Performance Evaluation of Mobile Intellligent Poultry Feed Dispensing System Using Internal Model Controller and Optimally Tuned PID Controllers

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ABSTRACT

This paper presents the performance evaluation of a mobile intelligent poultry liquid feed dispensing system by using a Genetic Algorithm (GA) tuned Proportional Integral Derivative (PID) controller, a Particle Swarm Optimization (PSO) tuned PID controller and an Internal Model Controller (IMC). The performances of the various controllers were evaluated using system responses in terms of the transient response as well as the Integral Absolute error. The obtained results showed that the IMC has the least performance as compared to the optimally tuned PID controllers with respect to the rise time, settling time and internal of the Absolute error. However, the IMC proffers a better solution with respect to the zero overshoot. On the overall the PSO Tuned PID controller offers significant performance enhancement to the system, thus ensuring a better and improve return on investment, reduced human involvement as well as improved productivity on the use of the system.

Keywords: PID controller, Particle Swarm Optimization, Genetic Algorithm, Feed Dispensing Internal Model Controller

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1. BACKGROUND TO THE STUDY

Intelligent Systems are systems that mimic and imitate human intelligence through the ability to learn through sensing of the environment they exist in as well as making corresponding decision to stimuli around them via the use of probabilistic principles (Rosenblat, Kneese and Boyd, 2014). According to Sen (2006), all control systems are intelligent to a certain extent, but the more intelligent the system is, the more its ability to handle complex situations and make complex decisions. The behaviour of an intelligent system is determined with the use of an intelligent controller (Meystel and Messina, 2000). Intelligent poultry feed dispensing systems are systems that attempt to replicate the activities of the human poultry farmer by dispensing feed to the poultry birds at specific time intervals (Olaniyi et al., 2015). These intelligent poultry feed dispensing systems are designed to reduce wastage of the feed, reduce the level of human involvement, reduce the contamination of the feed as well as reduce the stress and fatigue associated with monitoring of the poultry birds manually.

A number of intelligent poultry feed dispensing systems exist in literature, however, these systems suffer from instability, long response times and high levels of pulsation (Olaniyi et al., 2016). Due to these reasons, the need arises for the implementation of a control technique that will enhance stability and reduce pulsation, thereby increasing the efficiency of the system. Thus, this paper evaluates the performance of mobile intelligent feed poultry system with two optimally tuned PID controllers (using Genetic Algorithm and Particle Swarm Optimization) and IMC controller in quest to ascertain the level of solution proffered based on aforementioned shortcomings identified in Olaniyi et al., (2016).

The remaining part of the paper is organized into four sections. Section II presents a review of related works on poultry feed dispensing system; the system design considerations putting into consideration the controller design as well as the hardware design of the system are presented in Section III; Section IV presents the results and discussion of the findings. Section V concludes and provides recommendations for future research.

2. REVIEW OF RELATED WORKS

A number of related works exist in literature on the development of intelligent feed dispensing system. Adewumi, (2014) developed an intelligent poultry liquid feed dispensing system using fuzzy logic control Algorithm. Although the system was able to detect the level of the feed and dispense the feed if the level was low, it had limitations such as the inability of dispensing solid feed, immobility and the absence of a mechanism to prevent contamination. In Olaniyi *et al.,* (2014), a mobile intelligent poultry solid and liquid feed dispensing system was designed using fuzzy logic control technique. The system is capable of sensing the feed and water level and dispenses feed and water when the levels were low. But a limitation of this system was that fuzzy logic is not suitable for highly complex systems as it requires a lot of data and expertise to develop fuzzy rules and membership functions (Godil, Shamim, Enam and Qidwai, 2011).

Similarly, Adejumo, (2015) addressed some of the limitations of Adewumi, (2014) by developing a mobile intelligent poultry liquid feed dispensing system using GA tuned PID control technique. This system was mobile and dispensed the liquid feed in a recycling manner to avoid contamination. The results showed that the system had a better performance than the system implemented without a control technique. But the major limitation of this system was that it was not capable of dispensing solid feed. In addition the GA technique used suffers from premature conversion and is not efficient in solving large optimization problems (Jalilvand *et al*, 2011). In Olaniyi et al., (2016), a mobile intelligent poultry feed dispensing system was developed using PSO tuned PID control technique. The system was capable of dispensing both solid and liquid feed and also showed better performance than the system implemented without a control technique.

Based on the aforementioned, this paper attempts to tackle the limitations in Olaniyi et al., (2016) by evaluating the performance of developed intelligent scheme for the tuning of the PID controller parameters using renowned Genetic Algorithm and Particle Swarm Optimization Techniques and as well as the comparison of the result obtained with that obtained from the development of Internal Model Predictive Controller, in quest to ascertain the most efficient and effective controller for the poultry feed dispensing system.

3. SYSTEM DESIGN

In this section, the system overview is presented with detailed description of the system architectural design, the system modelling and as well as the controller design requirements and specifications. The architectural design of the system is as depicted in Figure 1 with the major components and sub-unit of the overall system namely: the Liquid and Solid Trough containment for the feed, the DC motors for the motion, the feeder and Drinker from where the birds collect their feeds, the Embedded Unit which houses the Hardware of the Controller from where all control signal for the control and regulation of the system operation originates from and as well as Power Supply Unit that supplies the required voltage to the system.

Characteristically, the system has the capability of motion within a structured environment and dispensing both solid and liquid feed in course of motion. The system moves forward and backward continuously in the predefined timing manner based on signals received from the on-board controller. This predefined movement helps to ensure no competition and undue struggling amongst the poultry birds whilst trying to feed thus removing the possibility of food wastage. Furthermore, another additive feature of the system to reduce feed wastage is the application of level sensor which enables it to determine the level of the feed in the feeder (Solid and Liquid) before dispensing additional ones into it. However, this work seeks to evaluate the performance of the liquid feed subsystem of the overall system presented in Olaniyi et al. (2016) based on the performance of different types of controllers.

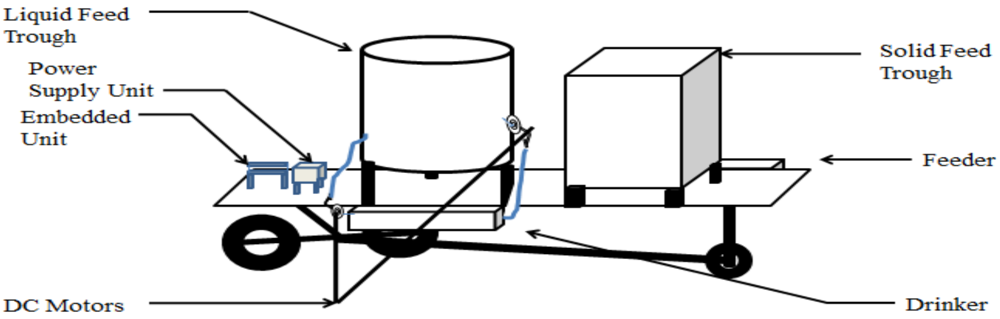

Figure 1: The Mobile Intelligent Feed Dispensing System Overview (Olaniyi et al., (2016))

3.1. System Mathematical Model

The mathematical model of the liquid feed dispensing unit was obtained based on the flow rate of the liquid feed entering and exiting the trough. The model is represented by the transfer function as presented in Olaniyi et al., (2016).

$$G_l(s) = \frac{8.5}{s + 0.07142} \qquad (1)$$

3.2. Controller Design

In this paper, two distinct types of controllers are implemented namely the PID Controller and the Internal Model Controller (IMC) in a bid to evaluate the performance effect on the liquid feed dispensing subsystem. Furthermore, in the determination of the parameters of the PID Controller two different techniques namely the Genetic Algorithm and the Particle Swarm Optimization Techniques were also used in the tuning of the controller parameters.

Thereafter, the output results of the GA-PID, PSO-PID and that of the IMC were compared in order to ascertain the extent of their performance on the system. The details of the controller design are as presented in section 3.2.1.

3.2.1 PID Controller

Conventionally, the Proportional Integral Derivative (PID) controller remains one of the most widely used control algorithm for the control of most industrial systems due to its robustness, reliability, simple structure and ease of tuning (Folorunso et al., 2013). Approximately 95 percent of control systems in the manufacturing industry are designed with this particular controller due to its ease of implementation in digital systems, robustness and cost effective maintenance (Jaen-Cuellar *et al.,* 2013). Furthermore, PID controllers are the optimum choice and perform better than other controllers in many applications (Costa, 2011). Figure 2 shows the PID controller structure.

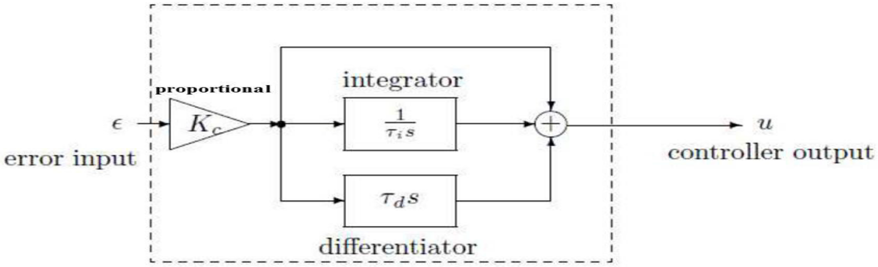

Figure 2: PID Control Structure (Kambiz and Mpanda, (2012))

PID Control has a simple structure and is a linear control methodology which acts directly on the error signal (Jalilvand *et al.*, 2011). It has been considered as a classical output feedback control mechanism for Single-Input-Single-Output systems (Adel, Ltaeif and Abdelkader, 2013). The controller calculates the error signal and adjusts the inputs continuously in an attempt to minimize the error (Costa, 2011).

The PID controller comprises of three elements which are the Proportional term (K_p), the Integral term (K_i) and the Derivative term (K_d). The function of each term is as follows (Kambiz and Mpanda, 2012):

i. **Proportional Gain (K_p):** Provides overall control action proportional to the error signal
ii. **Integral Gain(K_i):** Reduces steady state error through low frequency compensation by an integrator
iii. **Derivative Gain(K_d):** Improves transient response through high frequency compensation by a differentiator

It is required and necessary to tune the PID controllers in order to obtain its optimal parameters namely the proportional gain K_p, the integral gain K_i and the derivative gain K_d. In tuning these parameters there exist a number of applicable techniques such as the Ziegler-Nichols, Cohen-coon, pole placement, Internal Model Control (IMC) methods and Artificial Intelligence Techniques (Genetic Algorithm, Particle Swarm optimization, Firefly Algorithm) (Folorunso et al., 2013).

3.2.2. Genetic Algorithm Tuned PID Controller

Genetic Algorithm (GA) is a general purpose optimization method which is based on the principles of natural selection and genetics (Chandrasekar and Ramana, 2012). The algorithm randomly generates a population, selects individuals from that population to be parents and uses those parents to produce children for subsequent generations. The population thus evolves towards an optimal solution (Peyvandi, Zafarani and Nasr, 2011).

The principles of selection, crossover and mutation are used in the generation of these off springs until convergence or the maximum number of generations is reached (Chandrasekar *et al.,* 2012). The basic flowchart for the operation of the GA algorithm is as depicted in Figure 4.

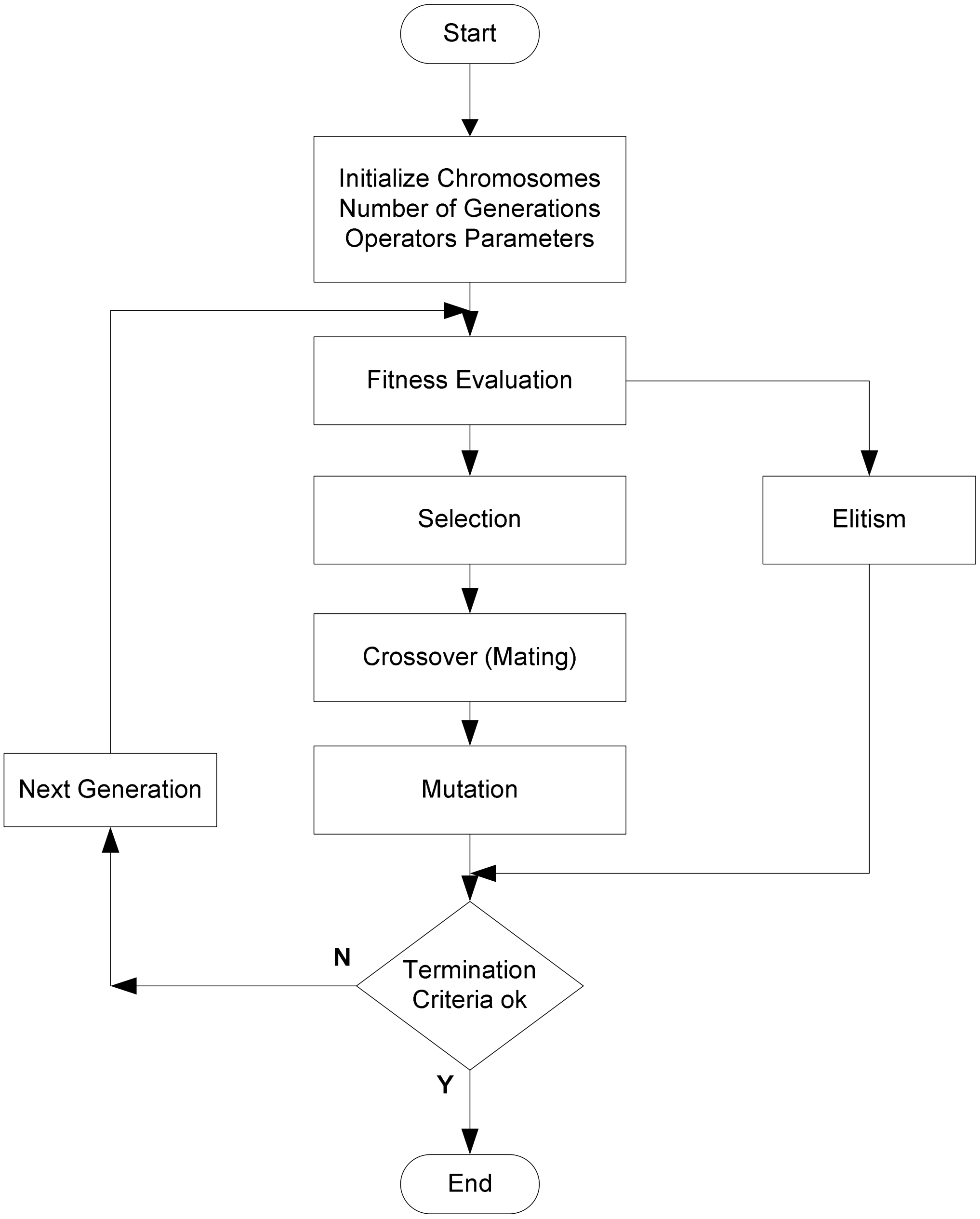

Figure 4: The Basic Genetic Algorithm Flowchart

The parameters of the Genetic Algorithm as well as the obtained PID controller parameters are as presented in Table 1.

Table 1: GA parameters used and PID parameters obtained using GA

S/N	Parameter	Value
1	Population	30
2	Generation	100
3	Crossover Rate	0.9
4	Mutation rate	0.1
5	Obtained Kp	1.554
6	Obtained Ki	0.5230
7	Obtained Kd	0

3.2.3. Particle Swarm Optimization Tuned PID Controller

Particle Swarm Optimization (PSO) is a global optimization method developed by Kennedy and Eberhart in 1995. It is developed from swarm intelligence and is based on the behaviour of bird flocks and fish schools. The PSO algorithm emulates the behaviour of animal groups that have no leaders and hence will find food by random (Bai, 2010; Rini, Shamsuddin and Yuhaniz, 2011). The particles search for food and communicate with one another. While they are searching for food, there is always one particle that has better resource information about where the food source can be located. Hence, through the communication, the particles will eventually converge towards the food source (Hussien, Selamat, Daud and Abidin, 2014). The process of the PSO algorithm to find optimal solutions to problems follows the behaviour of these particles (Rini *et al,* 2011).

PSO has many advantages over other global optimization methods such as fast convergence, simplicity and the ability to drive nonlinear plants and high order systems (Jaafar, Mohamed, Jamian, Aras, Kassim and Sulaima, 2014). The parameters of the PID controller were obtained using Particle Swarm Optimization. The PSO parameters as well as the obtained PID parameters are shown in Table 2.

Table 2: PSO parameters used and PID parameters obtained using PSO

S/N	**Parameter**	**Value**
1	Swarm Size	100
2	Number of Iterations	50
3	Acceleration Coefficients (C1 and C2)	2
4	Inertia Weight	0.9
5	Obtained K_p	1.5825
6	Obtained K_i	0.2278
7	Obtained K_d	0.0536

3.2.4. Internal Model Controller (IMC)

The IMC is a class of the model Predictive controllers and it is an effective method of control with limited computational requirements. It adopts a process model for feedback control and inverts part of the model used as a controller for the process (Folorunso et al., 2013). However, some parts of the model such as the right half pane and delay are not invertible. In such cases, linear filters are often included and tuning of the filter determines the performance of the IMC (Olaniyi et al., 2015). The structure of the IMC controller block diagram is as depicted in Figure 5, where $G_m(s)$ is the Model Process, $G_p(s)$ is the Plant Model and $G_{IMC}(s)$ represents the IMC controller.

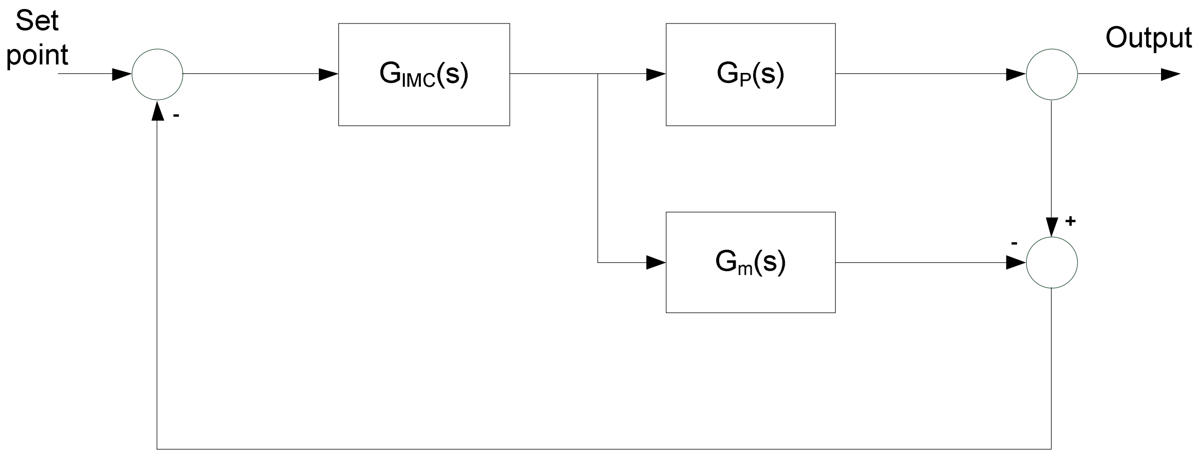

Figure 5: The IMC controller structure

From the system model shown in equation (1), the process transfer function $G_p(s)$ is given by:

$$G_p(s) = \frac{8.5}{s + 0.07142} \qquad (4)$$

Therefore the model process $G_m(s)$ is equal to the process transfer function $G_p(s)$. Factorizing the model process $G_m(s)$ into invertible and non-invertible parts,

$$G_m(s) = G_m^+(s) * G_m^-(s) \qquad (5)$$

Eliminating the non-invertible part $G_m^+(s)$ as it will lead to instability and realization issues if inverted, and taking into consideration only the invertible part $G_m^-(s)$ which is stable and causal.

We set the controller $G_C(s)$ to be equal to the inverse of the invertible part.

$$G_C(s) = [G_m^-(s)]^{-1} = s + 0.07142 \qquad (6)$$

Then $G_{IMC}(s) = G_C(s) * G_f(s)$, where $G_f(s)$ is a low pass filter of appropriate order.

$$G_f(s) = \frac{1}{[\lambda_f s+1]^n} \qquad (7)$$

Where λ_f the filter parameter and n is the order of the filter

$$G_{IMC}(s) = G_C(s) * G_f(s) \qquad (8)$$

$$G_{IMC}(s) = [S + 0.07142] * \frac{1}{[\lambda_f s+1]^n} \qquad (9)$$

The order of the filter *n* is selected to be equal to 1, because the order of the process model is 1. This is to prevent excessive differential control action. As a rule of thumb the filter parameter λ_f is selected to be at least twice as fast as the open loop response of the process model $G_p(s)$. Using this as an initial value for the filter parameter and continuously tuning, a desirable optimal response was obtained at λ_f =3.

Thus the G_{IMC} is given as

$$G_{IMC}(s) = \frac{s+0.07142}{3s+1} \qquad (10)$$

4. RESULTS AND DISCUSSIONS

The developed closed loop controller model using Matlab/Simulink for the IMC Controller, the PSO tuned PID as well as GA tuned PID is as depicted in Figure 6. The output from each of the controller subunit is fed into Graphic scope 7 to display the combinatory response output of all three controllers.

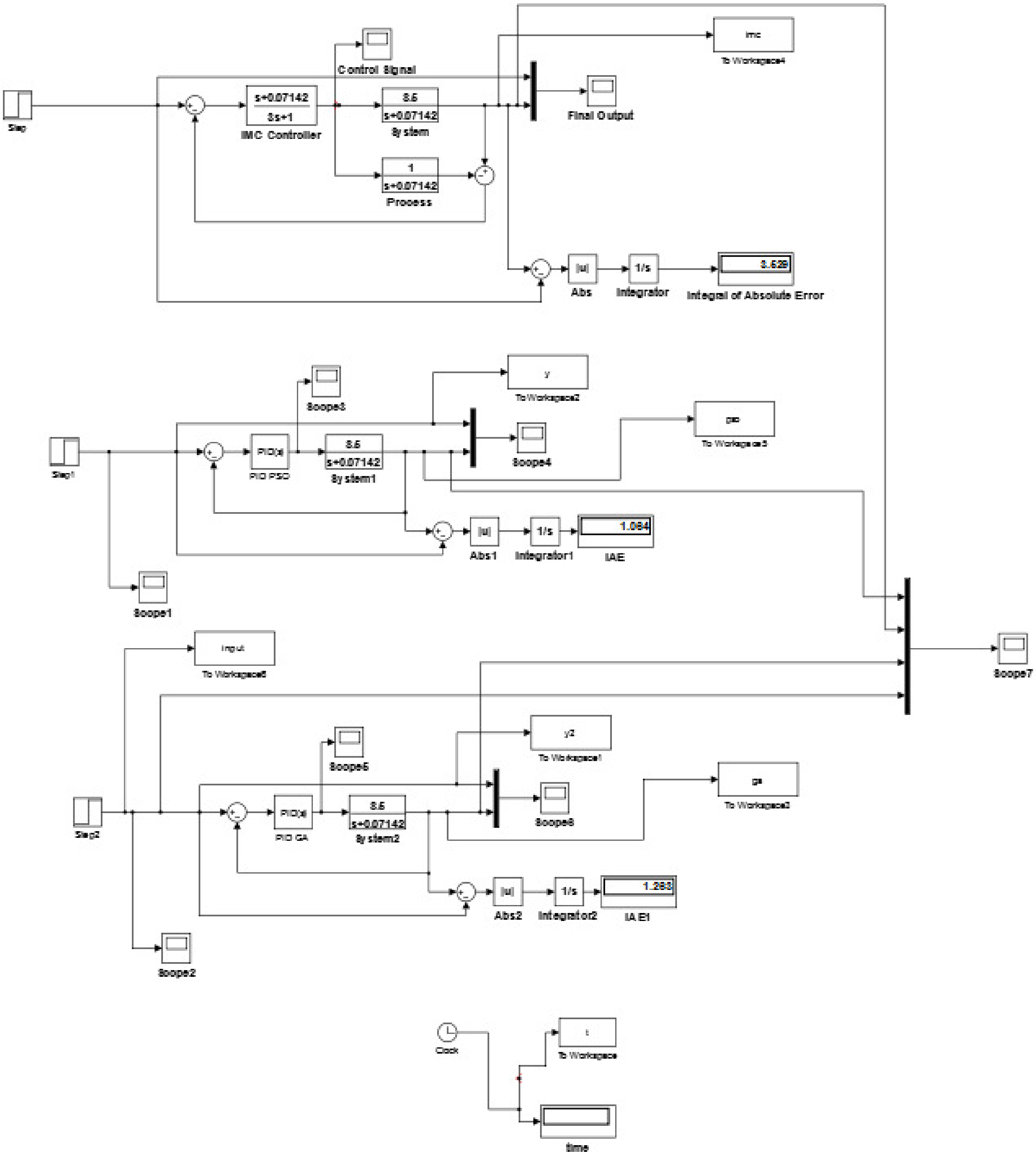

Figure 6: Simulink Block of the Controller Design

The Figures 7,8 9, 10 and 11 show the Open Loop response of the system, the response of the system using a PSO tuned PID controller, the response of the GA tuned PID , the response of the IMC controller and the combined responses of all controllers respectively. In Figure 7, the open loop response of the system indicated the need for a compensation/Controller for the system. The output response is considerable larger than the input to the system and the settling time of the response is too large hence the need for the introduction of the controllers. With the inclusion of the controllers as depicted in Figures 8, 9 and 10, it is observed that an improved performance was achieved with the system output response with respect to the transient response of the system.

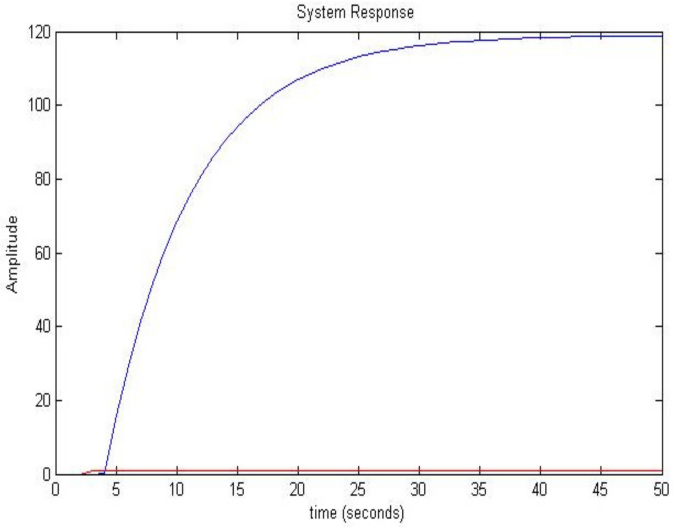

Figure 7: Open Loop Response of the System

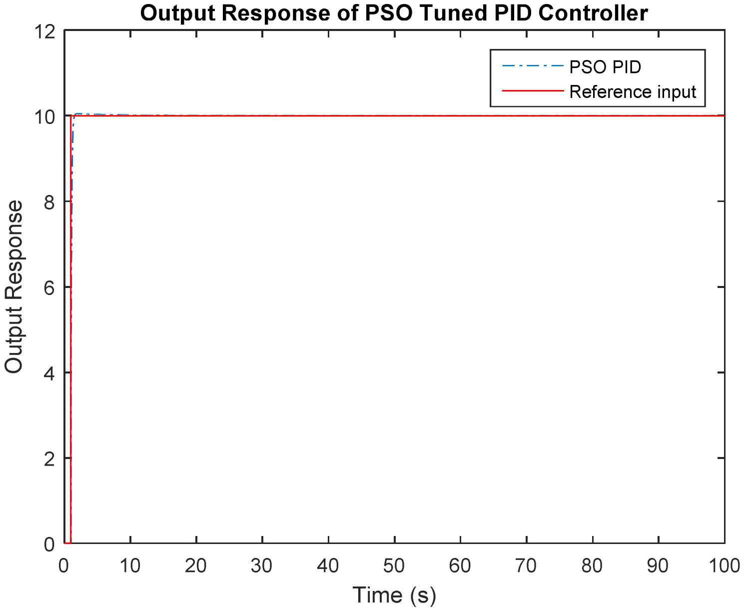

Figure 8: System Response of the PSO tuned PID controller

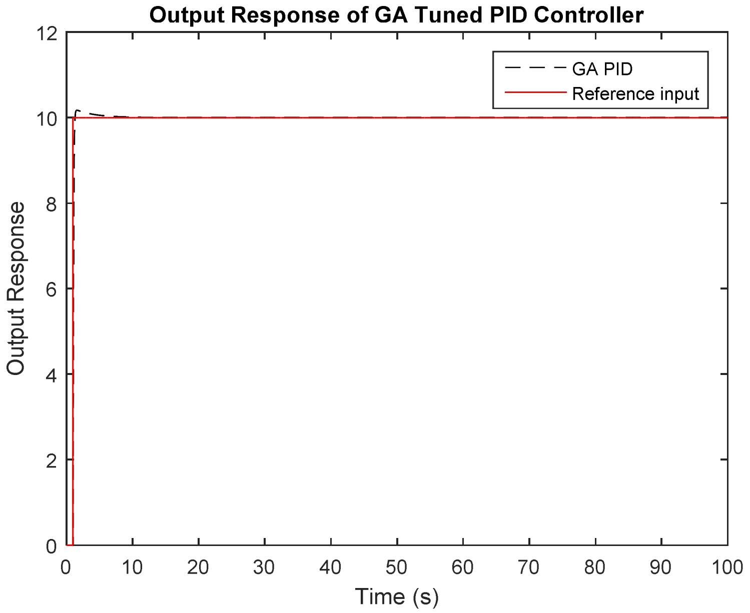

Figure 9: System Response of the GA tuned PID controller

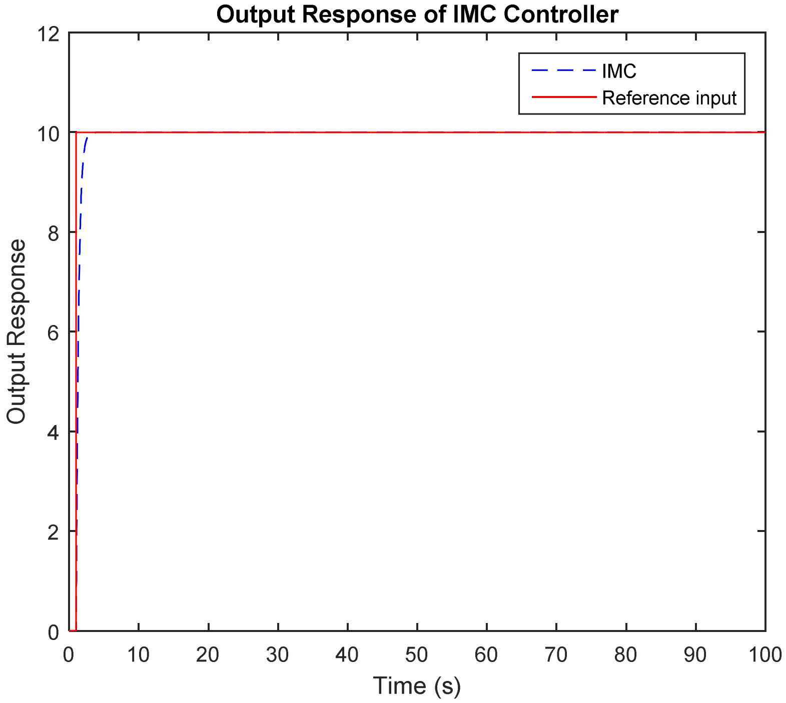

Figure 10: System Response of IMC

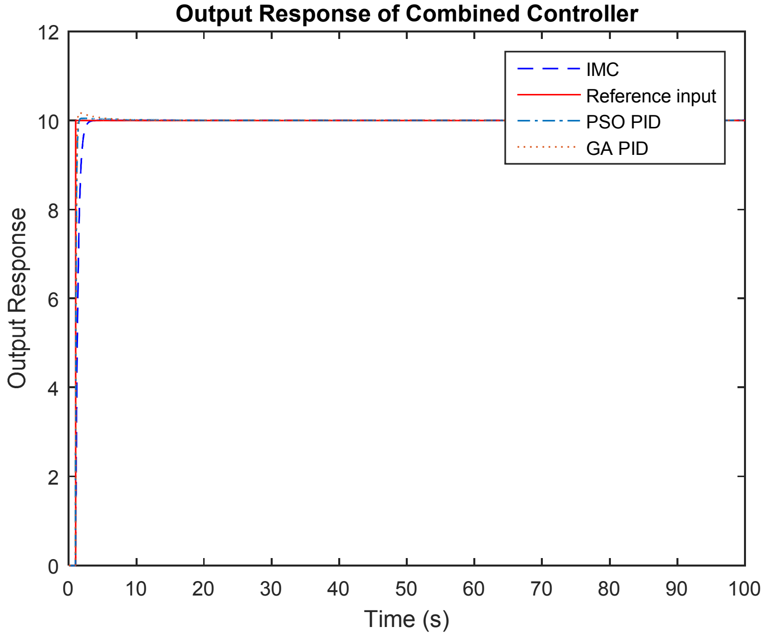

Figure 11: System Response of the combined controllers

The summary of the performance evaluation of the system with respect to the three controllers are as presented in Table 3, which indicated that the PSO-PID has the fastest rise time next to the GA-PID with the IMC having the lowest rise time. However, the GA-PID and the PSO-PID suffers some setback against the IMC in terms of overshoot with an overshoot of 2% and 0.5% respectively. Furthermore, the PSO-PID has the fastest settling time in comparison with others and the IMC having the slowest; however, all controllers have enjoyed a zero steady state error. In a like manner, a further analysis and comparison of the controller using the Integral of the Absolute Error (IAE) indicated that the IMC controller has the poorest performance next to GA-PID and the PSO-PID having the best performance. Thus based on the obtained result the PSO-PID offers considerable good performance over the IMC and the GA-PID Controllers.

Table 3: Summary of the performance of all the controllers

	GA-PID	PSO-PID	IMC
Rise Time(sec) Tr	0.25	0.2	0.8
Settling Time(sec) Ts	2.5	1.45	2.8
Over Shoot (%)	2	0.5	0
Steady Error ess	0	0	0
Integral Absolute Error (IAE)	1.263	1.064	3.529

5. CONCLUSION AND FUTURE WORK

This study successfully compares the performance of a mobile intelligent poultry liquid feed dispensing system using the PSO tuned PID, GA tuned PID and an IMC model predictive controller .The performances of the system against each controller were evaluated in terms of the transient response and Integral of the Absolute Error. The results showed that the system exhibited an undesirable response when implemented without a control technique. This response was enhanced with the implemented controllers, with the PSO tuned PID having the best performance in terms of the transient response and the IAE aside the 0.5% overshoot, and next was the GA tuned PID and lastly, the IMC controller. The mobile intelligent poultry feed dispensing system tuned with PSO PID controller will greatly reduce the workload of the average poultry farmer by reducing cost, wastage, contamination and fatigue. Furthermore, if implemented with a suitable control technique, the poultry feed dispensing system will be highly efficient in carrying out the specified task.

Although the developed system addresses some limitations in previous works, the system can be improved in the following ways:

a) The use of hybrid intelligent techniques by combining two or more intelligent techniques such as GA-PSO and Fuzzy-GA in order to improve the system performance.
b) The incorporation of a power management system to control the use of power as well as make optimal and efficient energy consumption.
c) The system can be developed to operate in an unstructured environment and incorporate mechanisms to detect and avoid obstructions.

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