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HOLONIC CONTROL OF POULTRY HOUSE TRAVELLING HOPPER FEEDERS AND COMPARATIVE COST ANALYSIS

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Abstract:

***This work is aimed at applying holonic control system to poultry house travelling hopper feeders with the comparative cost analysis. It adopts HCBA which is suitable for controlling the reconfigurable automated processes. The feeder consists of parts for different types of poultry feeds dispensable from the feed reservoirs and carried around by travelling hoppers along the feed carts. The simulations were carried out using MATLAB and SIMATIC software. The responses of the speed of each traveling hopper were determined to be 1.04 sec, 1.91 sec and 0.0841% for rise time, settling time and percentage overshoot respectively. The parameters of the embedded controller in STEP 7 CONT_C FB41 data block translate to a constant gain of 10, integral time constant of 100 ms and derivative time constant of 280 ms. Visual results from the HMI show the system's ability for customization, cooperation and autonomy for implementation of any poultry feeding program. The cost analysis shows that it is profitable for farm capacity of 10,000 birds and above with low labour cost and average annual energy cost of about N708,000. The feed wastage loss is reduced by 66% while depreciation is 10% as compared to cage system with belted conveyor feeder*.**

Keywords: Cost Analysis; HMI; Holon; Holonic Architecture; Holonic Control; Poultry Feeder; Travelling Hopper.

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1. Introduction

The Nigerian manufacturing sector has failed to undergo the critical structural transformation required for it to play a leading role in economic growth and development [1]. The sector is structurally weak and basic industries such as agriculture, iron and steel are not fully operational. Consequently, the sector is unable to attract the necessary investment for economic growths and remains a small player in the economy. Poultry farming remains low, characterized by poor and old equipment, ineffective feeding methods and low quality of poultry products in small quantities. In 2016, the Nigerian government introduced Agriculture Promotion Policy (2016 - 2020), toward

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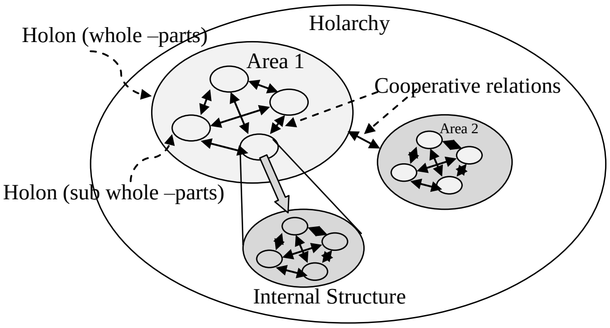
improving agricultural sector [2]. In its report, over 60 million tone of chicken requirement is deficit in Nigeria. In view of the above, the need to look into the current global trend in the industrial technologies and find its application to productive poultry farming is essential. Holonic systems approach provides endless possibilities of the application of technology not only to agriculture but also to other sectors of the economy.

In his observations on evolution of biological and social systems, [3] describes systems as those capable of evolving and growing to satisfy increasingly complex and changing needs by creating stable "intermediate" forms which are self – reliant and more capable than the initial systems. In living and organizational systems it is generally difficult to distinguish between 'wholes' and 'parts'; almost every distinguishable element is simultaneously a whole (an essentially autonomous body) and a part (an integrated section of a larger, more capable body). These led to the proposition of the word ‘holon’ which is a combination of the Greek words, 'holos' meaning whole and the Greek suffix 'on' meaning particle or part as in proton or neutron [4]. [5] observed that such properties would be highly desirable in a manufacturing operation which is subject to increasingly stringent demands and faster changes. He therefore proposed a building block or ‘holon’ based model for designing and operating elements comprising manufacturing processes. Thus, holonic control system is one that is partly ‘whole’ and partly ‘part’ of a bigger system.

The concept of holonic control systems has expanded and it is applied in the field of manufacturing and production systems. Examples of such paradigms are Reconfigurable Manufacturing Systems (RMS), Multi-Agent Systems (MAS), Bionic Manufacturing Systems (BMS), Holonic Manufacturing Systems (HMS), and more recently, Evolvable Production Systems (EPS) [6]. It is one of the concepts applicable to distributed systems and their management, but it has also potential for use in other industrial areas [7]. This concept brings the desirable properties of holons into the design of controllers for the purpose of achieving a more robust and friendly operations of machines in relation to the environment. The contribution of this work is the application of Holonic Components Based Architecture (HCBA) to the control of poultry house travelling hopper feeders and the comparative cost analysis with respect to existing feeders/methods of poultry feeding.

2. Related Work

The holarchic model can be seen as an attempt to modify and modernize perceptions of natural hierarchy [8]. It is a set of holons including their mutual relations that can co-operate to achieve a goal or objective. The holarchy defines the basic rules for co-operation of the holons and thereby limits their autonomy [7]. The concept of holarchy is illustrated in the following Figure 1.



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Some key properties of holonic systems have been studied in [9]. The two well known holonic control architectures are PROSA (Product – Resource – Order – Staff Architecture) and ADACOR (ADAptive holonic COntrol aRchitecture). In PROSA, a working holon which comprises an order holon, product holon and resource holon in varying degrees is sufficient for the control actions of the combined afore mentioned architectures. Thus, three basic holons form a necessary set. Several functions are assumed to be performed as static up-front activities. Product holon is responsible for the generation of process information and is traditionally considered as an off-line up front activity. The order holon makes way for the optimization and realization of the control objectives while the resource holon handles the operations [10] – [12]. ADACOR, the product holons represent the products available for production, the task holons represent the production orders and schedules, the operational holons represent the physical resources and the supervisor holons are responsible for coordination and optimization and combines the benefits of hierarchical and heterarchical control structures using an adaptive mechanism [6], [13] – [15]. Holonic Component Based Architecture (HCBA) is similar to PROSA as described in [16]. The resource and product components are regarded as the basic elements to make up this holonic system. The resource component or resource holon is a self-contained system component which can give treatments to works in process, such as fabrication, assembly, transportation, and testing. Typical resource components are machines, robots, AGVs, etc. Besides the visible physical part, a resource component contains an invisible control part which can perform its operations, decision making and communication ability by aid of its local database. On the other hand, the product component or product holon contains a physical part and a control part as well. A physical part may include raw material, parts and pallet/fixture. A control part may contain routing control, process control, decision making and production information. This architecture is similar to tactical and operational decisions level proposed in [17].

Holon can interact with its environment which may consist of human operators, machinery and other holons via specific communication protocols such as Petri net, Condition/Event systems or Place/Transition systems [9]. Humans communicate with the Holon via the human interface while other holons communicate with the holon via the inter-holon interface [12].

Holonic organization includes a set of holons arranged in different levels. Distributed holons try to achieve a common goal through cooperation and coordination. Two types of interactions can be seen in a holonic organization as shown in Figure 2 [8]:

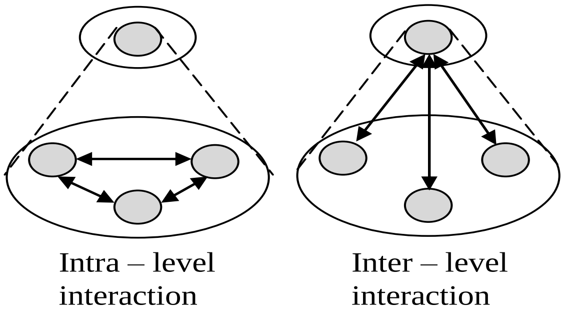

Figure 2: Interactions between holons

1) Intra-level interaction: Holons interact with each other agents at the same level. This type of interaction sometimes referred to as horizontal interaction.

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2) Inter-level interaction: Holons of two different levels in the hierarchy interact with each other. It sometimes referred to as vertical interaction.

Every information communication between holons is hosted by a set of hardware and software [16]. Thus device level control is usually carried out by hardware controller devices.

3. Methodology

Assuming a 4.0 square kilometers plot of land with rectangular poultry housing layout of size 50 x 30 x 25 in metres. The 2 – D view of the layout is shown in Figure 3. The layout consist of wing A to wing D with wings A & B forming section one and wings C & D forming section two. Free spaces are introduced to allow for movements, ventilation, installations of other components and control of orders. Along each wing is a block that designates a travelling hopper whose movement is bi – directional. The height of 25m is enough allowance to permit installations of overhead bars such as the carriage for the travelling hoper along designed wings.

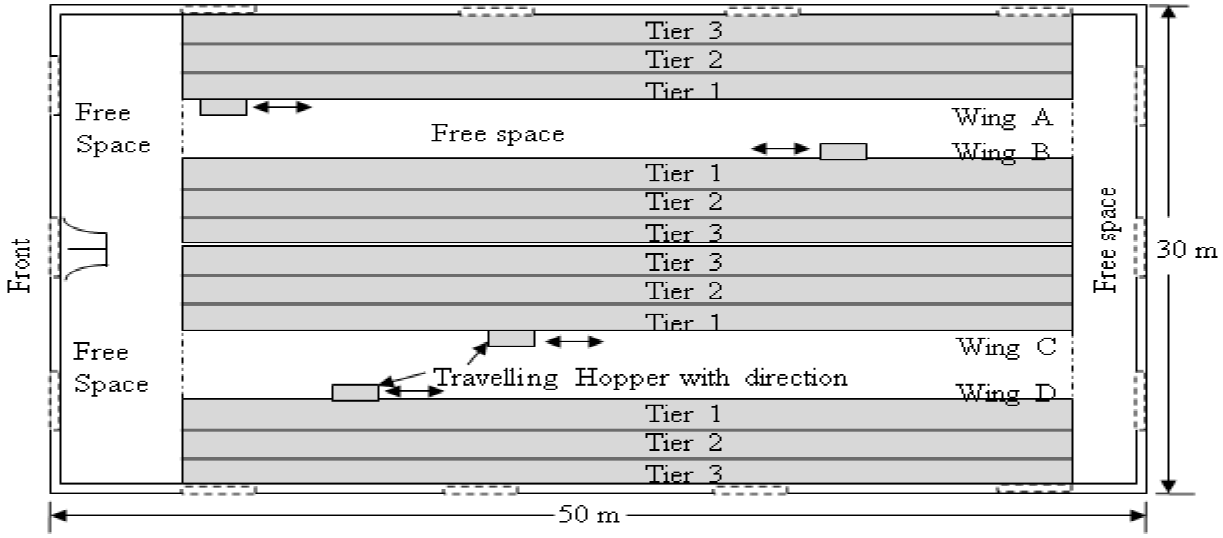

Figure 3. Physical layout of the model

3.1. Conceptual Design Models

The conceptual design for the entire system is made up of four units of travelling hoppers, one for each wing (with birds' cages and feed carts) and a unit of three feed reservoirs and a water tank. Each hopper has three compartments, one for each tier and is to be equipped with three servo motors (for controlling the dropping of feeds on the feed carts) and six level sensors/indicators. The entire model is shown in Figure 4. Each of the feed reservoirs also is to be equipped with two level sensors and a dc motor which is to be attached to an Archimedes' screw to facilitate the transportation of the feeds to the hoppers.

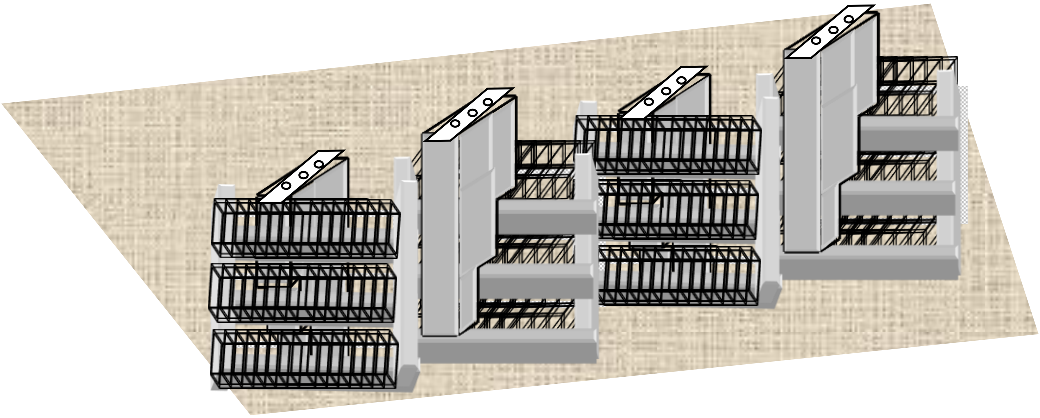

Figure 4: Conceptual design model of the poultry house feeding system

The following are holons declaration and features for the system under design.

1) Hopper control holons. Each hopper has its own control thus, we have four hopper holons
2) Feed carts control holons. We will also have four, one for each wing
3) Reservoirs control holon
4) Interface control holon (for operations and monitoring)

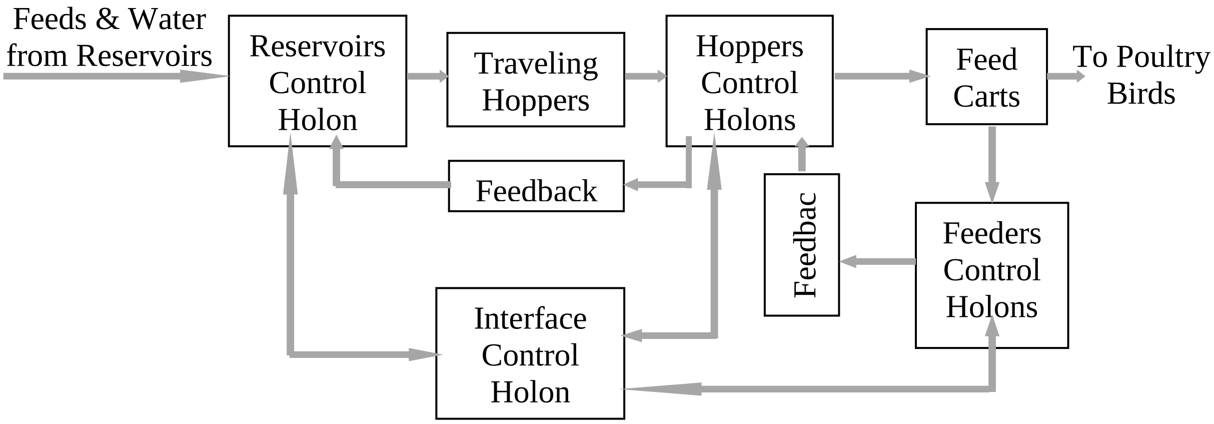

Figure 5: Block diagram of the holonic control of the automated process

Altogether, this work proposes ten (10) holons for the design and Figure 5 shows the block diagram of the holonic concept.

3.2. Travelling Hoppers Speed Regulation

The travelling hopper is the component part that is responsible for carrying sizable but required amount and type of poultry feed. The hopper discharges the feed on the feed cart so that the bird can have access to the feed. As established in [9], the hopper will carry an instantaneous feed of about 65 kg along its direction of movement. Programmable Logic Controller (PLC) is used to control motor speed as shown in Figure 6. At first, motor speed is transferred to PLC by mean of shaft encoder, then the PLC according to the program for embedded PID controller, generates the control signal to reach the desired speed.

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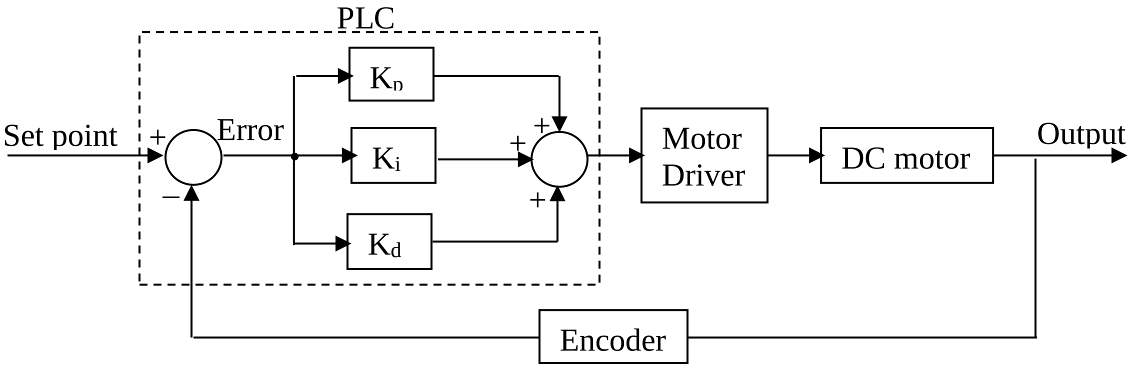

Figure 6: The PID motor controller diagram

The mass of the feeder, M is modeled as moving with a linear speed, $v(t)$ via chain and sprockets of radii, r and inertia, J. In between the driving chain and the load is the chain viscous friction, b and stiffness, k. This friction extends to the driven sprockets and the effects of ball bearings which can be lumped as translational viscous damper, f_v while the slack length is assumed negligible. The model for the speed control of one of four similar travelling hoppers is shown in figure 7.

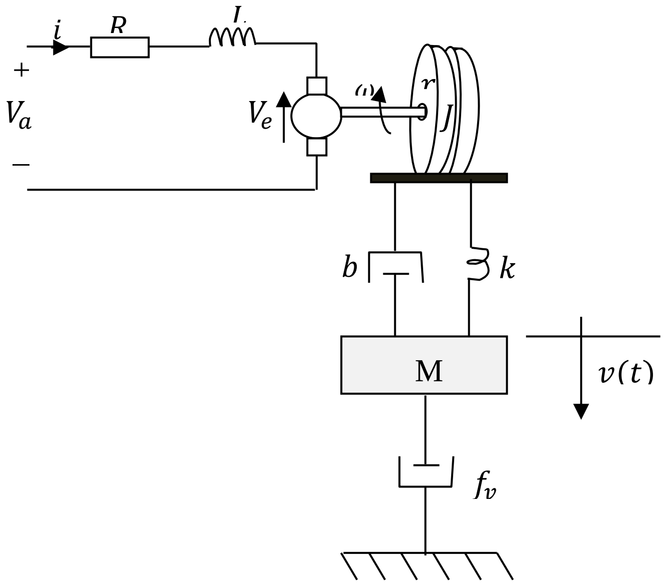

Figure 7: Motor-load model with chain and sprockets

As derived in [9], the model for the speed control is

$$V_a(s) = \left(\frac{J+r^2M}{rK_m}s + \frac{b+r^2f_v}{rK_m}\right)RV(s) + \left(\frac{J+r^2M}{rK_m}s + \frac{b+r^2f_v}{rK_m}\right)LsV(s) + \frac{K_v}{r}V(s)$$

$$V_a(s) = \left[\left(\frac{J+r^2M}{rK_m}s + \frac{b+r^2f_v}{rK_m}\right)R + \left(\frac{J+r^2M}{rK_m}s + \frac{b+r^2f_v}{rK_m}\right)Ls + \frac{K_v}{r}\right]V(s) \qquad (1)$$

$$\frac{V(s)}{V_a(s)} = \frac{1}{La1s^2+(Ra1+Lb1)s+(Rb1+c1)}$$

where $a1 = \frac{J+r^2M}{rK_m}$, $b1 = \frac{b+r^2f_v}{rK_m}$ and $c1 = \frac{K_v}{r}$

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$$\frac{V(s)}{V_a(s)} = \frac{{}^{1}/_{La1}}{s^2 + {}^{(Ra1+Lb1)s}/_{La1} + {}^{(Rb1+c1)}/_{La1}} \tag{2}$$

With PID, the close loop control system is

$$\frac{V(s)}{V_a(s)} = \frac{G_c{}^{1}/_{La1}}{s^2 + {}^{(Ra1+Lb1)s}/_{La1} + {}^{(Rb1+c1)}/_{La1} + G_c{}^{1}/_{La1}} \tag{3}$$

Where $G_c = K_p + \frac{K_i}{s} + sK_d$

$$G_c = K_p(1 + \frac{1}{T_i.s} + sT_d) \tag{4}$$

Where K_p is the proportional constant, T_i is the integral time constant and T_d is the derivative time constant. The parameter for simulation in MATLAB is given in table 1

Table 1: Model Parameters for Simulation

Parameters	Values
R	15.31 Ω
L	48 mH
J	0.00088 kg.m^2
f_v	0.2 Nm.sec/rad
d	0.2 Nm.sec/rad
K_v	0.6 Nm/A
K_m	0.6 Nm/A
R	0.25 m
M	65 Kg

3.3. Holonic Component Based Architecture and Integration

In HCBA, a holonic control is made up of separated and unorganized resource software components providing Human Machine Interface (HMI). They are one –to– one mapped to their associated physical equipment in the feeding system. Thus, a resource holon contains these two main parts, a software part in the holonic controller for control and decision-making, and a physical part in the physical system for actual process control. Figure 8 describes the integration of HCBA. The dynamic interaction between holons in HCBA is initiated once product holons are introduced. A product holon which may be provided by the process designer, or customer's order, carries a detail process plan (feeding program).

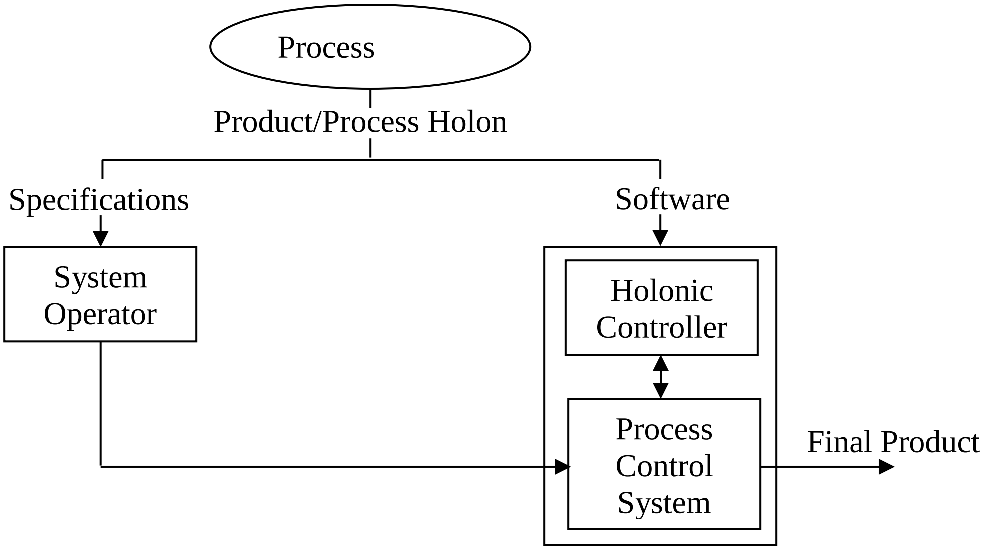

Figure 8: Operation of Holonic System

The software part of the product holon will try to make use of resource holons by proceeding with a series of negotiations. This stage is called dynamic integration. The holonic controller will return to the stage of static integration (where there is no interaction between holons) if all product holons have finished their tasks; this is because no interaction is now generated.

The control architecture for the feeding system is depicted in Figure 9. The system PLC (S7 – 300) is employed to integrate all component parts in the system and then link upward to the resource controller. Figure 10 shows the device level control flowchart given Feed Low Level Threshold (FLLT), Water Low Level Threshold (WLLT), Water High Level Threshold (WHLT), Hopper Low Level Threshold (HLLT), Hopper High Level Threshold (HHLT) and Limit Switch (LS). The implantation is done with Siemens STEP 7 Professional and WinCC 6.0 software.

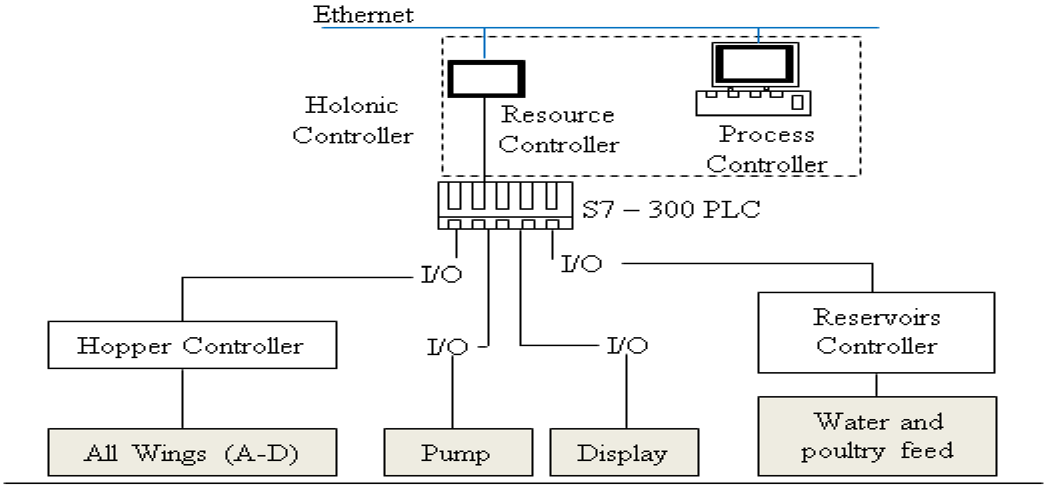

Figure 9: Control Architecture for the feeding

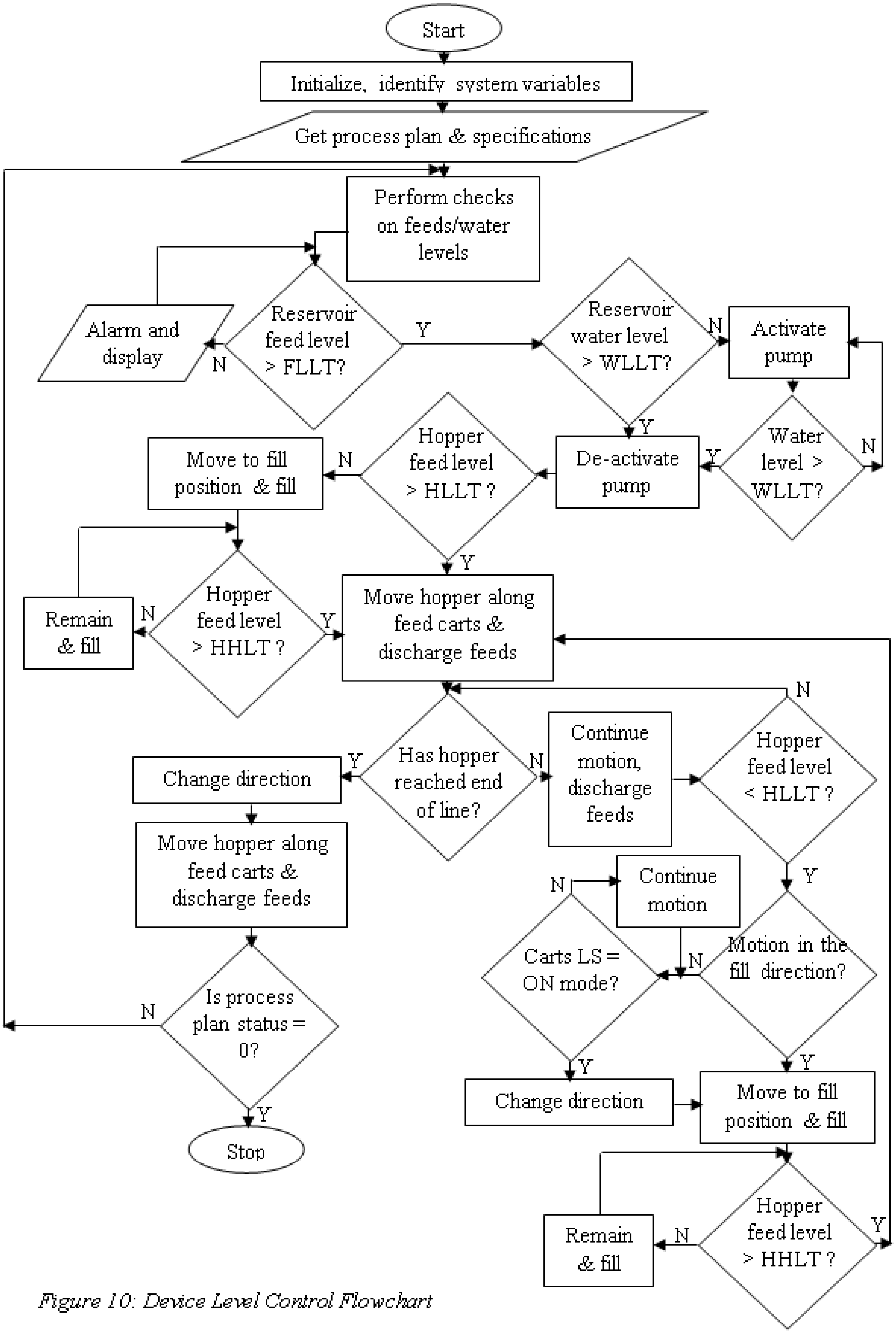

Figure 10: Device Level Control Flowchart

3.4. Comparative Cost Analysis

One of the important aspects of Engineering designs leading to a complete product is the cost. This cost ranges from design tools to every component part that will eventually make up the final product. In this work, the cost of various component parts will be considered and compared with the lump amount of three other poultry feeder systems available. The four categorization of the feeding system are:

1) Litter system with Grit feeder equipment (Litter-GF)
2) Open system with ETON static hopper (tripod) feeder (Open-ESHF)
3) Cage system with belted conveyor feeder (Cage-BCF)
4) Cage system with holonic travelling hopper feeder (Cage-HTHF)

The cost in term of equipment/capacity, labour/capacity, maintenance, depreciation, medicine (including vaccination, treatment and spraying), mortality loss and the amount of feed wastages are considered and compared.

The cost of parts needed for the realization the proposed poultry feeding system were obtained via market survey. The price of some parts such as the Siemens PLC and sensors which are not available locally, were looked up on the online market platforms such as indiamart, alibaba, ebay and amazon. The results of part list and cost implications are presented in table 2 of section 4, with dollar to naira conversion fix at 1$ = ₦360 as at the time of carrying out this survey. The costs of the alternative feeder/feeding methods using the stated reference ($ to ₦) conversion from the works of [18] – [20] and market survey, were considered and the results presented in section 4. Also, energy consumption of the feeding system was evaluated using the ratings of the power consumable by each part of the system that uses electricity. Table 3 of section 4 shows the energy consumption in watts-hour.

3.5. Other Performance Costs Analysis

Practical and realistic of estimate for maintenance, repair/replacement cost is 3 – 4% cost of the relative actual purchases and installations [21] – [22]. A variation of up to 4% is adopted for non-cage system while 3% is adopted for cage service equipment. For depreciation, averages are 6.67% and 10.00% for cage and non-cage respectively and are adopted [23]. So that

$$Depreciation = \%\ depreciation\ x\ equipment\ cost \tag{5}$$

For medicine, the cost of vaccination, spraying and treatment per bird per day is ₦0.36 for litter system. On a larger scale, using a Figure of merit with 30,000 birds per year, the cost of medicine per year will be ₦1,576,800.00. Other system has their variation of the Figure of merit as 0.35, 0.07 and 0.07 respectively [18], [24].

On feed wastages and mortality loss, [25] gives analysis for layers of 1,000 capacity as taking 5 bags of feed per day with a bag costing ₦15,000.00 (present price). [26] shows that layer mortality is due to stress and computed mortality index using

$$Mortality\ index = \frac{Number\ of\ birds\ killed\ per\ annum}{Number\ of\ beirds\ used\ per\ per\ annum}\ x\ 100\% \tag{6}$$

The mortality index for caged birds was computed as 1.03% and 1.13% for non-caged birds. The ideal value is less than 1.2%. For Day Old Chick (DOC) valued between ₦250.00 – ₦280.00, mortality losses are obtained at indices 1.13%, 1.10%, 1.03% and 1.03% respectively with inputs from MICON farms, Nature Blend farm and Espoly farm all from Enugu State Nigeria.

4. Results Analysis

The speed response to unit step input for one of four similar travelling hoppers is presented in Figure 11. For the controlled model, the rise time is 1.04 sec, the settling time is 1.91 sec and the percentage overshoot is 0.0841%.

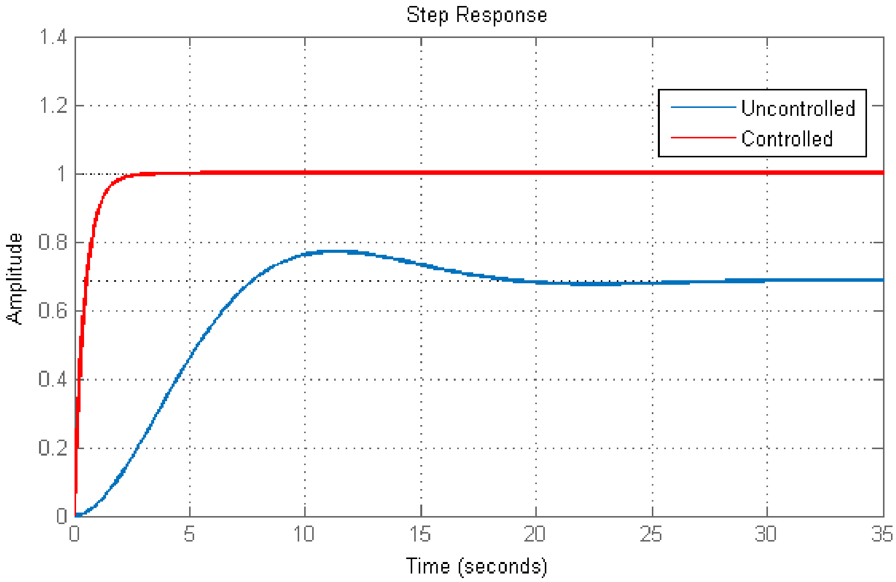

Figure 11: Speed response of the hopper to step input

The gains of the embedded PID are found to be $K_p = 10,\ K_i = 1\ and\ K_d = 28$. The Siemens Step 7 continuous control PID block requires the use of integral time constant T_i and derivative time constant T_d for it operation. The conversion of the PID parameters to its time constants equivalence gives $K_p = 10,\ T_i\ = 100ms\ and\ T_d\ = 280ms$.

4.1. Results of Control Holons From HMI

Implantation with STEP 7 and WinCC show results from Human Machine Interface (HMI) for various holons.For a test, wing A holons was injected with a 2 minutes, 2 times operations at 30 seconds interval (break) between operations for all the three tiers of the wing A hopper A. Similarly, wing B holon was tasked with a 3 three time 60 seconds operations with a 20 seconds interval time between operations only for the first two tiers of the wing B traveling hopper. Figure 12 show the result from the developed HMI for hopper control holon. It indicates if a travelling hopper is in motion, its direction, whether the feed level in any of the compartment is low or high and if the hopper is stationary or being filled.

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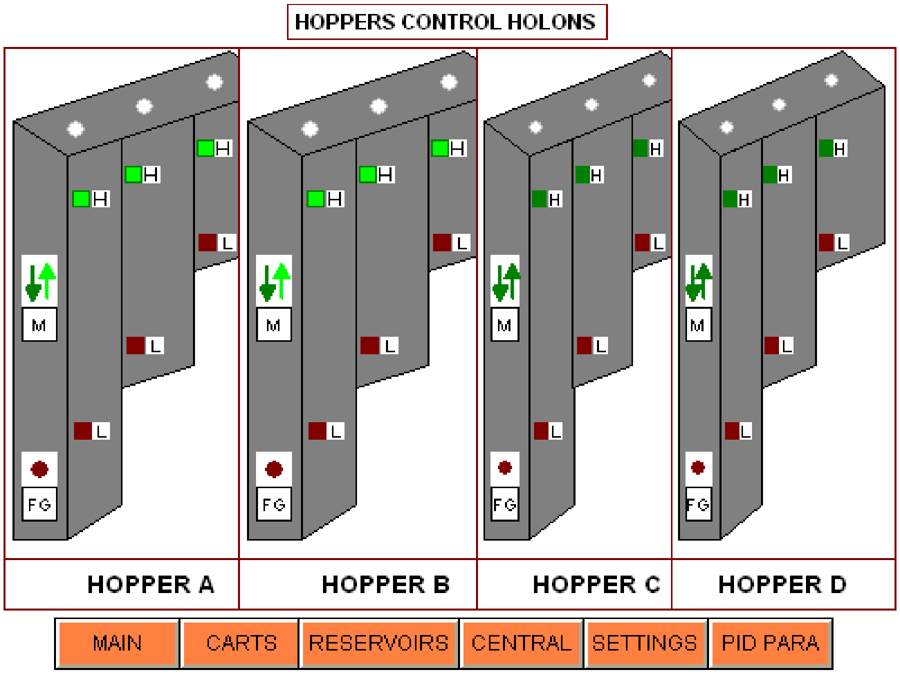
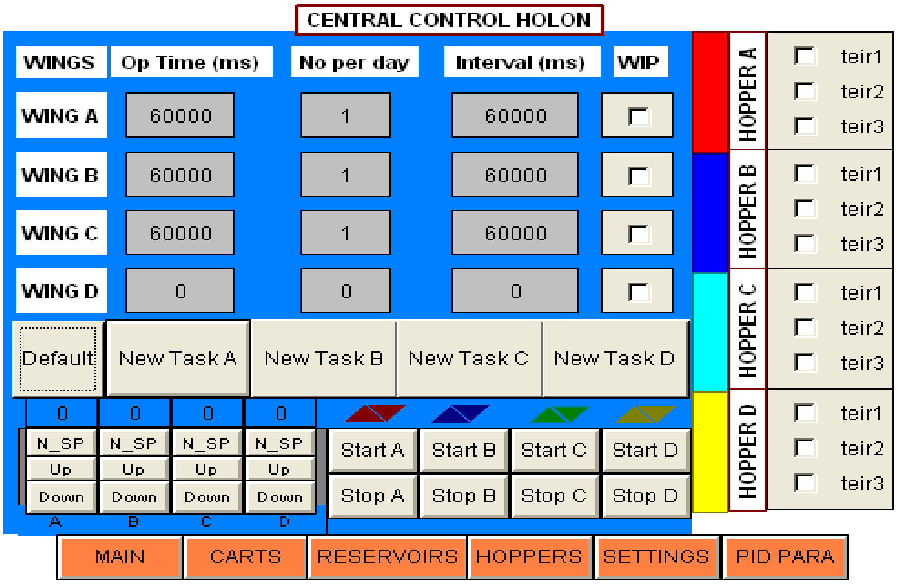


Figure 12: Results from HMI hopper holon

Once the given tasks are fulfilled, the central control holon resets the wings operations to default of 1 minute operational time once a day while the interval is also set to 1 minute. Figure 13 shows the HMI central control holon at default. This control holon shows the flexibility of implementing a specialized poultry feeding program for different types of poultry birds. From here, one can start a new feeding program, cancel an old one, start/stop a particular travelling hopper, increase or decrease the speed of a travelling hopper using a respective 'N_SP','Up' and 'Down' bottons. Hence feeding broilers, layers and/or quail in one farm with separate feeding plans is some adjustment away from an automated process.



CENTRAL CONTROL HOLON

WINGS	Op Time (ms)	No per day	Interval (ms)	WIP
WING A	60000	1	60000	☐
WING B	60000	1	60000	☐
WING C	60000	1	60000	☐
WING D	0	0	0	☐

Figure 13: HMI central control holon at default

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To test the self – organizing property of the system, a scenario was created for the filling of hopper D of wing D holon with poultry feeds. All condition were made idea but a minor fault was injected by not allowing the valve controlling the opening for the filling of tier 2 of hopper D (which is due for filling but the valve remained closed at the filling position) to open. This scenario is presented in Figure 14.

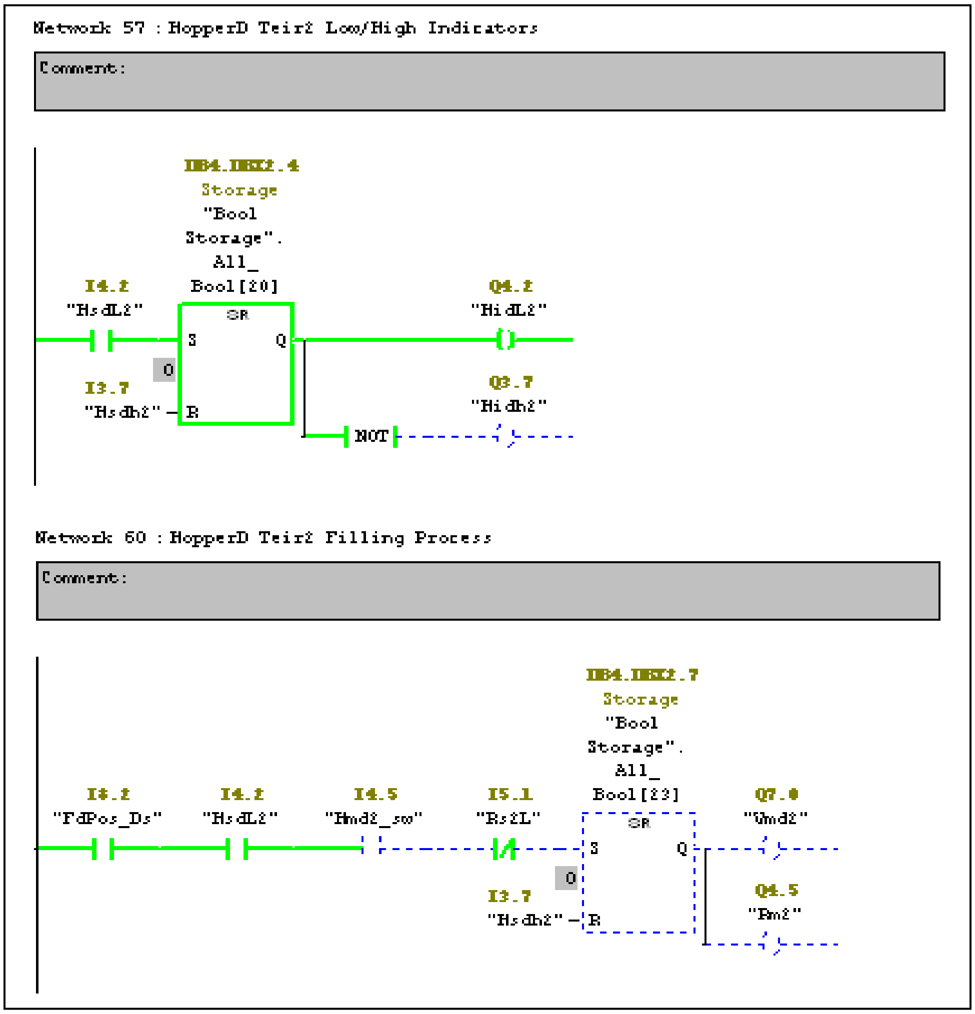

Figure 14: Ladder networks depicting a faulty situation

The ladder network 57 shows that hopper D tier 2 is due for filling. Network 60 shows that the hopper has reach the position to be filled since the filling position sensor for hopper D (FdPos_Ds) and hopper D tier 2 sensor (HsdL2) are active but the valve controlling the filling of hopper D tier 2 (Vmd2) is not 'ON'. The system re-organizes itself and move on with hopper D in motion to fulfill the demand of other tiers while waiting for the problem to be resolved. Figure 15 shows the hopper moving to complete other tasks.

While the operation time lasts with the given interval and number of times per day if the problem is resolved and the hopper get to the filling position again, the filling will take place as shown in Figure 16.

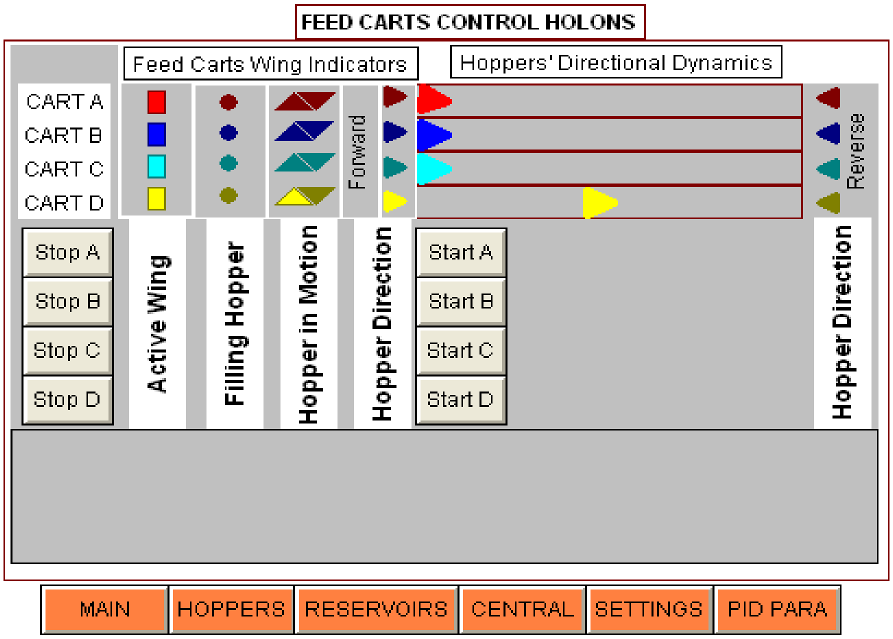

Figure 15: Hopper D moving to complete other tasks

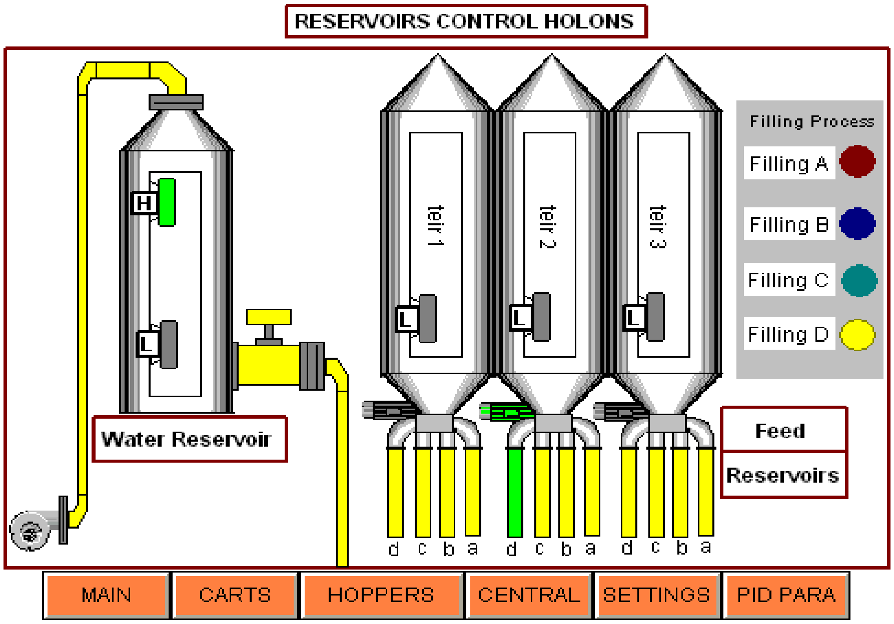

Figure 16: Hopper D tier 2 being filled from the feed reservoir

The SP_A/PV_A, SP_B/PV_B, SP_C/PV_C and SP_D/PV_D represent the bars for the set-points and process variables of the hoppers A, B, C and D respectively. When a set-point is adjusted, the process variable is the output tries to reach and settle at the value of the given set-point. To adjust the speed from the comfort of the workstation, Figure 17 shows how to do it by clicking "New SP" button and use the "Up" or "Down" buttons to increase or decrease the set-point for all the wing hoppers. For this system, the process variable always settled to the values of the new set-points.

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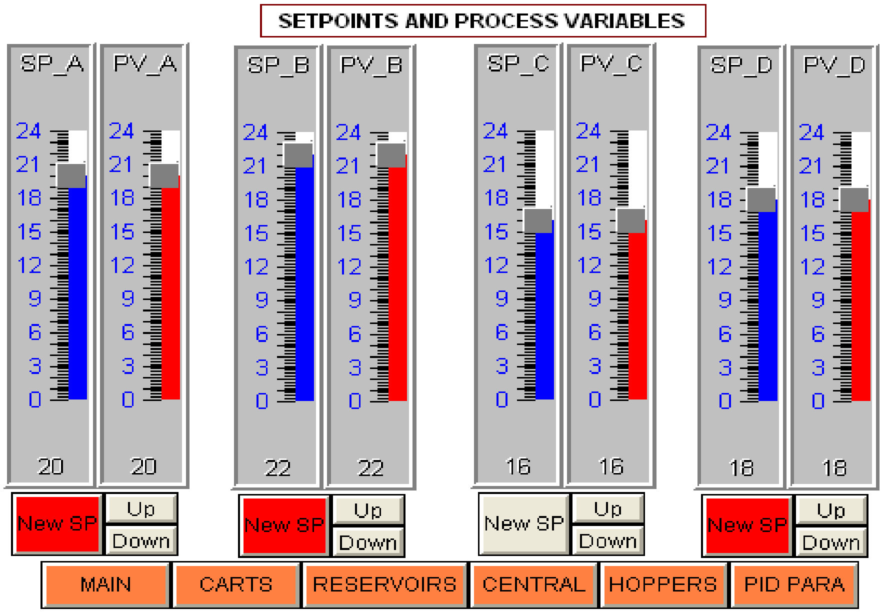
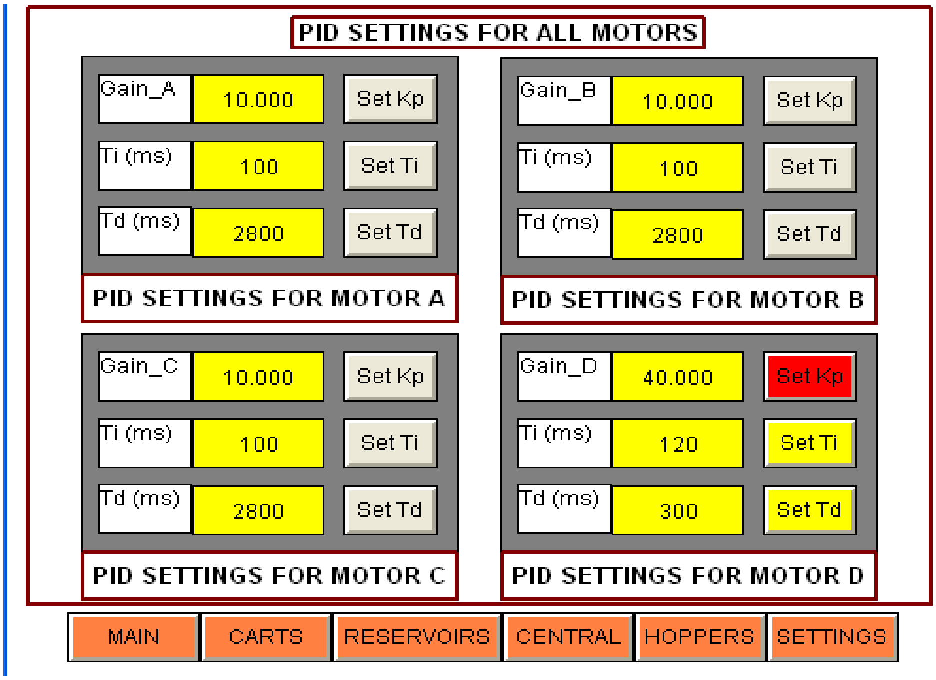


Figure 17: Adjusting the speed from the HMI

Due to repair/replacements of the controllable component parts such as the hopper and its driving actuator (motor), the parameters for the embedded PID may change and this can adversely affect the system performance. To solve this problem, the HMI screen shown in Figure 18 was designed to allow new PID parameters to be set for optimum response. For hoppers A, B and C, the default values of $K_p, T_i \text{ and } T_d$ were maintained as 10, 0.1 sec and 2.8 sec respectively. The Figure also shows the status of PID parameters for motor D (i.e hopper D and the motor controlling its speed) having new values and the colours of the set buttons indicate same.



PID SETTINGS FOR ALL MOTORS

Gain_A 10.000
Ti (ms) 100
Td (ms) 2800
PID SETTINGS FOR MOTOR A

Gain_B 10.000
Ti (ms) 100
Td (ms) 2800
PID SETTINGS FOR MOTOR B

Gain_C 10.000
Ti (ms) 100
Td (ms) 2800
PID SETTINGS FOR MOTOR C

Gain_D 40.000
Ti (ms) 120
Td (ms) 300
PID SETTINGS FOR MOTOR D

Figure 18: HMI screen for adjusting the PID parameters

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4.2. Results of Comparative Cost Analysis

The part list and costs of items needed for implementation of this work in Nigeria naira is presented in table 2 while the energy requirement and cost for the design in Nigeria naira is also given in table 3.

Table 2: Part List and Cost Implications for the Design

S/N	Items	Qty	Unit price (₦)	Total price (₦)
1	Inductive proximity (feed level) sensors	24	864.00	20,736.00
2	PP Liquid water level sensor (HFSD 52mm)	2	356.40	712.80
3	Feeder house roller chain S52/2K1/JA (5m)	64	6,550.60	419,238.40
4	Feeder house sprockets (610199.0)	12	3,960.00	47,520.00
5	Ball bearings	8	662.40	5,299.20
6	CNC chromed round bar rod	4	1,000.00	4,000.00
7	Overhead steel bars	1048	195.00	204,360.00
8	Feed reservoirs	3	25,000.00	75,000.00
9	Water tanks	1	27,000.00	27,000.00
10	Pump (I-flo 0.5 HP)	1	10,800.68	10,800.68
11	DC motors (24 V, 0.5 HP)	4	10,800.00	43,200.00
12	Water pipes (1-inch PVC)	600	140.00	84,000.00
13	Nipple drinkers	600	70.00	42,000.00
14	Water valves	1	180.00	180.00
15	Constructed hopper	4	35,000.00	140,000.00
16	Servo motors (5W dc)	15	1,050.00	15,750.00
17	Light indicators	25	100.00	2,500.00
18	Limit switches	8	468.00	3,744.00
19	Cages with feed troughs (120/bird/unit)	264	96,000.00	25,344,000.00
20	S300 PLC (314-DP-PN-2 CPU)	1	323,996.40	323,996.40
21	S300 PLC power (PS 307, 10A)	1	131,400.00	131,400.00
22	SM 321/322	6	156,600.00	939,600.00
23	HMI software (SIMATIC WinCC)	1	584,280.00	584,280.00
24	Installation	1	90,000.00	90,000.00
25	Miscellaneous	5%		1,427,965.87
	Total			**29,987,283.35**

The actual cost for the proposed feeding system does not include those of poultry birds cages, installations and miscellaneous. Hence, it will cost **₦3,125,317.48** for 30,000 birds capacity.

Table 3: Energy Requirement and Cost for the Design

S/N	Power/Electronic Components	Qty	Unit Watts (W)	Total Watts (W)
1	Inductive proximity (feed level) sensors	24	5	120
2	PP Liquid water level sensor (HFSD 52mm)	2	5	10
3	Pump (I-flo 0.5 HP)	1	380	380
4	Water valves	1	100	100
5	Servo motors (5W dc)	15	5	75

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6	Light indicators	25	3	75
7	Limit switches	8	5	40
8	S300 PLC power module (PS 307, 10A)	1	1760	1760
9	HMI Station (SIMATIC WinCC)	1	1000	1000
	Total Wattage (W) per hour			**3560**

Daily Energy Consumption per hour (in kWh) = 3560/1000 = 3.56kWh
Daily Energy Consumption (kWh, 19 hours) = 3.56 x 19 = 67.64kWh
Annual Energy Consumption (kWh) = 67.64 x 12 = 24688.60kWh
Unit charge per kWh (D1 category) = ₦28.68
Annual Energy Consumption Cost = 24688.60 x 28.68
= ₦708,069.05

The cost analysis for three types of poultry farms and feeder system was carried out and compared with those of the design in this research work. The types considered are liter system with Grit feeder (Litter-GF), open system with ETON static hopper feeder (Open-ESHF), cage system with belted conveyor feeder (Cage-BCF) and the one of this research which is cage with holonic traveling hopper feeder (Cage-HTHF). Costs were considered against the capacity of birds that can be fed using the particular system. Results of other costs such as maintenance, depreciation, medicine, feed wastages and mortality loss are presented in table 4. Figure 19 - 21 show the results obtained.

Table 4: Costs of other Performance Indices in Naira (₦) per 30,000 Birds Per Year

System	**Maintenance**	**Depreciation**	**Medicine**	**Wastage**	**Mortality**
Liter-GF	469,665.60	1,174,164.00	1,576,800.00	1,346,850.00	96,600.00
Open-ESHF	340,778.16	851,945.50	1,379,700.00	942,795.00	92,400.00
Cage-BCF	105,010.67	233,473.73	275,940.00	80,910.00	77,250.00
Cage-HTHF	93,759.52	208,458.68	275,940.00	26,970.00	77,250.00

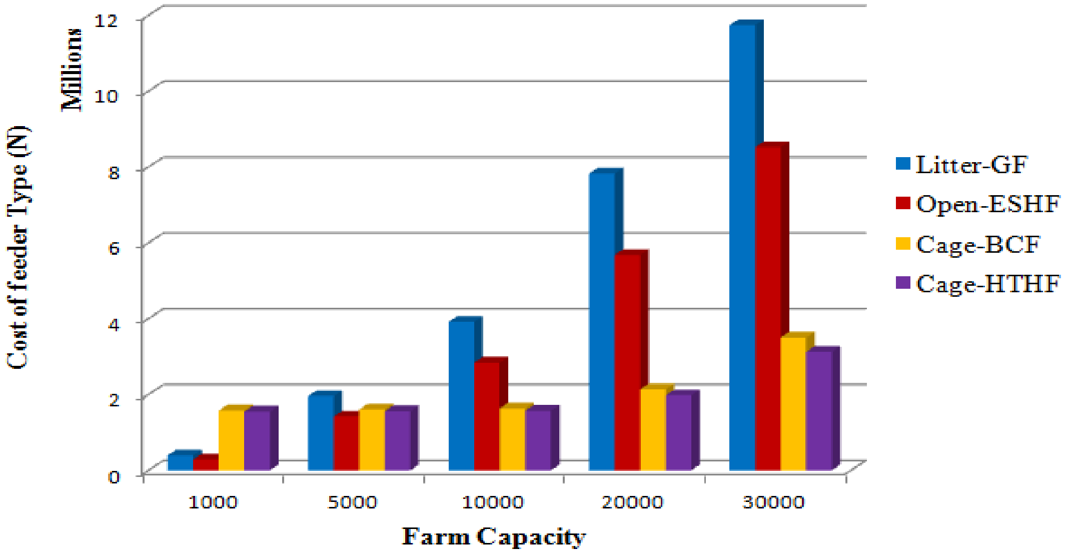

Figure 19: Feeder type, cost and capacity

From the Figure, it can be seen that from 1,000 to 5,000 birds capacity, Open-ESHF is best showing the cost lower than the rest of the feeder type/system. From 10,000 birds to 30,000 birds capacity, cage systems show better cost effectiveness with Cage-HTHF being more effective as the capacity of birds increases. At 30,000 capacity, the cost at Cage-HTHF is at all times lower (about 3.1 million naira). While it is better to operate the farm using Litter-GF and Open-ESHF for capacity up to 5,000 birds, it is more promising to operate the cage system (with Cage-HTHF) for capacities greater than 10,000.

Cost of labour is another factor separately considered in this work. The labour expenses increases with the capacity of birds being kept. However, this increase is not much so with the cage system. Figure 20 shows the cost implications of the aforementioned feeder types and system per year.

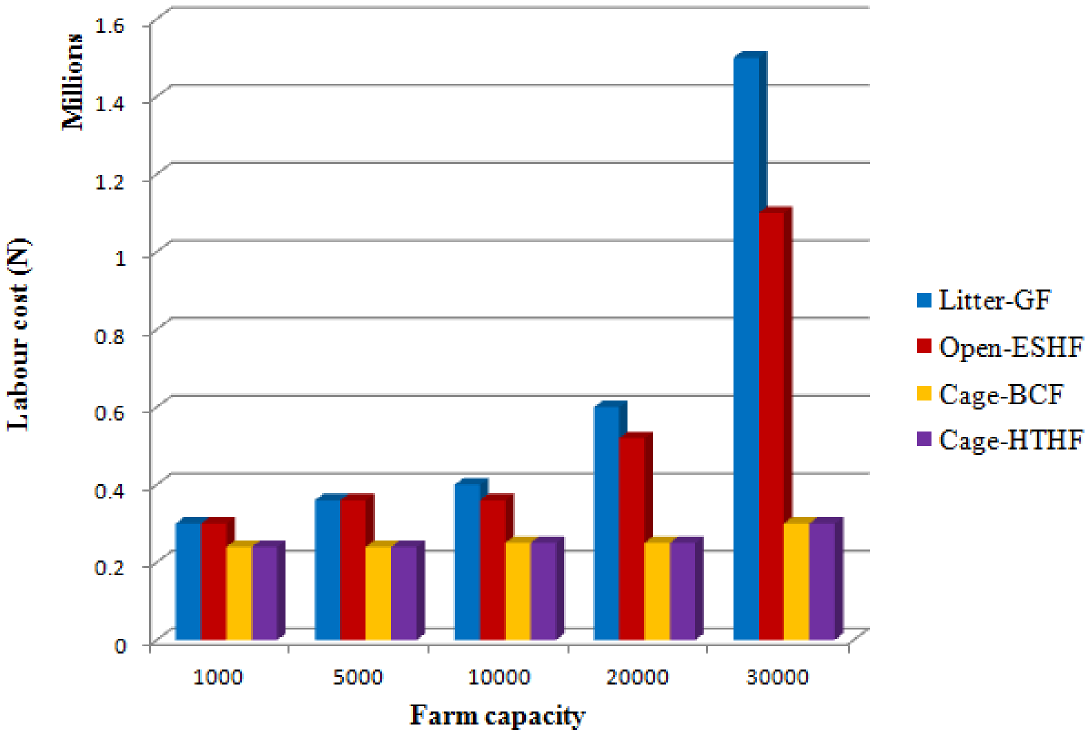

Figure 20: Labour costs for different feeder types and capacity

The cost of labour for the open systems is much higher at capacities greater than 10,000 per annum. The increase with the cage systems only shows small marginal increase and the capacity increases. Those of Cage-BCF and Cage-HTHF appear to be equal and lower both are automated processes with little human efforts needed mostly for supervision and coordination of activities. At 30,000 birds capacity, the labour cost for the design is about 300,000 naira.

Other performance indices include maintenance cost, depreciation, medicine, amount of feed wastages and mortality loss. Figure 21 show the compared costs of these indices per year and for 30,000 birds.

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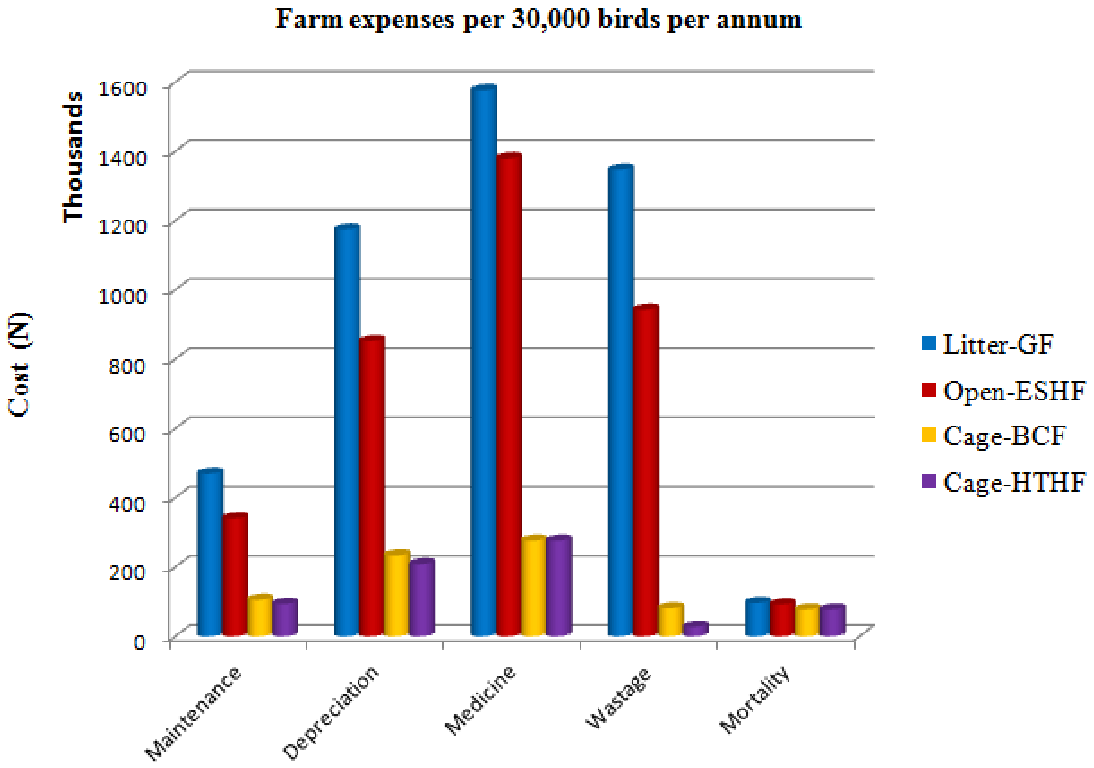

Figure 21: Costs and other performance indices for different feeder types

The cage systems indicate lower losses compared to the open systems hence, they are better options for commercial production. One key difference between the Cage-BCF and the Cage-HTHF is the amount of feed wastages. It is considerably lower (about ₦26,700 per annum) in Cage-HTHF than in Cage-BCF (about ₦81,000 per annum). This amount to 66.7% cost reduction. In similar manner, there is a difference of ₦25,015.05 in depreciation cost which also leads to 10.7% depreciation cost reduction.

5. Conclusion

The response of the regulated speed of the travelling hopper shows that it settles at 1.91 seconds with percentage overshoot of 0.0841%. This settling time is less than 2 seconds with almost zero overshoot. The holonic system demonstrated properties such as autonomy, customization and cooperation as shown in figures 12 – 18. It allows different poultry feeding program to be implemented without changing any equipment. Hence the feeding needs of different categories of poultry birds can be met when kept in one farm. The comparative cost analysis shows that this feeder type is more beneficial for poultry farm capacity of 10,000 and above in a cage system. The average energy consumption cost is about N708,000 in category D1 of public power supply. Figure 21 shows that feed wastage lost is reduced by 66% while that of depreciation is 10% reduction in Caged – HTHF as compared with the Caged – BCF. In future, it is desirable to look in the stability of this holonic control. Also, the use of software packages for cost analysis will provide more insight into the financial status of this feeder type.

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