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Holonic Content Design of a Caged Poultry Feeder

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Abstract: The use of biologically inspired self-organization concepts known as holonic system approach has proved to be suitable for being embedded in practical applications. This research work is aimed at applying holonic control system to the design of a poultry house feeding system. 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 hoppers' movement is bidirectional, one for each wing (wing A - D), having three compartments, one for each tier of battery cage system. 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. Also, 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. Results of the working HMI presents interfaces for carts control holon and central control holon with default operational time of 60 sec at an interval of 60 sec per day, subject to changes. Visual results from the HMI show the system's ability for customization, cooperation and autonomy.

Keywords: Holonic control, Holon, Hopper, Poultry feeder

1. Introduction

Holonic systems are those systems that are based on the philosophy put forward by [1] in which a system is described as something that is simultaneously a whole and a part. These systems are autonomous, self-reliant units called holons that possess some degrees of independence and handle contingencies without relying on inputs from higher authorities.

Over the years, the Nigerian agricultural sector has failed to undergo the critical structural transformation required for it to play a leading role in economic growth and development. The sector is structurally weak and unable to attract the necessary investment for economic growths [2]. Poultry farming remains low, characterized by poor and old equipment, ineffective feeding methods and low quality of poultry products in small quantities. In recent time, the Nigerian government has been making serious efforts such as the introduction of the Agriculture Promotion Policy (2016 - 2020), toward improving agricultural sector [3]. In its report, over 60 million tone of chicken requirement is deficit in Nigeria.

One important aspect of raising chickens is the issue of feeding. Feeding makes up the major cost of production and good nutrition is reflected in the bird's performance and its products. The effect of stocking pressure on birds' feed intake, frequency of feeding, uniformity, rationing and precision involved with the feeding system are some of the common challenges faced in rearing poultry birds. In view of the above, there is a need to look into the current global trend in the industrial technologies and apply it to poultry farming (feeding in this case) in Nigeria. Holonic content design of a poultry feeder seeks to improve the quality and quantity of poultry products in Nigeria.

2. Related Work

The concept of holonic 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) [4]. It is one of the concepts applicable to distributed systems and their management, but it has also potential for use in other industrial areas [5]. 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.

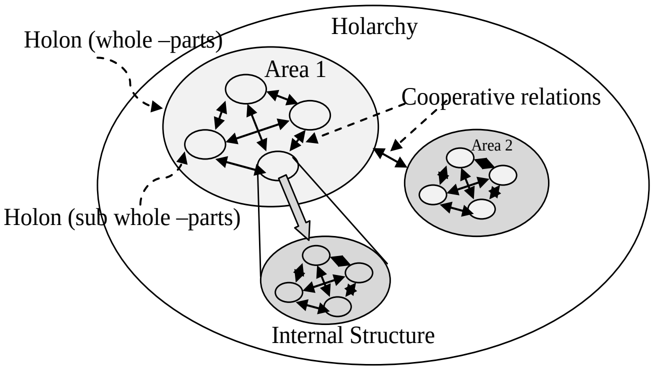

Figure 1: Holarchy

A hierarchy of holons is called a holarchy. The holarchic model can be seen as an attempt to modify and modernize perceptions of natural hierarchy [6]. 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 [5]. The concept of holarchy is illustrated in the following Fig. 1.

In [7] - [8], some key properties of holonic systems were proposed which include by not limited to:

i. Autonomy – the capability of a manufacturing unit to create and control the execution of its own plans and/or strategies (and to maintain its own functions).
ii. Cooperation – the process whereby a set of manufacturing units develop mutually acceptable plans and execute them.
iii. Self-organization – the ability of manufacturing units to collect and arrange themselves in order to achieve a production goal.
iv. Re-configurability – the ability of a function of a manufacturing unit to be simply altered in a timely and cost effective manner.

Others include modularity, data storage, unique system identification, remote accessibility, scalability, robustness, flexibility, etc. These form the building block of a manufacturing and production system for transforming, transporting, storing physical and information objects. It can be seen as consisting of a control part and an optional physical processing part of much different possible/available architecture.

2.1 Holonic Architecture

The most evolving architecture in manufacture/process control paradigm is the holonic control architecture. According to [9], the two well known architectures for the implementation of holonic control 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]. In 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 [9], [4], [13], [14].

Holonic Component Based Architecture (HCBA) is similar to PROSA as described in [15]. 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 [16]. At the tactical level, a decision concerns the production quantities for every item within a product family and for each period on a planning time horizon. Once divisions are made, a holon sub-lot at the operational level evaluates the variation in planning by using a re-planning linear programming model.

In [17], another holonic architecture called Hybrid Control Architecture (HCA) which deals with some limitations of existing architectures was described. HCA is an integrated scheduling and control architecture that integrates local distributed reactive mechanisms implemented into products/resources control holons/agents with global centralized scheduling mechanisms. It is intended to capitalize on the advantages of reactive and predictive/proactive approaches, while limiting their drawbacks [18]. In such HCA, the fundamental decision, facing a perturbation, for control holons/agents is whether to still follow the predictive/proactive, but centralized, schedule or not.

Yet another architecture employed in the design of holonic control systems is the Service Oriented Architecture. In [19] - [20], Service Oriented Architectures (SOA) and HMS as the two most currently studied referenced solutions for the next generation of manufacturing systems were studied. Both provide the necessary guidelines to create open, flexible and agile control environments for the smart, digital and networked factory. In addition, the dynamic and automatic reconfiguration of the distributed system, e. g., by adapting or creating new services offered by the several autonomous agents to face the new identified requirements, needs to be studied. Leitão in [21] asserts that MAS is being combined with other complementary technologies, notably SOA, cloud computing, data mining, augmented reality and wireless sensor networks to create the next level of systems design known as the Cyber-Physical Systems (CPS). The convergence of solutions and products towards the SOA paradigm adopted for smart CPS contributes to the improvement of the reactivity and performance of industrial processes, such as manufacturing, logistics, and others. This is leading to a situation where information is being available in near real-time based on asynchronous events, and to business level applications that are able to use high level information for various purposes, such as diagnostics, performance indicators, traceability, etc. [22] - [23].

2.2 Poultry House Feeding

Human involvements in the feeding system of poultry could lead to disease outbreak, undue fatigue and malnutrition of birds [24] - [25]. Birds can live longer without food than without water. Lack of a consistent supply of fresh water hinders the growth of young poultry; it leads to low egg production and early moulting in the laying flock. There are many factors that affect the feed rate and growth of the poultry birds. One of such is the light intensity and color. Studies using monochromatic light reviewed that there is a superior growth for broilers given blue or green light [26]. Some studies suggest that broilers are less active under blue or green light than under red or white light while yellow – red colored light leads to increase in birds' activities.

3. Methodology

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. Fig. 2 shows a wing/section of the model with a travelling hopper. 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. 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. In addition, each extension from the reservoirs is to the fitted with a rotary valve. The mathematical model for the design of the travelling hopper and its dynamic actuation model are presented in sections 3.1 and section 3.2 respectively. These models are simulated in MALAB/SIMULINK environment and the design implement in SIMATIC STEP 7 using S-300 Programmable Logic Controller (PLC) as hardware-in-the-loop. Fig. 3 shows the block diagram of the holonic control of the automated process.

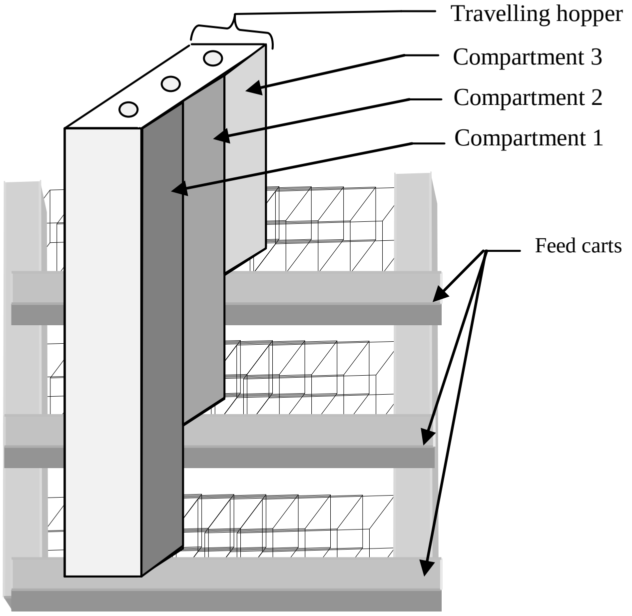

Figure 2. A section of the feeding system with the travelling

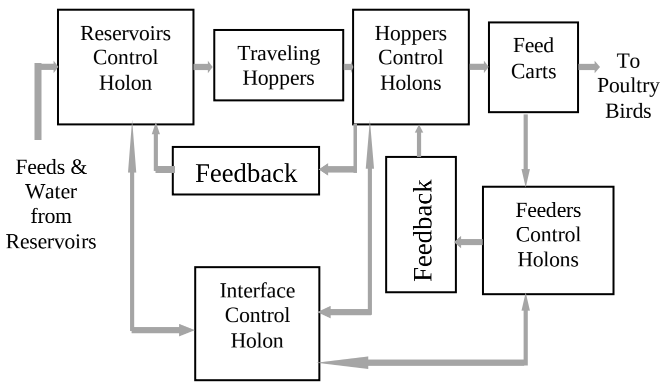

Figure 3: Block diagram of the holonic control of the automated process

3.1 Traveling Hopper Design

Considering the schematic in Fig. 4, it is assumed that the three compartments are approximately of equal volume. Its geometry suggests that each compartment is made up of a rectangular block and a triangular prism tilted at – 45 degrees. The top of the prism is removed to the width, j$= 0.015m$. This is taken to be negligible compare to the height of the side triangles, $y = 0.25m$.

Hence, volume of each rectangular block,

$V_r = length\ x\ width\ x\ height$

For the protruding prism,

$$V_p = area\ of\ side\ triangle\ (A)\ x\ length$$

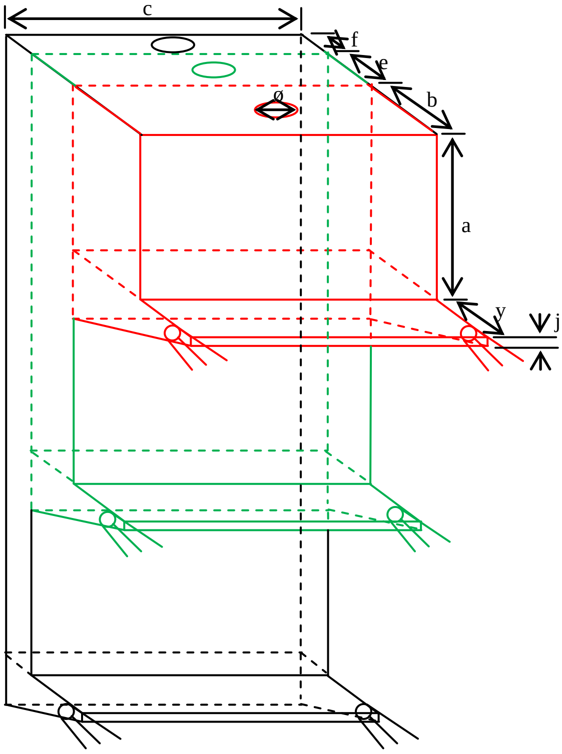

Figure 4: Schematic diagram of the travelling hopper

Therefore, for compartment 1 (tier 1 feeder):

$V_1 = V_{r1} + V_{p1}$

$V_1 = 3acf + \frac{1}{2}fyc$

$V_1 = cf(3a + \frac{1}{2}y)$ ---- (1)

For compartment 2 (tier 2 feeder):

$V_2 = V_{r2} + V_{p2}$

$V_2 = 2ace + \frac{1}{2}eyc$

$V_2 = ce(2a + \frac{1}{2}y)$ ---- (2)

For compartment 3 (tier 3 feeder):

$V_3 = V_{r3} + V_{p3}$

$V_3 = acb + \frac{1}{2}byc$

$V_3 = cb(a + \frac{1}{2}y)$ ---- (3)

Since the volumes are assumed to be approximately equal, equating (1) and (2)

$cf(3a + \frac{1}{2}y) = ce(2a + \frac{1}{2}y)$

$3af + \frac{1}{2}yf = 2ae + \frac{1}{2}ye$ ---- (4)

Equating (1) and (3)

$cf(3a + \frac{1}{2}y) = cb(a + \frac{1}{2}y)$

$3af + \frac{1}{2}yf = ab + \frac{1}{2}yb$ ---- (5)

From (4),

$e = \frac{(3a + \frac{1}{2}y)f}{2a + \frac{1}{2}y}$ ---- (6)

From (5),

$e = \frac{\left(3a+\frac{1}{2}y\right)f}{a+\frac{1}{2}y}$ ---- (7)

But distance between two feed carts, $a = 0.6m$ and $y = 0.25m$, choosing f= $0.1m$, from (6) and (7), we found $e = 0.15m$ and $b = 0.25m$.

Hence, the volume of each compartment, choosing c= $0.5m$,

$V = V_1$

$V = 3x0.6x0.5x0.1 + \frac{1}{2}x0.1x0.5x0.25$

$V = 0.09625m^3$

$V \approx 0.09m^3$ (due to allowances for other installations)

It implies that the hopper will be able to hold up to 0.09 cubic metre (90 litres) of poultry feed. In [27], the densities of poultry feeds were determined. Adopting the mean value of the most dense feed in kg/l, the bulk density of poultry finisher feed is 0.73 kg/l.

Now, $Density = \frac{Mass}{Volume}$

$Mass = Density\ x\ Volume$

$Mass = 0.73\ x\ 90$

$Mass = 65.7\ Kg$

The hopper will be able to carry an instantaneous feed of about 65Kg along its direction of movement.

3.2 Hopper Actuator Model

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. See Fig. 5.

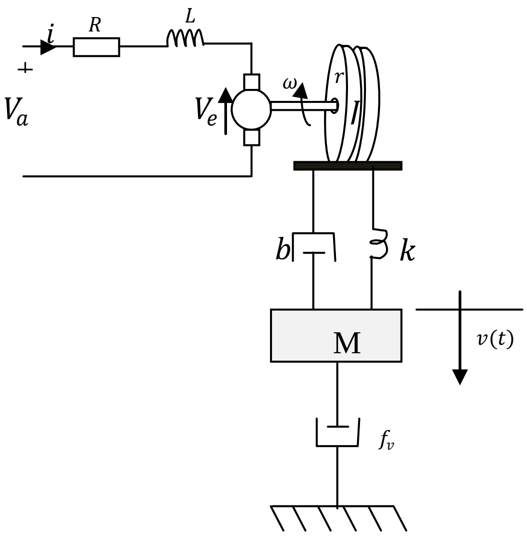

Figure 5: Motor-load model with chain and sprockets

Applying Kirchhoff's voltage law to the motor,

$V_a(t) = i(t)R + L\frac{di(t)}{dt} + K_v\omega(t)$ ---- (8)

Where $V_e = K_v\omega$ for the motor back emf.

In Laplace domain, the equation becomes

$V_a(s) = I(s)R + LsI(s) + K_v\Omega(s)$ ---- (9)

The motor torque is provided by electrical current through the winding and is given as

$T_m = K_m\omega(t)$

$K_m i(t) = J\dot{\omega}(t) + b\omega(t) + k\int\omega(t)dt + T_c(t)$ -- (10)

Where T_c is due to viscous damper, f_v. It is also assume that the chain stiffness negligible hence, in Laplace form, (10) becomes

$K_m I(s) = Js\Omega(s) + b\Omega(s) + T_c(s)$ -- (11)

By force – balance equation, let $F_c(t)$ denote the force by the chain drive, then

$F_c(t) = M\dot{v}(t) + f_v v(t)$ -- (12)

In Laplace domain,

$F_c(s) = MsV(s) + f_v V(s)$ -- (13)

Replacing the F_c with the T_c

$T_c(t) = rF_c(t)$ -- (14)

And

$v(t) = r\omega(t)$ -- (15)

In Laplace form, (14) and (15) become

$T_c(s) = rF_c(s)$ -- (16)

$V(s) = r\Omega(s)$ -- (17)

Substituting (13), (16) and (17) into (11) and eliminating $\Omega(s) = \frac{V}{r}$,

$$K_m I(s) = (Js + b)\frac{V(s)}{r} + r(Ms + f_c)V(s)$$

$$I(s) = \left(\frac{J + r^2 M}{rK_m}s + \frac{b + r^2 f_v}{rK_m}\right)V(s) \quad \text{-- (18)}$$

Substituting equation (17) and (18) into (9)

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

$$V_a(s) = \left[\left(\frac{J + r^2 M}{rK_m}s + \frac{b + r^2 f_v}{rK_m}\right)R + \left(\frac{J + r^2 M}{rK_m}s + \frac{b + r^2 f_v}{rK_m}\right)Ls + \frac{K_v}{r}\right]V(s) \quad \text{-- (19)}$$

Let $a1 = \frac{J + r^2 M}{rK_m}$, $b1 = \frac{b + r^2 f_v}{rK_m}$ and $1 = \frac{K_v}{r}$, then (19) becomes

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

$$\frac{V(s)}{V_a(s)} = \frac{1/_{La1}}{s^2 + {}^{(Ra1+Lb1)s}/_{La1} + {}^{(Rb1+c1)}/_{La1}} \quad \text{-- (20)}$$

Design criteria are such that the rise time is less than 3 seconds, the settling time is less than 5 seconds and the percentage overshoot is less than 5%.

The communication procedure, for executing a task between the WIP agent and the resource holon, is described in Fig. 6. The procedure is controlled by the co-ordination module in the WIP agent and resource holon respectively. A WIP agent plays as an active role to negotiate with resource holons.

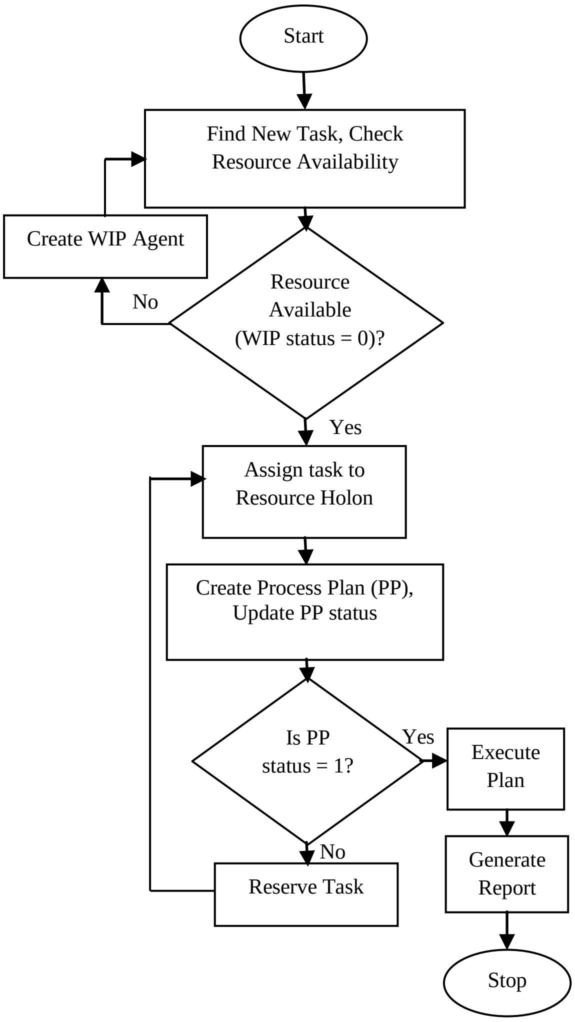

Figure 6: Flowchart for Holon Communication

4. Results and Discussions

The hopper's speed response presented in Fig. 7. It can be seen that the rise time is 1.04 sec, the settling time is 1.91 sec and the percentage overshoot is reduced from 12% of the uncontrolled system to 0.0841% of the finally controlled system. The gains of the embedded PID are $K_p = 10,\ K_i = 1\ and\ K_d = 28$.

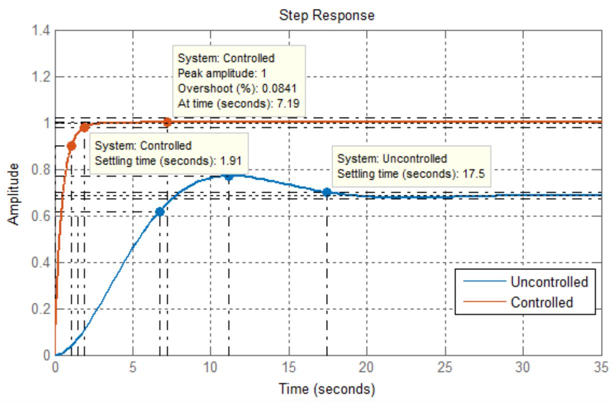

Figure 7: Final response of the system to step input

In order to use the developed continuous transfer function of the model as the plant system in STEP 7 programming, the plant was sampled at 0.1 seconds discretized using bilinear approximation. The Siemens Step 7 continuous control PID block requires the use of integral time constant T_i and derivative time constant T_d for its operation. The response to discretized system is shown in Fig. 8. The conversion of the control parameters to its time constants equivalence give:

$K_p = 10,\ T_i = 100ms\ and\ T_d = 280ms.$

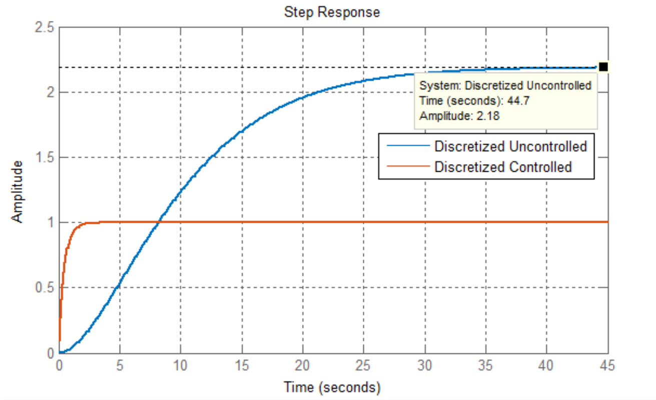

Figure 8: Response to the discretized system

When the system was fed an arbitrary input (a square wave) which simulate a change in direction of the traveling hopper, the result shown in Fig.9 was obtained and the system parameters given in Table 1.

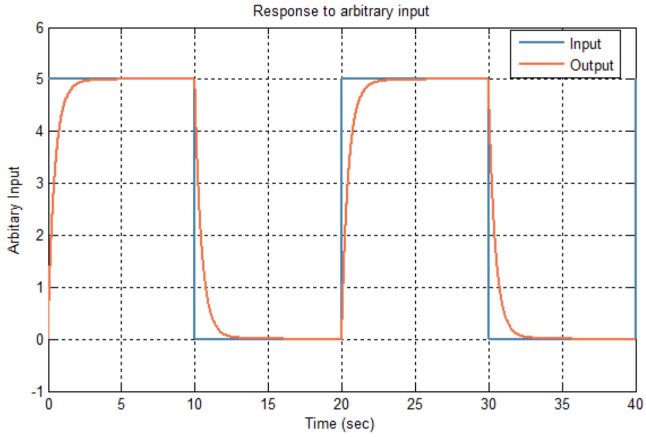

Figure 9: Response to arbitrary input

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

The input to the system driven by dc motor must go through a motor driver (H-bridge driver) to provide the required current and torque for any given set-point (speed). The motor driver supplied with 24 volts input signal (either forward signal or reverse signal) from the PLC changes the direction of the motor according to signal received. The outputs from the model are the speed in revolution per minute (rpm), the motor armature current in ampere (A) and the motor torque in Newton per metre (N/m) while the input is the armature voltage in volts (V). Fig. 10a and Fig. 10b show the actuators' characteristic responses to the driver's signals.

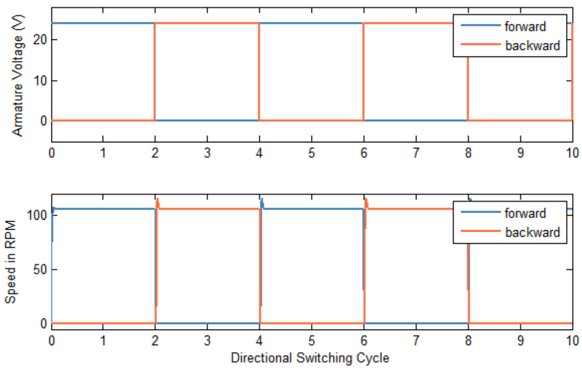

Figure 10a: Motor speed response to motor driver's directional signals

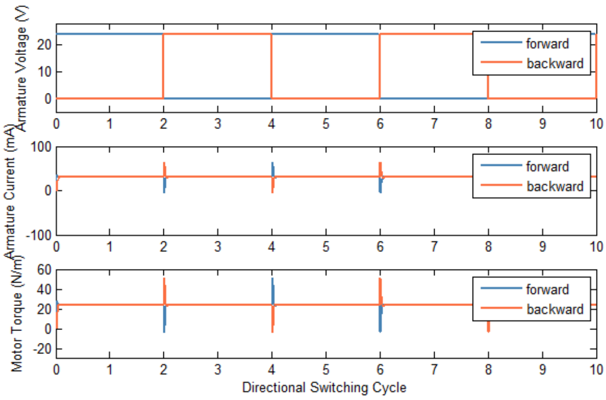

Figure 10b: Motor current and torque responses to motor driver's directional signals

After implementing the design in SIMATIC STEP 7, a test task holon was created showing wing A holon being 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. Fig. 11 and Fig. 12 show the results from the developed HMI.

From Fig. 11, it can be seen that only wing A and B are active with the given tasks. The columns "Op Time (ms)", "No per day" and "Interval (ms)" correspond to operational time in milliseconds, number of times of operation is to be carried out per day and the time interval between operations also in milliseconds respectively. The last column shows the Work In Process (WIP) created as soon as the given orders are accepted and being processed. The hoppers in operation and their respective tiers in service are being displayed as reports on the screen. The buttons for the wing-task commands changed to "A Now Busy" for wing A and "B Now Busy" for wing B. this is to ensure that no new task is allowed (rejected) while carrying out the given assignments unless the last given tasks in process is cancelled by pressing the "Default" button.

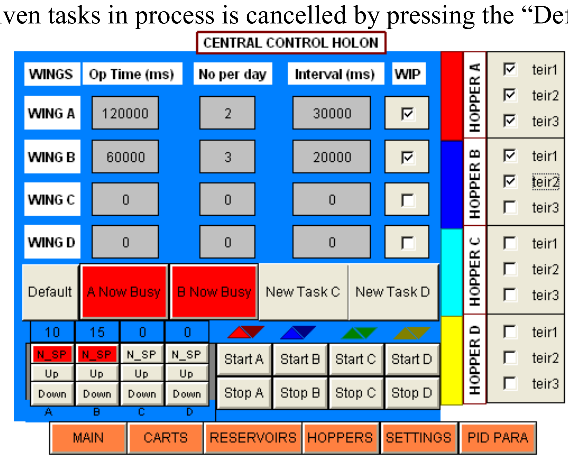

Figure 11: Results from HMI central control holon testing the system's autonomy

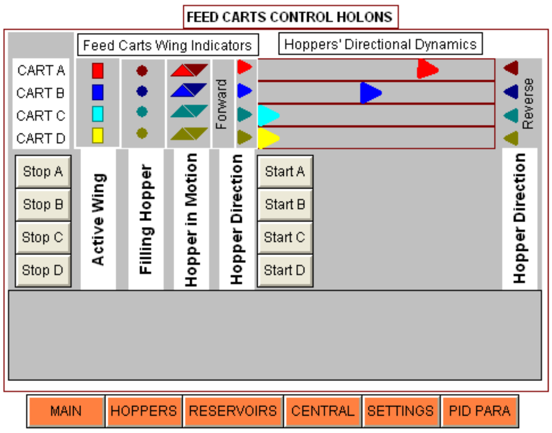

Figure 12: Results from HMI carts control holon testing the system's autonomy

Also worthy of note is the different speeds with which the travelling hoppers are moving made possible by new set-points (N_SP) buttons. For hoppers A and B, the speeds are set to 10 and 15 units respectively.

5. Conclusion

The implementation with the SIMATIC software incorporating hardware-in-the-loop helped in realizing the design based on HCBA. The speed response of the hopper is fast enough, settling at 1.19 seconds. The design is customizable in operation, exercises autonomy and cooperation with visual results from the HMI. The design concepts is not limited to application in poultry feeding only but can be applied in other production processes and control. Further work can be carried out on the stability of the design.

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