accurately represented the servo motor in the AGV's actuation system. Using simulation and test environment tests, the system identification process was validated, ensuring the correctness and dependability of the results and boosting trust in the control system's design.

## 3. Controller Design

The PID controller is a popular control algorithm that provides fast and precise control of dynamic systems. The three mode controller parameters, including the proportional gain ($K_P$), integral gain ($K_I$), and derivative gain ($K_D$), can be manually tuned using methods such as the Ziegler-Nichols method for closed-loop systems and the process reaction curve method for open-loop systems [12]. While these manual tuning methods can provide a precise selection of controller parameters, they may not eliminate steady-state error. To overcome these limitations, soft computing methods such as fuzzy logic can be used to modify PID controller parameters and achieve a faster and more optimal response with a shorter rise and settling times than the conventional PID controller [13].

From the PID Controller algorithm the output $\theta(t)$ and error input e (t) are related by the following equation,

$$\theta(t) = k_P e(t) + k_I \int e(t) + k_D \frac{de(t)}{dt} \tag{3}$$

Where, $k_P$=Proportional gain, $k_I$ = Integral gain $= \frac{1}{T_I}$ and $k_D = T_D = Derivative\ gain$

In this work, the self-tuning fuzzy PID controller was designed and implemented using LabVIEW fuzzy system designer and the NI MYRIO 1900 embedded device. The FC was based on an online tuning process that used the error and change in error as inputs to modify the $k_P$,$k_I$ and $k_D$ values. The self-tuning mechanism provided a dynamic, steady-state, and static performance without disturbances [14]. The structure of the FPID controller is shown in figure 5.

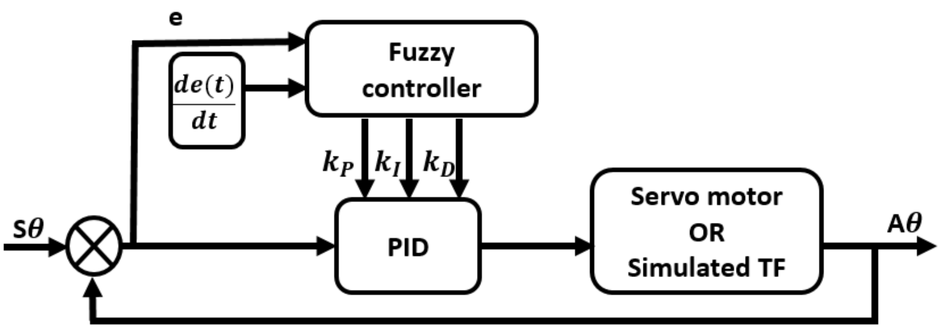



**Figure 5.** The structure of FPID.

The FC is based on the online tuning process for gains. This means that the controller can adapt to changes in the system in real-time and adjust its gains accordingly. The FC uses linguistic variables to represent the system's inputs and outputs. These variables are then processed by the fuzzy inference system to produce the control output. The FC is able to handle the nonlinearities present in the system and achieve better performance compared to a traditional PID controller [15].

The proposed FPID controller uses fuzzy inputs such as error and changes in error to modify the three controller parameters ($k_P$,$k_I$ and $k_D$) to achieve precise and faster optimal responses. Five fuzzy values (NL, NS, ZE, PS, and PL) are framed according to the error and change in error values. For the developed fuzzy logic control system, 25 rules are established for three controllers. Table 1 contains a list of rules for $k_P$ controller. The selection of the appropriate MF for FLCs is a crucial step in designing an effective control system.

The choice of the most suitable membership function for fuzzy logic controllers (FLCs) is dependent on the specific characteristics of the system under control and the level of accuracy required for the control task. The triangular function is often preferred due to its simplicity and robustness, making it a good choice for many applications. However, for complex and nonlinear systems, the Gaussian function offers greater flexibility and accuracy. In the present study, the triangular function was selected as the MF for the FLC because of the controlled system's simplicity and ease of implementation. Although the system is not particularly complex, precise control is crucial. Both input and output variables were assigned the triangular membership function, as illustrated in figure 6, as it provides sufficient accuracy for the application. Additionally, the ease of implementation of the triangular function is particularly advantageous, enabling the control system to be rapidly deployed. Also the centre of gravity method has been used as the defuzzification method, which requires less computation time while implemented with a data acquisition system.

**Table 1**. Fuzzy set rules for inputs and output of the proportional gain.

| **Change in error** / **Error** | **NL** | **NS** | **ZE** | **PS** | **PL** |
|---|---|---|---|---|---|
| **NL** | NL | NL | NS | ZE | PS |
| **NS** | NL | NS | ZE | PS | PL |
| **ZE** | NS | ZE | ZE | PS | PL |
| **PS** | ZE | PS | PL | PL | PL |
| **PL** | PS | PL | PL | PL | PL |

The table is divided into 5 rows and 5 columns, where the rows represent the fuzzy set for the change in error and the columns represent the fuzzy set for the error. The cells in the table represent the corresponding output values for the proportional gain, which are labeled NL, NS, ZE, PS, and PL. The degree of membership is not included in this particular table. The rules are formulated based on expert knowledge and are designed to modify the gains of the PID controller according to the current error and change in error. By using this table, the fuzzy logic control system can make decisions on how much to adjust the proportional gain of the PID controller based on the current error and change in error values. figure 6. shows a graphical representation of the Fuzzy Control system MISO for proportional gain only with inputs of error and change in error, and output of the proportional gain parameter ($K_P$) of the PID controller and every gain has different fuzzy rules.

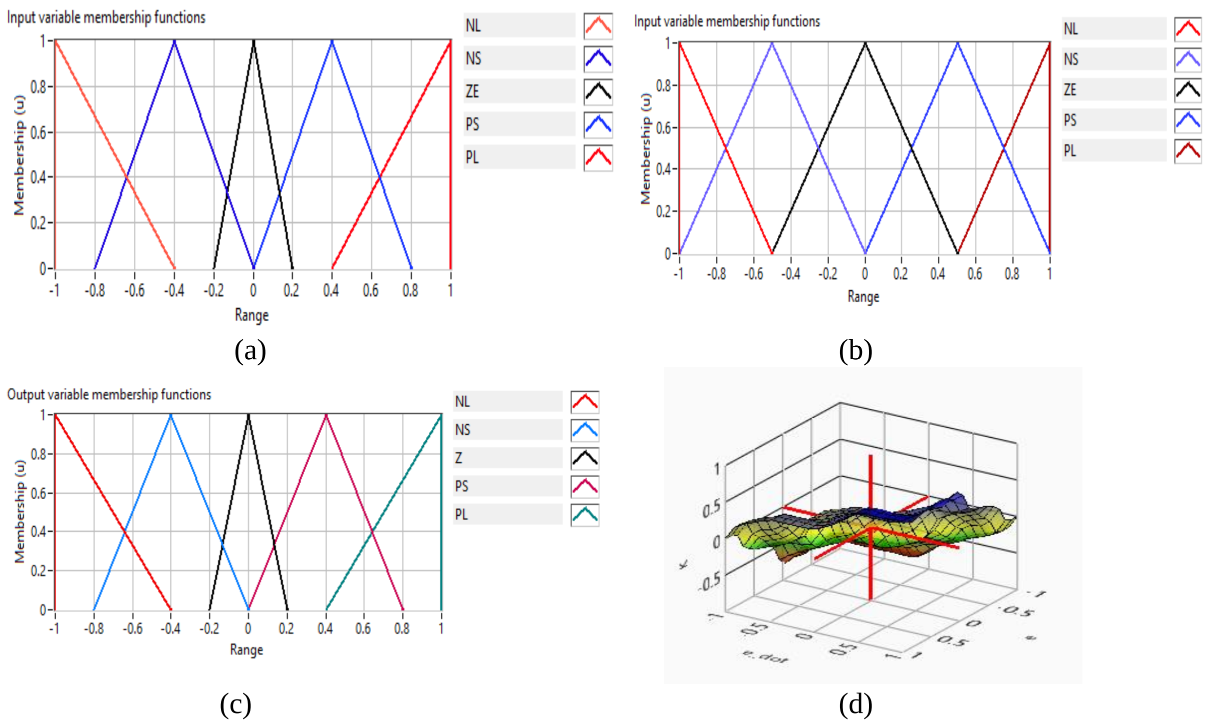



**Figure 6.** MFs of FC (a) Error (b) Change in Error (c) $K_P$ gain (d) I/O relationship mesh.

After using fuzzy logic to determine the optimal values for the FPID controller parameters, a normalizing process was employed to convert performance ratings with multiple data measurement units into a decision matrix with a compatible unit. However, error and change in error are always between 0 and 1 (radian), so there is no need to normalize and denormalize them. For the output gains, a scaling factor based on previous knowledge of the system was used to denormalize it.

## 4. Performance Evaluation

Both the PID and FPID were evaluated in simulation using a doublet input that required the servo to move from 0 to 10 degrees, then to -10 degrees, and back to 0 again in order to evaluate the efficiency of the devised controllers. To evaluate each controller's performance, the response from each was recorded and compared. The RIO1900 was used to create the FPID controller so that it could work independently in the real-time environment, simultaneously commanding and receiving output from the servo. To see if there were any noticeable differences, the FPID controller's performance was compared to that of the simulation environment on a PC. This selection of powerful embedded device resulted in minimized complexity and ensured effective execution of the fuzzy control algorithm.

### *4.1. Simulation results*

In the simulation phase, the performance of the FPID controller designed using the fuzzy logic-based self-tuning approach was compared with a traditional PID controller tuned using the Ziegler-Nichols method. The results showed that the FPID controller outperformed the traditional PID controller in terms of several metrics. Specifically, the FPID controller demonstrated significantly better performance in terms of settling time and rise time, and also showed less overshoot compared to the traditional PID controller. Furthermore, the self-tuning mechanism of the FPID controller allowed for greater adaptability to changes in the system, resulting in more accurate control actions. The use of fuzzy logic-based self-tuning also allowed for easier implementation and a reduced need for manual intervention in the tuning process. During the simulation phase, a doublet input was used to evaluate the performance of both controllers as shown in figure 7. Comparing the results in table 2 of the PID and FPID controllers in the simulation environment, it's clear that the FPID controller outperformed the PID controller in several key metrics. First, the overshoot percentage for the FPID controller was significantly lower at 0.018% compared to 0.13% for the PID controller. This suggests that the FPID controller was able to regulate the system with less oscillation and overshoot. Second, the rise time for the FPID controller was faster at 0.426 seconds compared to 0.78 seconds for the PID controller. This indicates that the FPID controller was able to respond more quickly to changes in the system, resulting in a faster rise time. Third, the settling time for the FPID controller was also faster at 0.452 seconds compared to 0.86 seconds for the PID controller. This indicates that the FPID controller was able to settle the system more quickly and accurately compared to the PID controller. Finally, the control effort which are calculated by dividing the controller output by the maximum voltage (5V) required by the FPID controller was lower at 0.513 compared to 0.58 for the PID controller. This suggests that the FPID controller was able to regulate the system with less control effort.

Overall, these results suggest that the FPID controller can be a more effective method for regulating system behavior compared to the PID controller, at least in a simulation environment.

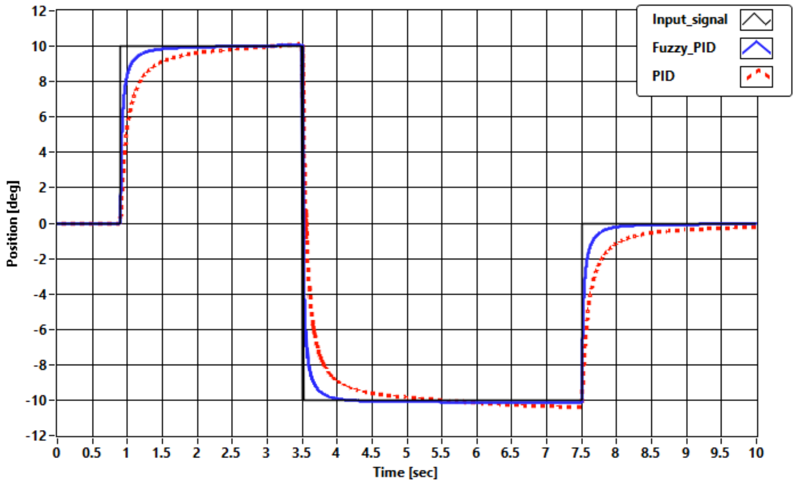
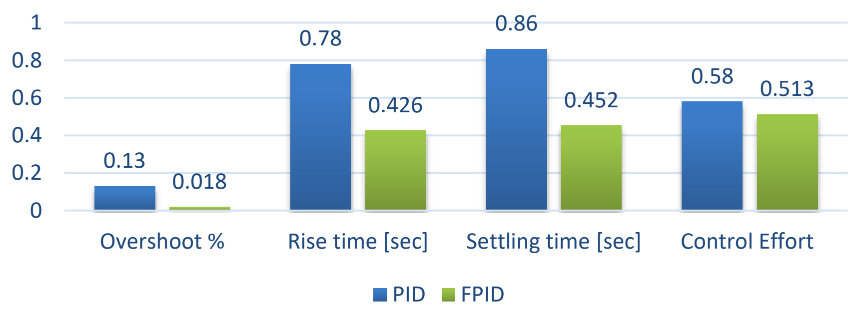



**Figure 7.** Simulation results for both controller.

**Table 2**. Simulation results.




*4.2. Real-time results*

After evaluating the FPID controller in the simulation phase, it was important to verify its performance in real-time. To do so, a test environment was set up and the real-time FPID controller was tested in comparison to the simulation results as shown in figure 8.

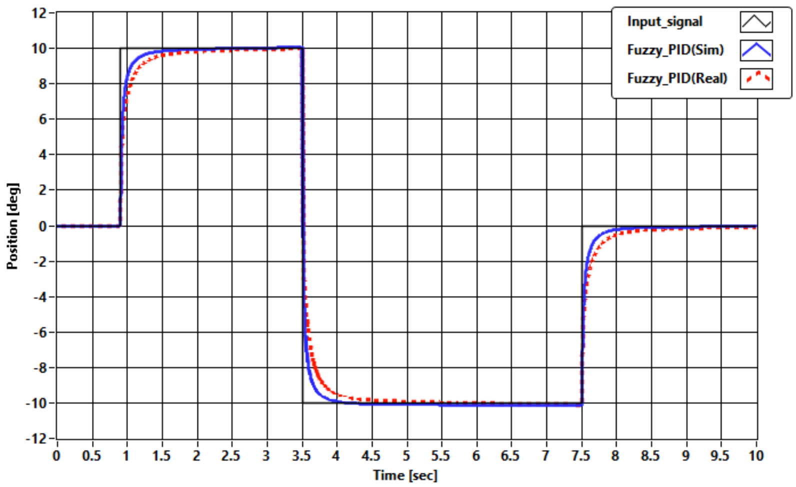
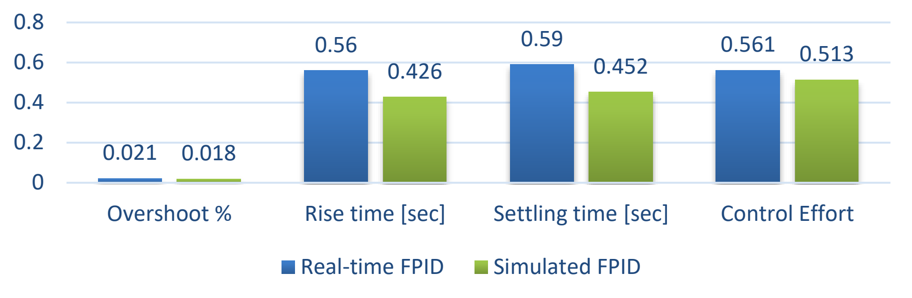



**Figure 8**. Real-time and simulation response of FPID.

**Table 3 .** Real-time results.




The results in table 3 show that the FPID controller performed well in both simulated and real-time settings. The overshoot percentages were low, with the simulated controller achieving a slightly better result at 0.018% compared to the real-time controller at 0.021%. The simulated controller had a faster rise time (the time for the system to reach a certain percentage of its steady-state value), achieving it in 0.426 seconds compared to 0.56 seconds for the real-time controller. Both controllers had similar settling times (the time for the system to settle within a certain error threshold) of 0.452 seconds and 0.59 seconds, respectively. The control efforts required by the controllers were relatively low, with the simulated controller requiring slightly less control effort at 0.513 compared to 0.561 for the real-time controller. Overall, the results showed that the FPID was more efficient in controlling the AGV actuation system in real-time. However, the performance of the FPID in real-time was consistent with its performance in simulation. There were no significant differences between the simulation and real-time testing, which indicated the efficiency of the design of the controller.

## 5. Conclusion

In conclusion, this study demonstrated the effectiveness of system identification techniques and advanced control strategies in enhancing the performance of the actuation system of Aerial Gliding Vehicles (AGVs). The system identification process effectively modelled the actuation system of the AGVs, which was later used to design two types of controllers: a traditional PID and an FPID. The experimental results showed that the AGV under FPID control exhibited improved stability and accuracy, precise speed tracking, and reduced rise time, settling time, control effort and overshoot compared to traditional PID control. Moreover, the real-time implementation of the FPID controller on the RIO1900 proved to be an effective standalone controller that can control the servo and receive output at the same time. The results of this study can be useful in the development of advanced control strategies for AGVs and other similar systems, contributing to their stability and maneuverability in various applications. The future goal of the work is to integrate and build on the above in the process of developing and designing an autopilot for the AGV.

## 6. References

[1] Liu, J. et al. (2014) ‘Novel approach for designing a hypersonic gliding–cruising dual Waverider Vehicle’, *Acta Astronautica*, **102**, pp. 81–88. doi:10.1016/j.actaastro.2014.04.024.

[2] Rao, S.B., Chatterjee, A. and Kanistras, K. (2022) ‘System identification of an unmanned aerial vehicle with actuated wingtips’, *Journal of Intelligent & Robotic Systems*, **105**(1). doi:10.1007/s10846-022-01599-z.

[3] Simpkins, A. (2012) ‘System identification: Theory for the user, 2nd edition (Ljung, L.; 1999) [on the shelf]’, *IEEE Robotics & Automation Magazine*, **19**(2), pp. 95–96. doi:10.1109/mra.2012.2192817.

[4] Pintelon, R. and Schoukens, J. (2012) ‘Model Selection and Validation’, in *System identification: A frequency domain approach*. Hoboken, NJ, USA: John Wiley & Sons Inc.

[5] Heong Ang, K., Chong, G. and Li, Y. (2005) ‘PID control system analysis, design, and Technology’, *IEEE Transactions on Control Systems Technology*, **13**(4), pp. 559–576. doi:10.1109/tcst.2005.847331.

[6] Kofinas, P. and Dounis, A.I. (2019) ‘Online tuning of a PID controller with a fuzzy reinforcement learning mas for flow rate control of a desalination unit’, *Electronics*, **8**(2), p. 231. doi:10.3390/electronics8020231.

[7] Kim, K., Rao, P. and Burnworth, J.A. (2010) ‘Self-tuning of the PID controller for a digital excitation control system’, *IEEE Transactions on Industry Applications*, **46**(4), pp. 1518–1524. doi:10.1109/tia.2010.2049631.

[8] Tayara, H., Lee, D.J. and Chong, K.T. (2015) ‘Auto PID tuning of speed control of DC motor using particle swarm optimization based on FPGA’, *Applied Mechanics and Materials*, **776**, pp. 390–395. doi:10.4028/www.scientific.net/amm.776.390.

[9] Yang, Z., Li, L. and Liu, B. (2014) ‘Auto-tuning method of fuzzy PID controller parameter based on self-learning system’, 2014 *11th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)* [Preprint]. doi:10.1109/fskd.2014.6980836.

[10] Rai, A., Das, D.K. and Lotha, M.M. (2019) ‘LabVIEW platform based real-time speed control of a DC servo motor with fuzzy-pi controller’, *2019 International Conference on Electrical, Electronics and Computer Engineering (UPCON)* . doi:10.1109/upcon47278.2019.8980036.

[11] Mohamed, M.I., Safwat, E. and Kamel, A.M. (2022) ‘Modeling, simulation and attitude control of an aerial gliding vehicle’, *2022 13th International Conference on Electrical Engineering (ICEENG)* . doi:10.1109/iceeng49683.2022.9782063.

[12] Elbakri, M.A. (2015) ‘Implementation of real-time concentration process control system design based on PID and Fuzzy Logic Controller’, *Applied Mechanics and Materials*, **772**, pp. 147–153. doi:10.4028/www.scientific.net/amm.772.147.

[13] Jogalekar, K. et al. (2013) ‘Implementation of PID Architecture in FPGA for DC Motor Speed Control’, *2013 International conference on Circuits, Controls and Communications (CCUBE)* . doi:10.1109/ccube.2013.6718557.

[14] Sheet, A.F. (2021) ‘Optimization of DC motor speed control based on Fuzzy Logic-PID controller’, *Analysis and data processing systems*, (3), pp. 143–153. doi:10.17212/2782-2001-2021-3-143-153.

[15] Arulmozhiyal, R. and Kandiban, R. (2012) ‘Design of fuzzy pid controller for Brushless DC Motor’, *2012 International Conference on Computer Communication and Informatics* . doi:10.1109/iccci.2012.6158919.