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Performance Evaluation of the Effect of Optimally Tuned IMC and PID Controllers on a Poultry Feed Dispensing System

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Abstract: *Proportional-Integral-Derivative (PID) controllers and Internal Model Controllers (IMC) are effective tools in control analysis and design. However, parameter tuning, and inaccurate model representation often lead to unsatisfactory closed loop performance. In this study, we analyse the effect of PID controllers and IMCs tuned with Genetic Algorithm (GA) and Fuzzy Logic (FL), on a poultry feeding system. The use of GA and FL for tuning of the PID and IMC parameters was done to enhance the adaptability and optimality of the controller. A comparative analysis was made to analyse closed loop performance and ascertain the most effective controller. The results showed that the GA-PID and FL-PID gave a better performance in the aspect of rise time, settling time and Integrated Absolute Error (IAE). On the other hand, the GA-IMC and FL-IMC gave better performances in the aspect of the performance overshoot. Therefore, for processes in which a faster response and lower IAE are desired, the GA-PID and FL-PID are more effective while for processes in which the major objective is to minimise the overshoot, the GA-IMC and FL-IMC are more suitable.*

Keywords: *PID Controller, Internal Model Controller, Poultry Feed, Fuzzy Logic, Genetic Algorithm.*

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I. INTRODUCTION

THE choice of a suitable control technique is an optimization task which involves analysis and comparison of the performances of different control structures based on stability and robustness [1]. Several techniques have been implemented in control system design including conventional Proportional Integral and Derivative (PID), Model Predictive, Internal Model, Robust, Optimal and Intelligent control techniques.

The Proportional Integral and Derivative (PID) control technique is one of the most widely used control technique in industrial control due to its low cost and simplicity [2]. This is because it can guarantee satisfactory performance for a wide range of industrial and control process, while using a simple algorithm. Several techniques exist for tuning PID controllers, however, every method has its constraint [3]. Due to this drawback, tuning and designing PID controllers has remained a major challenge to control engineers and researchers.

Traditional PID tuning techniques include Ziegler-Nichols (ZN), Tyreus-Luyben (TL), Astrom-Hagglund (AH) and Cohen-Coon (CC) methods. However, in the case of the ZN, TL and AH methods, the system needs to be put in a state of oscillation which is not always possible for technological plants. As for the CC method, it is more suitable for first order time delay processes [4]. As a result of these shortcomings of the traditional tuning methods, other tuning methods have been explored which involve optimisation algorithms, artificial intelligence and computational methods. PID controller tuning is a difficult task especially in systems with dead time and time delays [5]. Due to this shortcoming of PID control, the Internal Model Controller (IMC) has often been used as a substitute for PID control [3], [5], [6].

Internal Model Controller (IMC) provides a simple, effective and powerful platform for analysis of control system design and performance [3]. IMC has a number of advantages which include simplicity in structure and the tuning of just one parameter (unlike the PID which requires the tuning of three parameters). The IMC is mainly based on the nominal model of the system plant. However, it is almost impossible to get a completely accurate representation of the system plant due to the fact that most systems are complex in nature. As a result of this, the performance and robustness of the controller will reduce due to model uncertainties and inaccuracies. Due to this drawback, the need arises for the adoption of adaptive and optimised control techniques to improve the accuracy of the controller design [7].

Poultry farming, despite its immense contribution to the economy, is still carried out manually in the tropics. This manual pattern of farming which involves feeding of the poultry birds, results in wastage of the feed, high level of human involvement, stress and a low return on investment [8]. A number of poultry feeding systems exist as seen in the works of [10], [9], [11] and [12]. However, these systems lack a proper control mechanism to improve stability and robustness.

[13] and [14] implemented a PID control mechanism optimally tuned with Genetic Algorithm and Particle Swarm Optimisation respectively. However, due to the difference in the systems, an appropriate comparison could not be made and hence, the more suitable control technique could not be determined.

Several works exist in the area of comparison between IMC and PID controllers. In [1], a performance assessment was done on the effect of PID and IMC controllers on a mixing process. The results showed that the IMC exhibited a more robust performance, a faster rise time and lower overshoot than the PID controller. In the work of [15], a performance evaluation of different controllers was done on a first order plus delay process. The controllers involved were PID controllers tuned with Ziegler-Nichols (Z-N) and Cohen-Coon (C-C) tuning techniques, an IMC and a controller based on Integral of Time-Weighted Absolute Error (ITAE). The results showed that the ITAE based controller provided a lower settling time and no overshoot as compared to the other controllers. The C-C PID controller provided the second lowest settling time, followed by the IMC, while the Z-N PID controller gave the largest settling time.

In [7], the effects of a nonlinear IMC and a PI controller were examined on a turbocharged gasoline engine. Here, the results obtained showed that the overall performance of the IMC was better than the PID in aspects such as constant speed, variable speed, wastage and boost, giving a lower overshoot and a faster response than the PID. In [13], a performance evaluation was made between optimally tuned PID controllers and an Internal Model Controller (IMC). The results showed that the optimally tuned PID controllers gave an overall better performance than the IMC. However, in this case, the PID was tuned with Genetic Algorithm and Particle Swarm Optimisation. Hence, it could be argued that the addition of these optimisation algorithms gave the PID controller an advantage over the IMC.

In this paper, we present a comparison between the effects of PID control and Internal Model Control on a poultry feed dispensing system in order to determine the more suitable control technique for the system. The PID and IMC were tuned using Genetic Algorithm (GA) and Fuzzy Logic (FL). The use of GA and FL techniques for PID controller tuning is due to the difficulty in optimally tuning PID parameters to provide a satisfactory performance. Also, due to the difficulty in obtaining an accurate representation of the plant, GA and FL are used to tune the IMC to compensate for model inaccuracies as well as provide a robust performance of the controller. The system performance was evaluated based on the rise time, settling time, overshoot and Integrated Absolute Error (IAE).

II. BACKGROUND OF STUDY

1. Proportional Integral and Derivative (PID) Control

PID controllers are widely used in industrial control applications due to their simplicity, robustness and satisfactory closed loop performance [17]. The PID transfer function is given in equation 1.

$$G_c(s) = K_p + \frac{K_i}{s} + K_d s \qquad (1)$$

Where K_p, K_i and K_d are the proportional, integral and derivative gains respectively. These three gains need to be selected and adjusted to give an optimal performance of the controller. The selected of these parameters is referred to as "tuning". Each parameter has an effect on the performance of the controller. The proportional gain increases the response of the system, the integral gain eliminates the steady state error while the derivative gain improves transient response [18]. Several tuning methods of the PID controller exist. There are traditional tuning techniques such as the Ziegler Nichols and Cohen Coon techniques. There are other techniques which are based on computational optimisation and artificial intelligence such as neural networks, genetic algorithm and fuzzy logic. In this study, we adopt an optimised tuning technique using Genetic Algorithm and Fuzzy Logic, to tune the PID parameters. A basic PID control process is shown in figure 1.

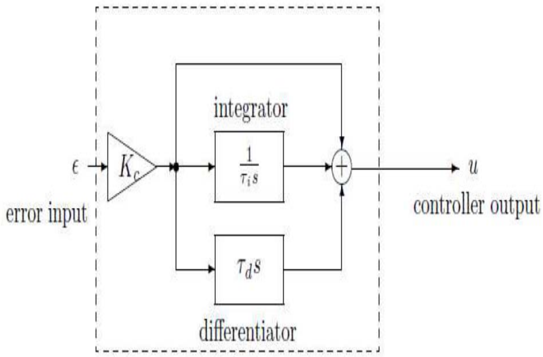

Figure 1: A PID Control Process [19].

2. Internal Medical Controller (IMC)

IMC was first proposed in 1982 by Garcia and Morari and gained researcher's attention because of its simplicity, robustness, good tracking performance, ease of disturbance elimination and convenience in tuning. The IMC also has an ideal control feature of zero steady state error as well as ease in adjusting its parameters [6]. IMC has gained widespread acceptance recently due to its simple control algorithm, robustness and tuning of only one parameter, λ. The IMC has had a significant effect in the field of control systems in the aspects of performance issues such as robust and optimal design as well as intuitiveness [20]. The block diagram of a typical IMC control process is shown in figure 2.

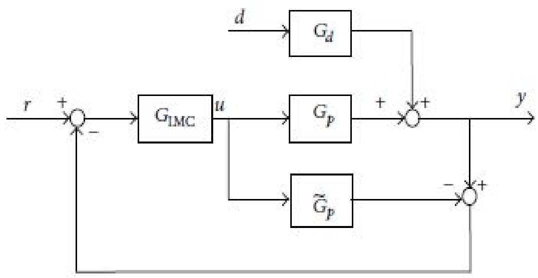

Figure 2: An IMC Control Process [6]

Where G_{IMC} is the IMC controller, G_p is the process, $\hat{G}_p$ is the process model and G_d is an external disturbance. The transfer function of the IMC is derived from figure 2 as shown in equation 2.

$$G_c(s) = \frac{G_{IMC}(s)}{1 - G_{IMC}(s)\tilde{G}_p(s)} \qquad (2)$$

The IMC is a type of model predictive based control (MPC) technique which uses the plant model as an important tool for the design and implementation of the controller. The controller mainly comprises of the inverse of the process model augmented with a low pass filter. The filter is of the general form shown in equation 3 [20].

$$F(s) = \frac{1}{(1 + \lambda s)^n} \tag{3}$$

Where n is sufficiently large to make the controller proper and λ is a tuning parameter responsible for robustness, process/model mismatch and closed loop performance.

Thus, the IMC controller can be written as shown in equation 4.

$$G_{IMC}(s) = P_M^{-1}(s)F(s) \tag{4}$$

F(s) is the filter while P_M^{-1} is the inverse of the plant model.

In the area of process control, MPC methods have been used to get desired setpoints and disturbance rejection. IMC technique has been used especially in plants where a suitable model can be obtained. In theory, a perfect control is mathematically possible is an exact model of the process can be obtained [4]. In this work, we use Genetic Algorithm and Fuzzy Logic to tune the filter gain of the IMC.

3. Fuzzy Logic

Fuzzy Logic was first proposed by Lofti Zadeh in 1965 as a method of problem solving which involved decision making using imprecise or vague information. The method was based on human reasoning where humans use knowledge which do not have well defined boundaries or precise information [21]. The use of fuzzy logic in control has become quite attractive because of its self-adapting capability, which allows it to maintain a desired closed loop performance by learning about changes that may affect the behaviour of the plant [22].

A basic Fuzzy Logic system consists of four major parts which are the Fuzzifier, Rule Base, Inference Engine and the Defuzzifier [23]. The fuzzifier converts the crisp inputs into fuzzy inputs. This makes the input data correspond with the conditions in the rule base. The fuzzification is done with the use of membership functions. Membership functions are graphical representations which map an input value to the appropriate fuzzy set value. The rule base comprises of the IF-THEN rules which are used to make decisions based on the inputs. The inference engine maps the input data to the corresponding output based on the rules in the rule base. The defuzzifier converts the fuzzy outputs to crisp output which can be understood by the designer [12]. Figure 3 shows a basic fuzzy logic system.

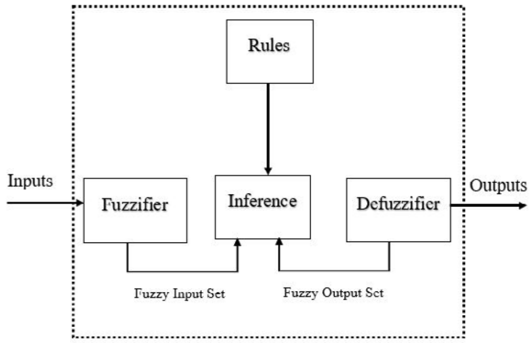

Figure 3: A Fuzzy Logic System

4. Genetic Algorithm

Genetic Algorithm (GA) was proposed by John Holland in 1975 as a metaheuristic inspired by nature which is used to solve search and optimisation problems [24]. GA attempts to find the optimum solution by simulating natural selection and genetic mechanism. It is based on the principles of evolution and finds an optimal solution of a problem from generation to generation [25]. GA provides a technique for traversing a search space and find the most optimum solution within a short period of time. It was wide applications in engineering, computer science, economics and mathematics.

GA starts with a random population of individuals where each individual represents a solution of the problem. The algorithm then uses principles of crossover and mutation to generate a new population and a fitness function is used to evaluate the fitness of each solution. This process is repeated until a stopping condition is met or an optimal solution is achieved [26]. Figure 4 shows the flowchart of a genetic algorithm process.

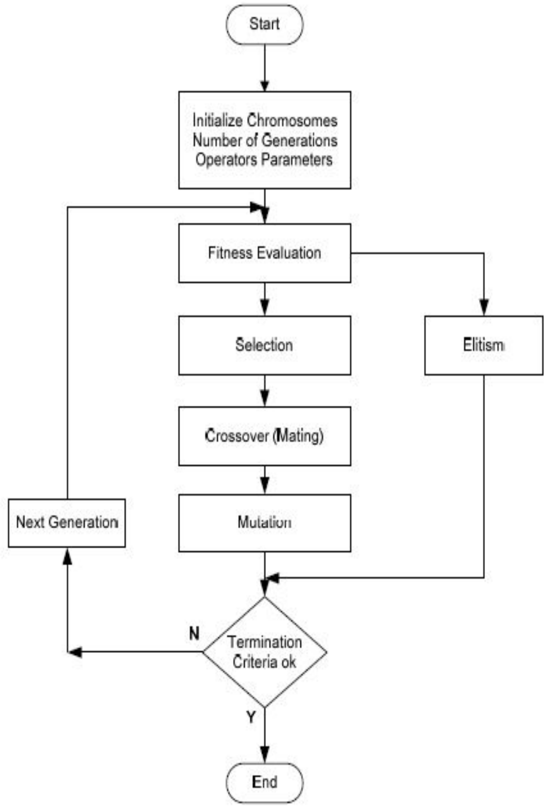

Figure 4: Genetic Algorithm Flowchart [16]

III. RESEARCH METHODOLOGY

1. System Model and Description

The poultry feeding system comprises of two subsystems: the solid feed subsystem and the liquid feed subsystem. The system model used in this study is the model adopted by Olaniyi, Folorunso, Kolo, et al., (2016). The transfer functions for the solid feed subsystem and liquid feed subsystems are provided in equations 5 and 6 respectively.

$$G_l(s) = \frac{8.5}{S + 0.07142} \quad (5)$$

$$G_s(s) = \frac{3.475}{0.00374^2 + 0.51599S + 12.33831} \quad (6)$$

2. PID Controller Design

a. Fuzzy Logic PID (FLPID)

The fuzzy inference system (FIS) was developed using the fuzzy logic toolbox in MATLAB R2018b. The Mamdani FIS was implemented due to its wide acceptance and suitability for human inputs. The FIS comprised of two inputs and three outputs. The inputs are the error and change in error while the outputs are the proportional gain (Kp), integral gain (Ki) and derivative gain (Kd). Figure 5 shows a representation of the Fuzzy Logic PID control system.

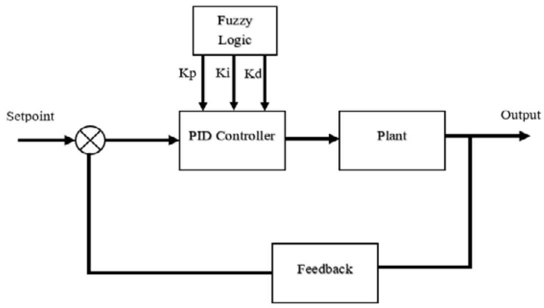

Figure 5: FL-PID Control System

The triangular membership function was used in implementing all the input and output variables. The error had a range of -2 to 2 and the change in error had a range of -1 to 1. The membership functions for the error were Negative (Neg), Zero (Zer) and Positive (Pos) with values of [-2, -1,0], [-1, 0, 1] and [0, 1, 2] respectively. The change in error also had three membership functions, Negative (Neg), Zero (Zer) and Positive (Pos) with values of [-1 -0.5, 0], [-0.5, 0, 0.5], and [0, 0.5, 1] respectively.

The outputs Kp, Ki and Kd had ranges of 0 to 10, 0 to 10 and 0 to 5 respectively. The output variables had three membership functions each named big, medium and low. The membership functions for Kp and Ki had values of [0, 2.5, 4.5], [2.5, 5, 7.5] and [5.5, 8, 10] each, while Kd had values of [0, 1, 2.25], [1.25, 2.5, 3.75] and [2.75, 4, 5]. Figures 6 to 10 show the membership functions for each variable.

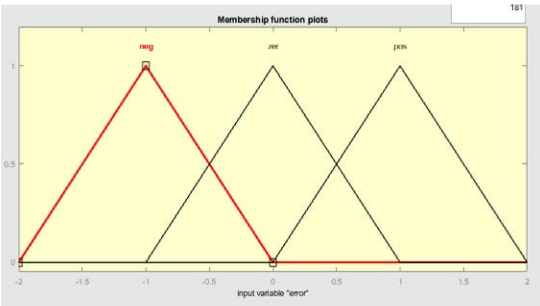

Figure 6: Membership Function for Input

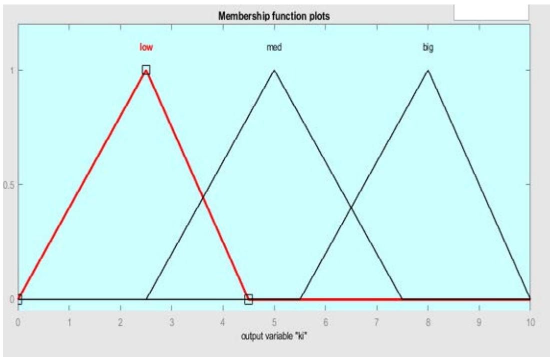

Figure 7:Membership Function for Change in Input

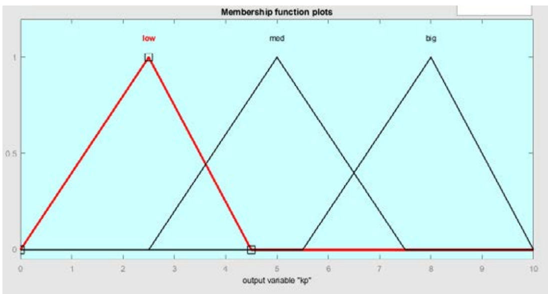

Figure 8: Membership Function for Kp

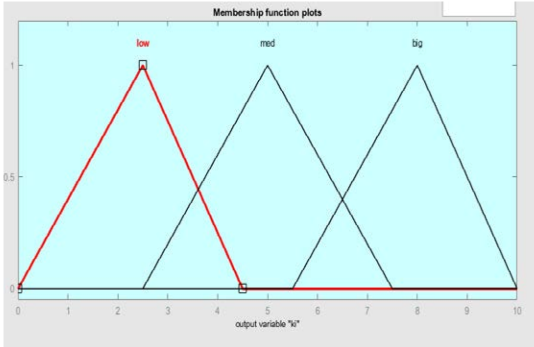

Figure 9: Membership Function for Ki

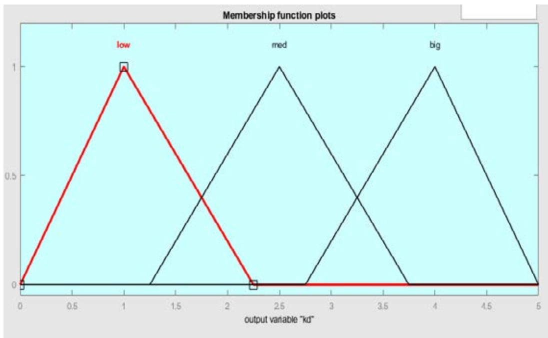

Figure 10: Membership Function for Kd

The fuzzy rules were designed based on the following considerations:

- If the error is large, the proportional gain should be large to reduce the error and speed up the response. This makes the system susceptible to overshooting, hence, the derivative gain should be small to minimize the overshoot.
- If the error and change in error are both zero, the proportional, integral and derivative gains should be kept to the minimum.
- If the error is small, the proportional and integral gains should be increased to improve speed and eliminate steady state errors while the derivative gain should be kept moderate to avoid oscillations.

The fuzzy rules obtained are shown in table 1 while figures 11 and 12 show the rule viewer and surface viewer respectively.

Table 1: Fuzzy Logic Rules for PID Controller

Error/ Change in Error	Neg	Zer	Pos
Neg	Kp = big Ki = low Kd = low	Kp = big Ki = low Kd = low	Kp = med Ki = med Kd = low
Zer	Kp = big Ki = low Kd = med	Kp = med Ki = med Kd = med	Kp = low Ki = big Kd = med
Pos	Kp = med Ki = med Kd = big	Kp = low Ki = big Kd = big	Kp = low Ki = big Kd = big

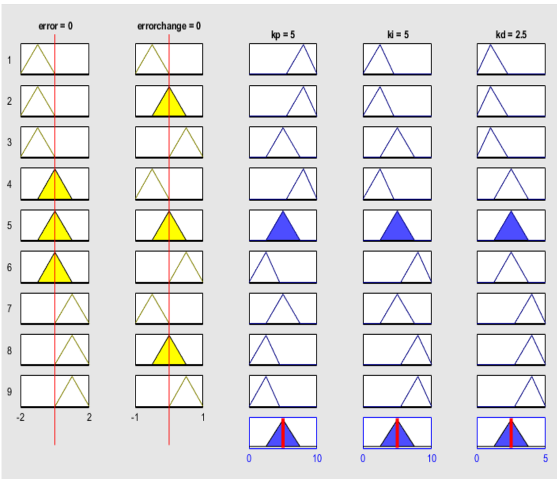

Figure 11: Rule Viewer for FLPID

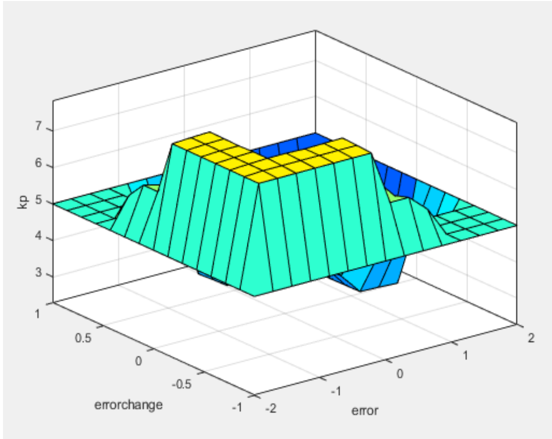

Figure 12: Surface Viewer for FLPID

Defuzzification was achieved using the centroid technique which provided the crisp outputs (Kp, Ki and Kd). These crisp outputs were used as the gains for the PID controller.

b. Genetic Algorithm PID (GAPID)

Genetic Algorithm was used to determine the values for the proportional, integral and derivative gains of the PID controller. The GA parameters used and the corresponding PID parameters are provided in table 2. The PID values of the liquid subsystem and solid subsystem are different as the systems are of different orders. As a result of this, the liquid subsystem (First Order) only had PI values while the solid subsystem (second order) had PID values. Figure 13 shows the diagram of the Genetic Algorithm PID control system.

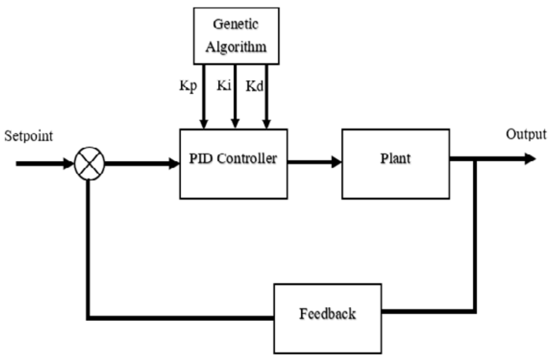

Figure 13: GA-PID Control System

Table 2: GAPID Parameters

Parameter	Value
Population	200
Crossover Rate	0.9
Mutation rate	0.01
P (Solid)	6.0968
I (Solid)	7.6436
D (Solid)	2.3670
P (Liquid)	8.1158
I (Liquid)	6.2945

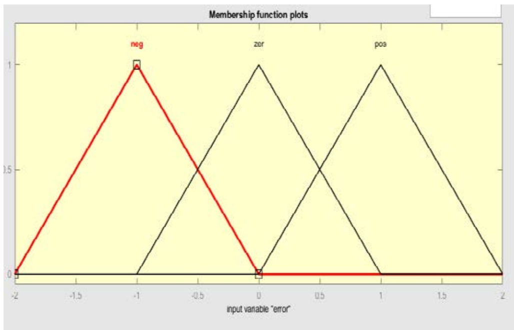

Figure 15: Membership Function for Error

3. IMC Design

Fuzzy Logic IMC (FLIMC)

The Mamdani FIS was also implemented in this case. However, in this case, only one tuning parameter was available which was the filter gain, λ, of the IMC. The FIS comprised on one input (the error) and one output (lambda). The input had a range of -2 to 2 and three triangular membership functions (neg, zer, pos) with values of [-2, -1, 0], [-1, 0, 1] and [0, 1, 2]. The output had a range of 0 to 10 and three membership functions (neg, zer, pos) with values of [0, 25, 4.5], [2.5, 5, 7.5] and [5.5, 8, 10]. The centroid technique was used for defuzzification which provided the crisp output, λ which was in turn used as the filter gain for the IMC. Figure 14 shows the Fuzzy Logic IMC system while Figures 15 and 16 show the membership functions for the input and output.

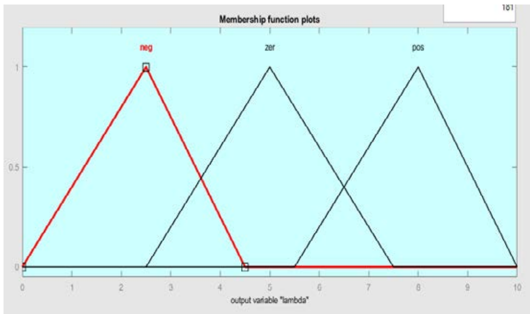

Figure 16: Membership Function for Lambda

The fuzzy rules were designed based the criteria that if the error is large, a smaller λ will reduce rise time and provide a faster recovery. However, a large λ value will improve steady state performance. Figures 17 and 18 show the rule viewer and surface viewer for the FLIMC. The rules obtained shown in table 3.

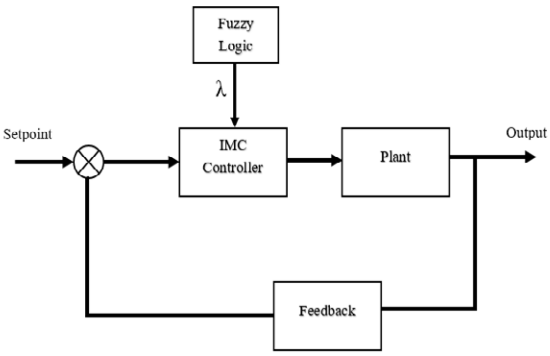

Figure 14: FL-IMC Control System

Table 3: Fuzzy Logic Rules for IMC

Error	Lambda
Neg	Pos
Zer	Zer
Pos	Neg

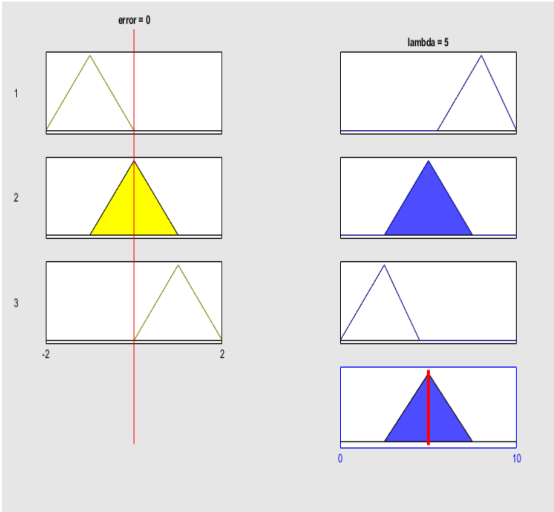

Figure 17: Rule Viewer for FLIMC

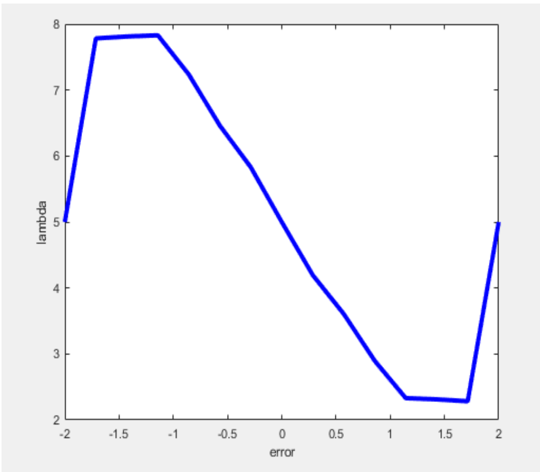

Figure 18: Surface Viewer for FLIMC

After implementation with the FIS, the values of λ for the liquid subsystem and solid subsystem were obtained as 2.3309 and 2.25 respectively.

b. Genetic Algorithm IMC (GAIMC)

Genetic Algorithm was used to tune the IMC filter gain parameter, λ. The GA parameters implemented are the same as in the case of the PID. The filter parameters obtained for the liquid subsystem and solid subsystem were obtained as 3.6965 and 4.5757 respectively. Figure 19 shows the representation of the Genetic Algorithm IMC system.

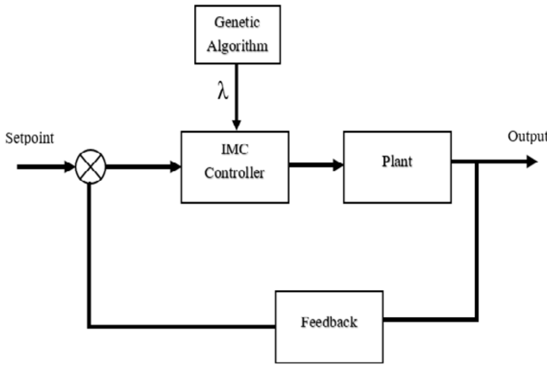

Figure 19: GA-IMC Control System

IV. RESULTS AND DISCUSSION

The system was modelled in SIMULINK (MATLAB R2018b version). Figure 20 shows the SIMULINK model implementation. The closed loop performance of each controller was evaluated based on the rise time, settling time, percentage overshoot and the Integrated Absolute Error (IAE).

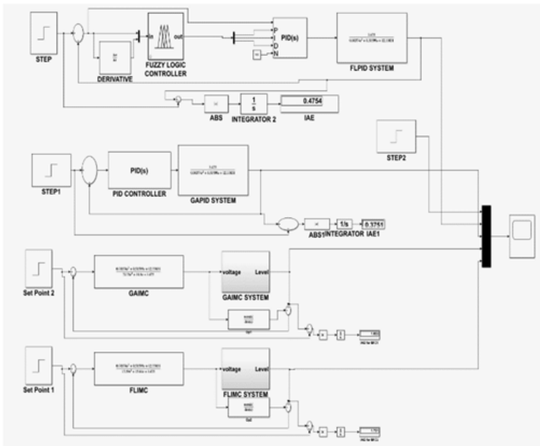

Figure 20: SIMULINK model for all the controllers

Figure 21 presents the system response of the solid subsystem. It shows the output signals of the various control systems in response to a step input. The GAPID gave the lowest rise time with a value of 0.003 seconds, followed by the FLPID which had a value of 1.433 seconds. The GAIMC gave the highest rise time with a value of 15.080 seconds while the FLIMC had a rise time of 7.418 seconds. In the aspect of the settling time, and IAE, a similar trend was observed as the GAPID gave the lowest settling time and IAE with values of 3.325 seconds and 0.4684 respectively. The FLPID had the second lowest settling time and IAE with values of 4.950 seconds and 0.721 respectively. On the other hand, the GAIMC and FLIMC gave the highest settling times with values of 17.856 seconds and 8.785 seconds respectively. The IMCs also had the highest IAEs with the GAIMC giving an IAE of 9.151 and the FLIMC giving an IAE of 4.501. The GAIMC and FLIMC provided a much better performance in the aspect of overshoot as the overshoot values obtained were both 0.505%. However, the FLPID and GAPID gave very high overshoots with values of 50.267% and 32.667% respectively.

Summarily, the GAPID gave the best performance in terms of the rise time, settling time and IAE. It was followed by the FLPID and the GAIMC gave the poorest performance. However, in terms of the overshoot, the GAIMC and FLIMC gave a better performance than both PID controllers. These results indicate that on the chosen system, the GA and FL PID controllers will give a faster response, faster system performance and minimal time delays. However, there is a risk of overshooting which could lead to voltage surges or signal distortions.

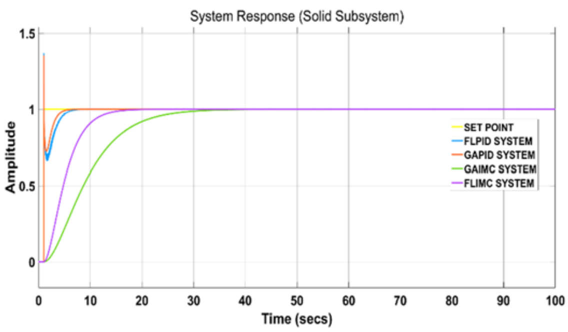

Figure 21: System Response of Solid Subsystem

Figure 22 shows the control signals for the solid subsystem. It highlights the output signals of the various controllers and how the signals attempt to reduce the error (difference between the output and the setpoint). It can be observed that in the cases of all the controllers, the control signals start at very high values to compensate for the large initial errors. However, as the time increases, the amplitudes of the control signals reduce due to a gradual reduction in the error value. Eventually the control signal settles at 0, indicating an absence of error and hence, there is no need for controller action. This shows how the controllers reduce the errors in the system and thus, providing a stable and regulated system performance.

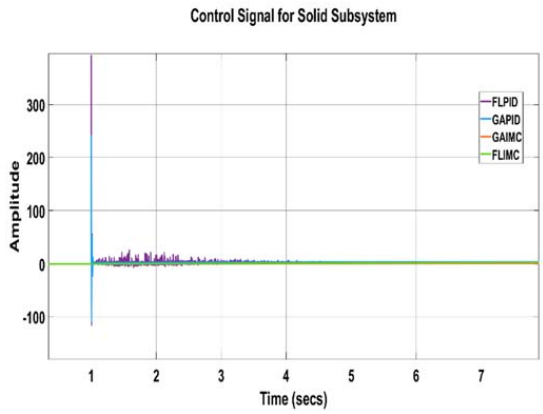

Figure 22: Control Signal for Solid Subsystem

Figure 23 presents the IAEs for the various controllers. It shows the behaviour of the IAE values of the control systems. It can be seen that initially, the IAEs rise rapidly due to the presence of large initial error values. However, as time progresses the IAEs stop increasing and remain steady at their respective points. This is due to the action of the various controllers to minimise the error values of the overall system.

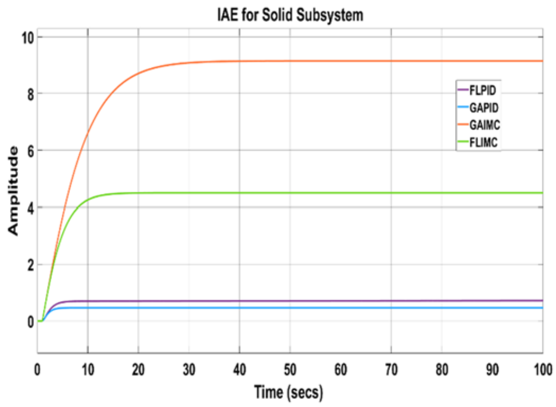

Figure 23: IAE for Solid Subsystem

Figure 24 shows the system response of the liquid subsystem. It shows the output response of the various controllers to a step input. The GAPID gave the lowest rise time with a value of 0.316 seconds, followed by the FLPID which had a value of 0.513 seconds. The GAIMC gave the highest rise time with a value of 7.964 seconds while the FLIMC had a rise time of 5.041 seconds. In the aspect of the settling time, and IAE, the GAPID gave the lowest settling time and IAE with values of 0.459 seconds and 0.026 respectively. The FLPID had the second lowest settling time and IAE with values of 0.654 seconds and 0.038 respectively. On the other hand, the GAIMC and FLIMC gave the highest settling times with values of 11.129 seconds and 7.062 seconds respectively. The IMCs also had the highest IAEs with the GAIMC giving an IAE of 3.696 and the FLIMC giving an IAE of 2.331. The GAIMC and FLIMC provided a slightly better performance in the aspect of overshoot as the overshoot values obtained were 0.495 % and 0.497% for the GAIMC and FLIMC respectively. The FLPID and GAPID gave overshoots with values of 1.531% and 0.505% respectively.

In summary, the GAPID gave the best performance in terms of the rise time, settling time and IAE. It was followed by the FLPID and the GAIMC gave the poorest performance. However, in terms of the overshoot, the GAIMC and FLIMC gave a slightly better performance than the GAPID and FLPID. From these results, it can be seen that the FL and GA PID controllers will give faster performances and system response with low overshoots. This makes the PIDs more suitable for this subsystem as the IMCs have slower responses.

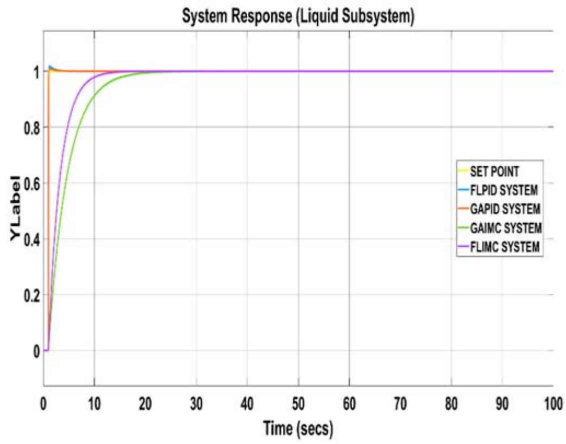

Figure 24: System Response of Liquid Subsystem

In figure 25, the control signals for the liquid subsystem are shown. It highlights the control actions of the various controllers on the liquid subsystem. Similar to the solid subsystem, the initial control signals have large values due to the large initial error values. Eventually, the control signals drop to 0 due to the absence of errors and hence, the absence for the need of controller action.

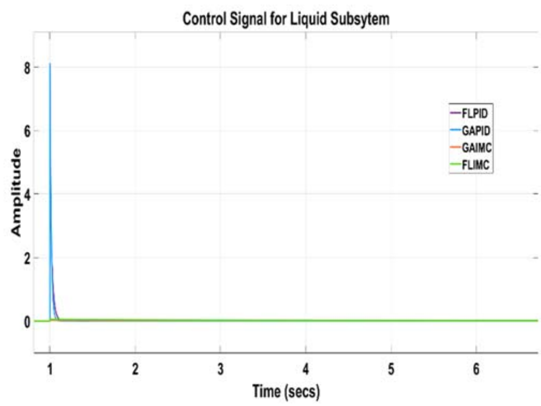

Figure 25: Control Signal for Liquid Subsystem

Figure 26 shows the IAEs for the liquid subsystem. Also, similar to the solid subsystem, IAEs rise rapidly at the initial phase due to the presence of large error values. However, as the time increases and as a result of appropriate controller action, the errors stop increasing and remain steady at the final IAE values.

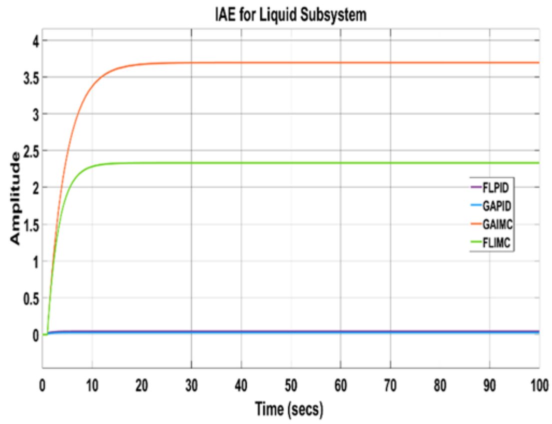

Figure 26: IAE for Liquid Subsystem

A summary of the system response parameters obtained for the solid subsystem and liquid subsystem are shown in tables 4 and 5 respectively.

Table 4: Summary of System Response Parameters from Solid Subsystem

Controller/ System Response Parameter	FLPID	GAPID	FLIMC	GAIMC
Rise Time (Secs)	1.433	0.003	7.418	15.080
Settling Time (Secs)	4.950	3.325	8.785	17.856
Overshoot (%)	50.267	32.667	0.505	0.505
IAE	0.721	0.4684	4.501	9.151

Table 5: Summary of System Response Parameters from Liquid Subsystem

Controller/ System Response Parameter	FLPID	GAPID	FLIMC	GAIMC
Rise Time (Secs)	0.513	0.316	5.041	7.964
Settling Time (Secs)	0.654	0.459	7.062	11.129
Overshoot (%)	1.531	0.505	0.497	0.495
IAE	0.038	0.026	2.331	3.696

V. CONCLUSION AND RECOMMENDATIONS

This study evaluated the performance of IMC and PID controllers tuned with Fuzzy Logic and Genetic Algorithm. From the results presented in tables 4 and 5, the GAPID gave the best performance of all the controllers in terms of rise time, settling time and IAE. The FLPID gave the second best performance. The GAIMC and FLIMC performed better than the PID controllers in the aspect of overshoots. Therefore, for systems in which fast response and low IAE are the major design considerations, the GAPID and FLPID will provide a faster and more accurate performance. However, if the design consideration is to minimize the overshoot, the GAIMC and FLIMC will give the best performance in terms of the overshoot. Future works can attempt to analyse the performance of different artificial intelligent techniques such as neural networks and adaptive neuro fuzzy techniques on control system performance.

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