

Towards The Development of a Mobile Intelligent Poultry Feed Dispensing System Using Particle Swarm Optimized PID Control Technique

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ABSTRACT

The manual pattern of feeding of poultry birds incurs an exorbitant cost on poultry farming. This pattern of feeding which is predominant in the tropics gives a low return on investment, low yield and low profit. These shortcomings are as a result of contamination of the poultry feed, wastage of the feed, fatigue and stress involved with monitoring of the birds and administration of the feed. Hence, there is a need for a system which is capable of addressing these limitations. This study proposes the design of a mobile intelligent poultry feed dispensing system using Particle Swarm Optimized PID control technique. The system will be capable of moving from one point to another within a deep litter poultry house, as well as dispense both solid and liquid feed to poultry birds at specific time intervals. The system shall be intelligent with a Proportional-Integral-Derivative (PID) controller tuned with the Particle Swarm Optimization algorithm in order to increase the performance of the system. The successful development of the anticipated intelligent poultry feeding system is expected to reduce human intervention, increase yield and profit as well as provides high return on investment in poultry farming.

Keywords: PID Controller, Particle Swarm Optimization, Microcontroller, Precision Livestock Farming, Dispensing

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1. BACKGROUND TO THE STUDY

The application of the principle of process engineering to intensive and extensive livestock management is referred to as Precision Livestock Farming (PLF) [1]. In PLF, the potential of Information and Communication Technology (ICT) is utilized to assist farmers to automatically monitor animals onsite and remotely. This in turn improves production efficiency, increases animal and human welfare using appropriate hardware and necessary software techniques [2]. The application of PLF to poultry feeding has provided tremendous benefits from literature for improved production efficiency of chicken, geese, guinea fowls and most importantly, improved techniques of rearing of birds [3]. The poultry industry contributes immensely to the development of the Nigerian economy as it serves as a major source of egg and meat which have a high nutritional value in the supply of protein. There are mainly four management systems employed in the rearing of poultry birds which are the Free Range system, Battery Cage system, Deep Litter system and Perchery houses [4]. In the free range system, birds are kept in an open space and fed manually. Some of the shortcomings of this method are missing of some birds and lot of human involvement [5]. In the Battery Cage system, the birds are kept in individual cage compartments in a large controlled environment [6]. The major challenge of this method is that it is very expensive to implement and there is a high risk of

disease outbreak and cannibalism [7]. In the case of the Deep Litter system, the birds are kept in a building with leaves, saw dust, dry grasses or straw on the floor. The birds are allowed to move freely within the building. This method reduces the level of worm infection and provides protection for the birds against predators [5].

Poultry farmers in Nigeria encounter many problems such as contamination of the feed, wastage, high level of human involvement and stress of constant monitoring of the poultry birds. Some of these problems are tackled by increasing the work force on the farm or individually monitoring the birds but these are stressful and expensive to implement. Due to the limitations outlined, there is a need to develop an intelligent mobile system that will dispense both solid and liquid feed to the birds as well as control the amount of feed that is dispensed to poultry birds in poultry farms. A number of related works exists in literature. Authors in [8] designed and constructed a computer controlled poultry feed dispenser and temperature regulator. The system was made up of a dispenser which was capable of communicating with a computer via a parallel port. The system was also capable of dispensing feed at specific time intervals. But some of the limitations of the system were that it was not sensitive to obstructions, there was a high cost of maintenance and the system was affected by long distances due to the parallel port connection.

Furthermore, in [3] a mobile intelligent poultry feed dispensing system was developed which was able to move, detect and avoid obstructions and dispense solid feed to poultry birds. But some of the limitations of the system were that it could not dispense liquid feed and the solid feed dispensed was sometimes too large for the chicks to feed on. Similarly in [9], a mobile intelligent poultry feed and water 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 some of the limitations of this system were that it was not mobile and 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 [10].

In addition, [11] developed an intelligent poultry liquid feed dispensing system using fuzzy to address the limitations of [3]. 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. The author in [5] addressed some of the limitations of [11] by developing a mobile intelligent poultry liquid feed dispensing system using Genetic Algorithm (GA) tuned PID control technique. This system was mobile and dispensed the liquid feed in a recycling manner to avoid contamination. But the major limitation of this system was that it was not capable of dispensing solid feed. In addition the GA characteristics suffer from premature convergence and are not efficient in solving large optimization problems [12]. In this paper, we propose to design a mobile intelligent poultry feed dispensing system using Particle Swarm Optimized PID control technique as anticipated in [13]. The system shall be capable of moving from one point to another within a deep litter poultry house and dispenses both solid and liquid feed to poultry birds at specific time intervals. The system is made intelligent with a Proportional-Integral-Derivative (PID) controller tuned with the Particle Swarm Optimization algorithm in order to increase the performance of the system. The PSO algorithm will be implemented based on its characteristics which include the swarm size, acceleration coefficients and inertia weight.

The remaining part of the paper is organized into four sections. Section 2 presents a brief overview of Particle Swarm Optimization (PSO) and rationale for optimizing anticipated system with PSO; The PID control and rationale for PID in our system are briefly discussed in Section 3; Section 4 presents mechanical, hardware and software design consideration of the anticipated intelligent mechatronic poultry feeding system. Section 5 concludes our proposition and our plan towards final development of the anticipated intelligent system.

2. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is a global optimization method developed by Kennedy and Eberhart in 1995. It is developed from swarm intelligence and 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 [14] [15]. 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 [16]. The process of the PSO algorithm to find optimal solutions to problems follows the behaviour of these particles [15]. PSO has been applied in a number of areas such as gantry crane systems, dynamic first order systems and magnetic levitation systems [17].

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 [18].

The PSO algorithm is given as follows [19]:

1. Randomly initialize particle positions and velocities
2. While not terminate
 - a. For each particle i :
 - i. Evaluate fitness y_i at current position x_i
 - ii. If y_i is better than $pbest_i$ then update $pbest_i$ and p_i
 - iii. If y_i is better than $gbest_i$ then update $gbest_i$ and g_i

- b. For each particle i

Update velocity v_i and position x_i using:

$$v_i = v_i + U(0, \phi_1)(p_i - x_i) + U(0, \phi_2)(g_i - x_i) \quad (1)$$

(1)

$$x_i = x_i + v_i \quad (2)$$

For each particle i :

- x_i is a vector denoting its position
- v_i is the vector denoting its velocity
- y_i denotes the fitness score of x_i
- p_i is the best position that it has found so far
- $pbest_i$ denotes the fitness of p_i
- g_i is the best position that has been found so far in its neighbourhood
- $gbest_i$ denotes the fitness of g_i
- $U(0, \phi_i)$ is a random vector uniformly distributed in $[0, \phi_i]$ generated at each generation for each particle.
- ϕ_1 and ϕ_2 are the acceleration coefficients determining the scale of the forces in the direction of p_i and g_i [19]

2.1 Rationale for PSO for Controller Optimization

Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) techniques are popular optimization techniques in Controller tuning but PSO has numerous advantages over GA. PSO is simple and has fewer parameters to adjust compared to GA. The calculation complexities of mutation, selection and cross over in GA are absent in PSO and hence, PSO calculations can be completed easily and faster [14]. PSO also has an effective memory capability and can adapt to changes in an environment [20]. Other advantages of PSO are that it can be applied to both scientific and engineering research and it occupies bigger optimization ability [15].

In literature, a number of related works in have been reported in the area of PID Controller tuning with PSO. In [16], PSO was used to tune the PID controller for a coupled tank system. The study showed that the PSO tuned PID controller exhibited better performance than the PID controller that was tuned using classical techniques. Authors in [21] carried out a study on the comparison of PI controller tuning using GA and PSO for a multivariable experimental four tank system. The system compared the performance of decentralized GA and PSO tuned PI controllers. The results showed that the PSO tuned PI controller showed better performance and robustness in both servo and regulatory responses. Also in [22], a study on PID controllers tuning optimization with PSO algorithm for nonlinear gantry crane system was carried out. The results of the study showed that the PSO tuned PID controllers were effective in moving the trolley and the length of the rope as fast as possible and with low payload oscillation.

These competitive performance advantages of PSO compare to GA accounted for further tuning of the Poultry feed dispensing system's PID Control with Particle Swarm Optimization (PSO) technique as anticipated in [13].

3. PID CONTROLLERS

The Proportional-Integral-Derivative (PID) controller is a closed loop controller and is one of the most widely used controllers in industrial applications. 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 [23]. Furthermore, PID controllers are the optimum choice and perform better than other controllers in many applications [24]. PID Control has a simple structure and is a linear control methodology which acts directly on the error signal [12]. It has been considered as a classical output feedback control mechanism for Single-Input-Single-Output systems [25]. The controller calculates the error signal and adjusts the inputs continuously in an attempt to minimize the error [24]. The efficacy of the PID controller lies in the tuning technique used in determining its parameters [26].

The PID controller shown in Figure 1 comprises of three elements which are the Proportional term (K_p), the Integral term (K_i) and the Derivative term (K_d). Equation (3) shows the transfer function for a PID controller [27].

The function of each term is defined as follows:

- Proportional Gain (K_p):** Provides overall control action proportional to the error signal
- Integral Gain (K_i):** Reduces steady state error through low frequency compensation by an integrator
- Derivative Gain (K_d):** Improves transient response through high frequency compensation by a differentiator [27]

$$G_{PID}(S) = K_p + \frac{K_i}{s} + K_d S \quad (3)$$

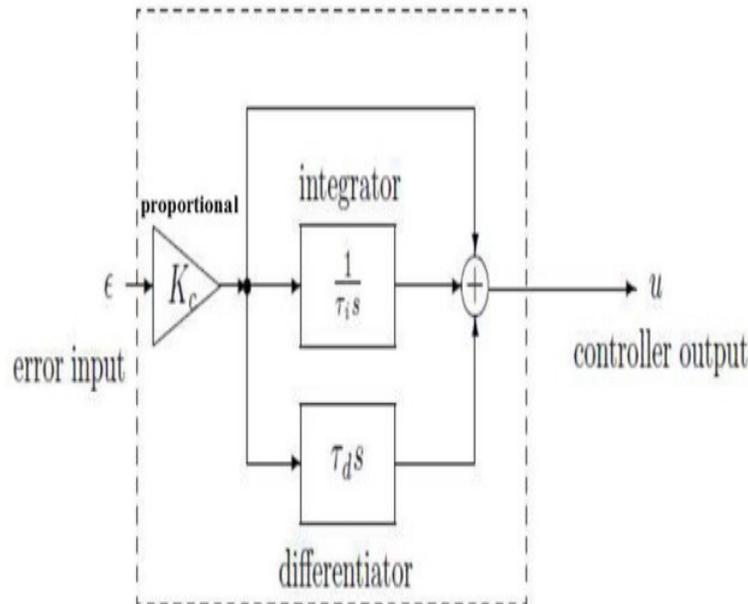


Figure 1: A PID Control System [27].

3.1 Rationale for Intelligent PID Controller in the system design

PID Control by convention is a linear control methodology which acts directly on the error signal [12]. It has been considered as a classical output feedback control mechanism for Single-Input-Single-Output systems [25]. The PID controller calculates the error signal and attempts to minimize the error by adjusting the inputs continuously [24]. In order to achieve the desired performance, the three parameters (K_p , K_i and K_d) of the PID controller need to be tuned. Tuning of the PID parameters involves adjusting the proportional, integral and derivatives gains in order to make the output of the control system track a target value efficiently [25]. The tuning methods of the PID controller are mainly classified into Traditional tuning techniques and intelligent tuning techniques [12]. Tuning PID parameters is very crucial in finding the optimal parameters that will give satisfactory results [17].

Traditional methods of tuning PID controllers are easy but satisfactory results are not usually obtained. Due to the difficulty in finding optimal PID parameter values, researchers have been using other intelligent methods to find the most appropriate value for those parameters [22]. Furthermore, tuning methods in which the proportional, integral and derivative gains are fixed have the disadvantage of lacking capability and flexibility [28]. Moreover, the intelligent tuning technique allows for online tuning of the parameters and flexibility of the parameters. This accounted for intelligent tuning of the anticipated feed dispensing system intelligent optimization technique with Particle Swarm Optimization.

4. SYSTEM DESIGN

This section describes the methodology and materials used in the design of the proposed mobile intelligent poultry feed dispensing system.

4.1 Proposed System Overview

The mobile intelligent poultry feed dispensing system consists of various parts which include the wheels, troughs, feeder, drinker, DC motor, DC liquid pump, Arduino Mega 2560 microcontroller, a feed conveyor and the liquid feed hose. The Arduino Mega 2560 is the controller of the system. It ensures that the design requirements of the system are met at all times. The system is designed in such a way that the solid feed trough will be filled with the solid feed and the liquid feed trough will be filled with the liquid feed. A power button will be pressed and the system will move forward. The system will then dispense the solid feed to the feeder for ten seconds and dispense the liquid feed to the drinker for five seconds. The time of dispensing of the feed is selected based on the rate at which the DC motor and DC pump dispense the feed to the feeder and drinker respectively. The system will then wait for the poultry birds to feed from the feeder and drinker before moving forward again to a new location. The system has a feed level sensor for the solid feed. This is designed so as to reduce the rate of wastage of the feed. In addition, the system has a mechanism of recycling the liquid feed after the feeding time has elapsed. This is done so as to reduce the rate of contamination and wastage of the feed. Figure 2 shows an overview of the proposed system while Figure 3 shows a block diagram of the proposed system.

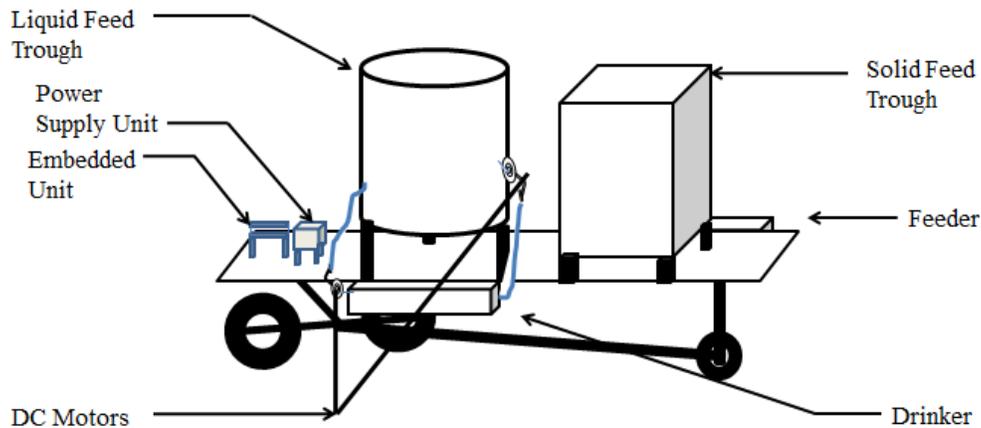


Figure 2: Overview of the mobile intelligent feed dispensing system

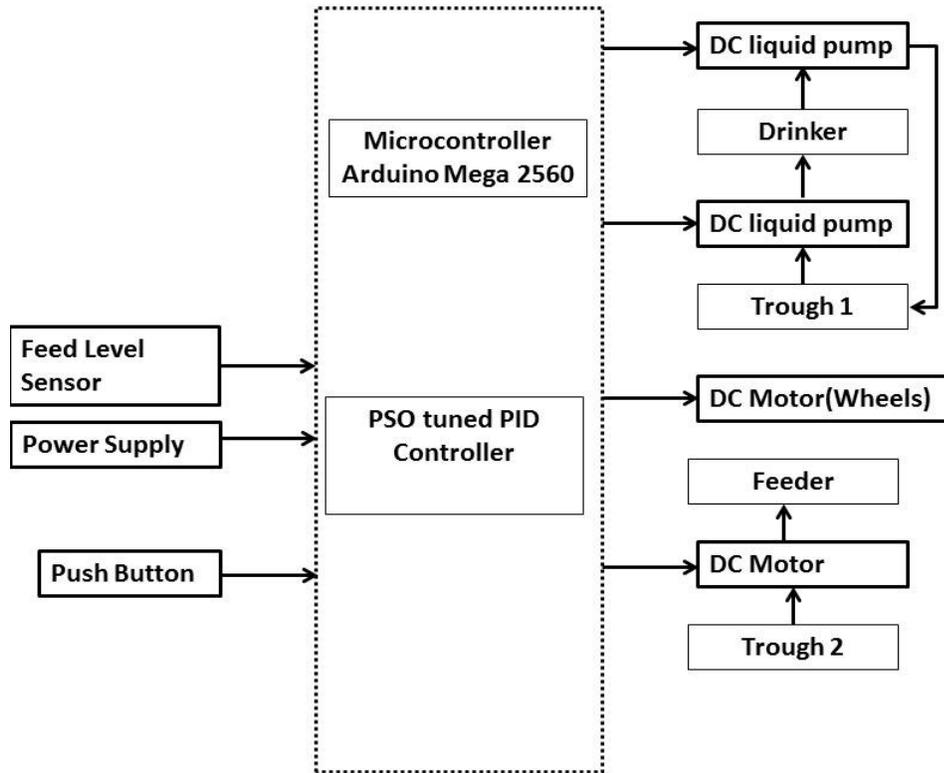


Figure 3: Block Diagram of the mobile intelligent poultry feed dispensing system

4.2 System Hardware Design Considerations

The dispensing system is design to be controlled by an Arduino 2560 microcontroller board (PID Controller) for cost and flexibility reasons. The system shall consist of a mechanical unit which comprises of DC motors for the movement of the system from one point to another at specific time intervals and also for the dispensing of the solid feed. The system also shall comprise of DC pumps for dispensing of the liquid feed. The system shall be powered by a 12V DC battery which shall be regulated to 5V using the LM7805 voltage regulator in order to power the microcontroller. The system shall also comprise of feed sensing unit which shall be implemented with a Sensor (Light Dependent Resistor) in order to determine the level of the solid feed before it is dispensed to avoid wastage of solid feeds.

4.2.1 System Mathematical Modelling

The system in Figure 2 can be modelled as Figure 4. Figure 4 consists of PID controller connected in series with two parallel subsystems (the solid and liquid feed). The subsystems represent the solid feed dispensing unit and the liquid feed dispensing unit. In order to obtain a transfer function of the whole system, the transfer functions of both the solid feed dispensing unit and the liquid feed dispensing unit need to be obtained separately. Figure 5 shows the block representation of the liquid feed of the system.

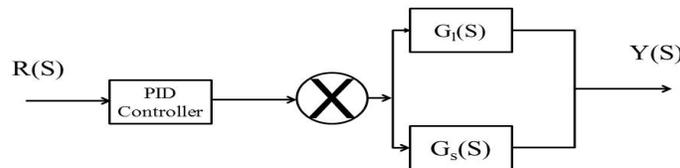


Figure 4: Block representation of the system model in Figure 2.

Where,

- $G_l(s)$ is the Liquid fed dispensing unit and
- $G_s(s)$ is the Solid Feed Dispensing Unit.

a. Liquid Subsystem Modelling

The liquid feed trough model was obtained based on the flow rate of the liquid feed entering the trough and the flow rate of the liquid feed exiting the trough. The flow rate of the feed entering the trough is denoted as F_{in} while the flow rate of the feed exiting the trough is denoted as F_{out} . The height of the trough is denoted as h . The liquid subsystem is assumed to be cylindrical, hence the use of the cylindrical shape.

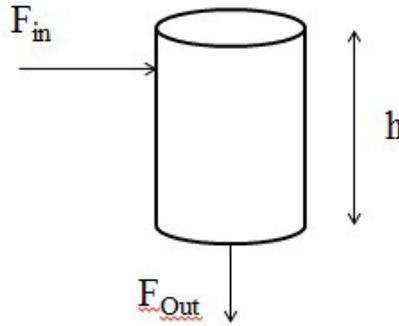


Figure 5: Model diagram of the liquid feed trough

Where:

F_{in} = Rate of flow into the container (inflow)

F_{out} = Rate of flow out of the container (outflow)

h = height of container

The volumetric flow rate of a liquid is given as:

$$\text{Flow Rate} = \frac{dv}{dt} \quad (4)$$

The volume of the container is:

$$\text{Vol} = \pi r^2 h = Ah \quad (5)$$

$$\text{Hence, } \frac{dv}{dt} = A \frac{dh}{dt}$$

$$\text{Also, } A \frac{dh}{dt} = F_{in} - F_{out} \quad (6)$$

The flow rate of the liquid feed entering the trough is directly proportional to the applied voltage. On the other hand, the flow rate of the liquid feed exiting the trough is directly proportional to the height of the trough.

In-flow is proportional to the applied voltage,

$$\begin{aligned} F_{in} &\propto V \\ F_{in} &= K_1 V \end{aligned} \quad (7)$$

Out-flow is proportional to the height of the container,

$$\begin{aligned} F_{out} &\propto h \\ F_{out} &= K_2 h \end{aligned} \quad (8)$$

$$\text{Since, } A \frac{dh}{dt} = F_{in} - F_{out}$$

$$A \frac{dh}{dt} = K_1 V - K_2 V$$

Therefore,

$$\frac{dh}{dt} = \frac{K_1 V}{A} - \frac{K_2 h}{A}$$

$$\frac{dh}{dt} = \left(\frac{K_1}{A}\right)V - \left(\frac{K_2}{A}\right)h$$

Using Laplace Transforms:

$$SH = \left(\frac{K_1}{A}\right)V - \left(\frac{K_2}{A}\right)H \tag{9}$$

$$SH + \left(\frac{K_2}{A}\right)H = \left(\frac{K_1}{A}\right)V$$

$$H\left(s + \frac{K_2}{A}\right) = \left(\frac{K_1}{A}\right)V$$

$$\frac{H}{V} = \frac{\frac{K_1}{A}}{s + \frac{K_2}{A}} \tag{10}$$

The following parameters are obtained based on the area of the proposed liquid feed trough and the proposed DC liquid pumps to be used for the liquid feed dispensing unit

Table 1: Parameters

Parameter	Value
A (Area of Container)	1256cm ²
K ₁ (Flow Constant)	10676
K ₂ (Flow Constant)	89.7

Substituting into equation (10), we have;

$$G_1(s) = \frac{0.008}{s + 0.07142} \tag{11}$$

b. Solid Feed subsystem

The solid feed trough model was obtained based on the electrical input which is the applied voltage and the mechanical output which is the angular velocity of the DC motor as shown in Figure 6. The velocity of the motor determines the rate of dispensing of the solid feed. Unlike the liquid feed model, the dispensing rate does not depend on the height of the solid feed trough.

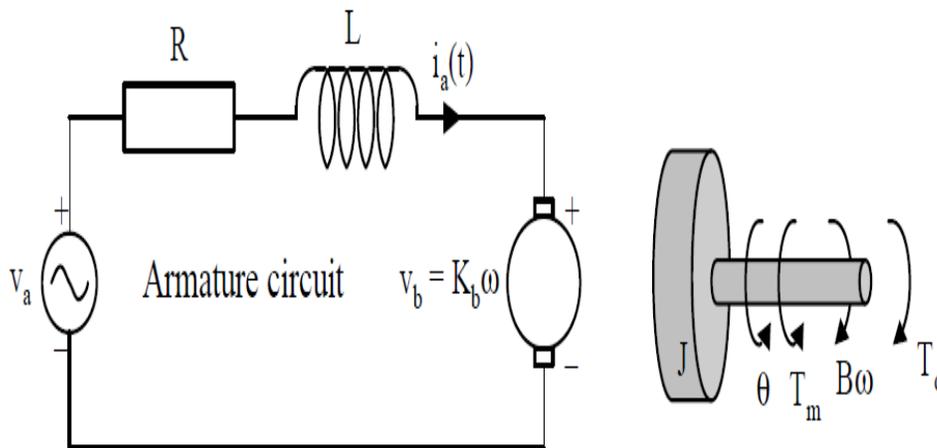


Figure 6: Model diagram of the solid feed trough of the dispenser

Where:

$i_a(t)$ = Armature current

R = Armature resistance

L = Armature inductance

v_b = Back EMF

T_m = Motor Torque

v_a = Applied voltage

J = Rotor inertia

ω = Angular Velocity

B = Viscous friction co-efficient

K_t = Torque Constant

K_b = Back EMF constant

θ = Angular displacement

T_d = Disturbance Torque

For the Electrical Circuit, the sum of voltage drops is given as:

$$i_a(t)R + L \frac{di_a(t)}{dt} + v_b(t) = v_a(t)$$

Transforming into Laplace, we have:

$$I_a(s)R + LSI_a(s) + V_b(s) = V_a(s) \quad (12)$$

The torque – armature current relationship is given as:

$$T_m(t) = k_t i_a(t)$$

Transforming into Laplace, we have:

$$T_m(s) = k_t I_a(s) \quad (13)$$

As for the Mechanical Circuit,

$$T_m(t) = J \frac{d\omega(t)}{dt} + B\omega(t)$$

Transforming into Laplace, we have:

$$T_m(s) = JS\Omega(s) + B\Omega(s) \quad (14)$$

The back EMF – angular velocity relationship is given as:

$$v_b = k_b \omega(t)$$

Transforming into Laplace, we have:

$$V_b = k_b \Omega(s) \quad (15)$$

Substituting the value of I_a in equation (11) for I_a in equation (10), we have:

$$\begin{aligned} \frac{T_m(s)}{k_t} R + LS \frac{T_m(s)}{k_t} + V_b(s) &= V_a(s) \\ \frac{T_m(s)R + LST_m(s)}{k_t} + V_b(s) &= V_a(s) \\ \frac{T_m(s)(R+LS)}{k_t} + V_b(s) &= V_a(s) \end{aligned} \quad (16)$$

Substituting the value of V_b in equation (13) for V_b in equation (14)

$$\frac{T_m(s)(R+LS)}{k_t} + k_b \Omega(s) = V_a(s) \quad (17)$$

Substituting the value of $T_m(s)$ in equation (12) for $T_m(s)$ in equation (15)

$$\frac{jS\Omega(s) + B\Omega(s)(R+LS)}{k_c} + k_b\Omega(s) = V_a(s)$$

$$\frac{(R+LS)(JS+B)\Omega(s)}{k_t} + k_b\Omega(s) = V_a(s)$$

$$\Omega(s) \left(\frac{(R+LS)(JS+B)}{k_t} + k_b \right) = V_a(s)$$

$$\frac{\Omega(s)}{V_a(s)} = \frac{1}{\frac{(R+LS)(JS+B)}{k_t} + k_b}$$

$$G(s) = \frac{\text{output}}{\text{input}} = \frac{\Omega(s)}{V_a(s)}$$

Therefore,

$$G_2(s) = \frac{k_c}{(R+LS)(JS+B) + k_t k_b} \quad (18)$$

Table 2: Values obtained based on the proposed DC motor to be used for the solid feed dispensing unit.

Parameter	Value
K_t	3.475 NM/Amp
K_b	3.475 V/rad/sec
B	0.03475 MN/rad sec
J	0.068 Kg/m ²
R_a	7.56 Ω
L	0.055H

Substituting the following values into the transfer function:

We have:

$$G_2(s) = \frac{3.475}{0.008745s^2 + 0.518995s + 12.33331} \quad (19)$$

4.3 System Software Design Considerations

The Particle Swarm Optimization algorithm shall be implemented in MATLAB R2013a. The optimized algorithm shall be used to tune the PID controller. The tuned PID controller is envisioned to enhance the performance of the dispensing system in terms of the rise time, settling time and overshoot. The Hardware of the controller is implemented using the Arduino Mega 2560 which is programmed via the Arduino Integrated Development Environment. Figure 7 shows the flowchart of the operation of the anticipated mobile intelligent poultry feed dispensing system.

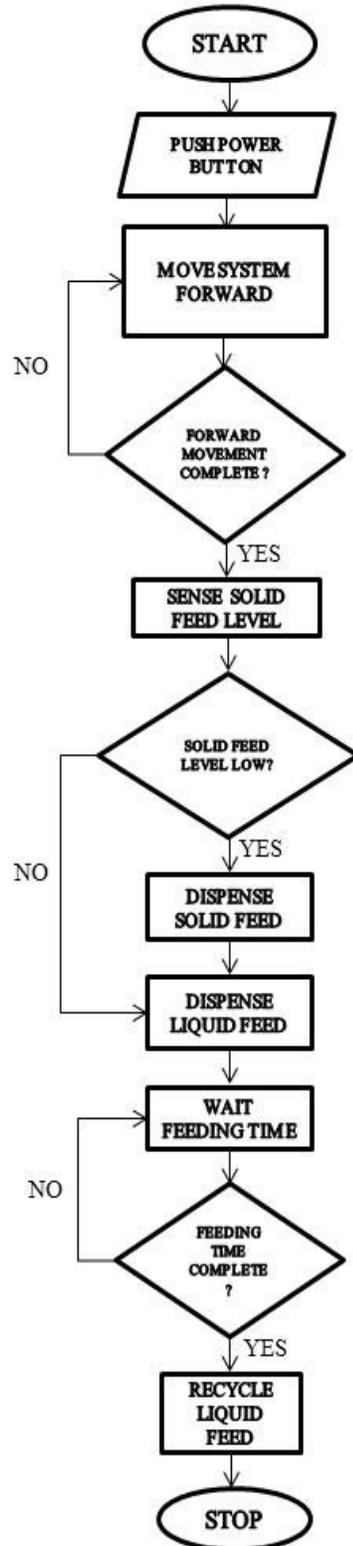


Figure 7: Mobile Intelligent Poultry Feed Dispensing System Flowchart

5. CONCLUSION AND FUTURE WORKS

The development and application use of the anticipated intelligent mechatronic system in the poultry industry will immensely reduce the labour poultry farmers undergo in feeding their poultry birds. The proposed system will apply ICT resources in order to improve human and animal welfare. The system will also provide a cost effective method of administering feed to poultry birds, reducing contamination, reducing wastage and also provide a method that is easy to adopt by poultry farmers. This in turn will result in an increase in profit and yield. At this stage the proposed design is open to suggestions. In Future, the design system in section four shall be developed using the appropriate microcontroller and electronic components to improve efficiency, boost productivity and reduce human intervention in deep litter poultry systems. In addition, hybrid intelligent techniques shall be investigated in the process of improving the performance of the system. Finally, a power management system can be incorporated in order to control the energy consumption of the system.

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