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DEVELOPMENT OF A SOLAR-POWERED INCUBATOR WITH AN AUTOMATIC CONTROL SYSTEM

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Abstract: Incubators provide enabling environment for egg hatching and their efficiency greatly depend on accurate monitoring and control of environmental conditions within the device. This monitoring and control require a stable supply of power. However, most rural communities are not connected to the national grid and where connections are established, epileptic supply is mostly experienced. This work develops a solar-powered incubator to guarantee stable power supply. The power-demanding components of the incubating system were selectively direct current (dc) biased to get rid of the inverter in order to lower the cost of production. The control unit which is essential for controlling the vital environmental and physical conditions consists of the temperature sensor, humidity sensor and also the dc motor speed controller that occasionally turns the eggs' tray. This turning is important to prevent the yolks from sticking to the shell. This work drifted from the orthodox tilting of the eggs' tray by exploiting tray shaker to achieve the turning effect. All these are coordinated by a microcontroller (Arduino Uno) programmmed in C-language to enhance the process. Several tests were carried out. The results indicate that the time taken for the temperature and humidity to bounce back to the set values differ for different weather conditions. The average values of time taken for the temperature and humidity to bounce back to set values were respectively 0.37 minutes and 0.47 minutes for a dewy weather; 0.65 minutes and 0.49 minutes for a sunny weather; 0.28 minutes and 0.30 minutes for calm weather; 1.19 minutes and 1.64 minutes for a raining weather. The built system has also eliminated the challenge of epileptic power supply and a less complex and effect egg shaking mechanism achieved.

1. INTRODUCTION

Incubation is the process of keeping the fertilized eggs warm in order to allow proper development of the embryo into a chick (Okpagu and Nwosu, 2016). An incubator is a system that simulates natural conditions that are favourable for egg hatching. The most important conditions are temperature, humidity, ventilation and egg turning. The control of these conditions is of extreme importance for successful hatching of eggs. It is very essential to control the temperature and humidity inside the incubator. These ranges are between 36 to 39^{o}C and 50 to 70% respectively (Okonkwo and Chukuezie, 2012). If the temperature or humidity is less or more it will affect the hatching efficiency. To control these parameters there is need for a stable power supply. Nigeria, being a developing country, still faces the challenge of stable power supply. Several rural areas are yet to be connected to the national grid and epileptic power supply where connections are established.

Energy plays key role in shaping national economies and social developments. Several renewable energy projects in many countries have shown clearly that renewable energy can directly contribute to poverty alleviation by providing a substantial amount of energy needed for creating businesses and employment especially in rural communities that have not yet been connected to the national grid (Federal Ministry of Environment, 2013).

Problem Statement

In an effort to diversify the economy, the Nigeria government is tilting towards agriculture to provide a backup to 'over dependent' petroleum resources. Modern poultry farming, though economically lucrative is close to obscurity especially in rural areas. The natural incubation is fast becoming insufficient to cater for the increasing population growth; as such, the construction of an incubator that can hatch more eggs than a mother hen could handle at a time is necessary to match the demand of the increasing population. An incubator

must simulates the natural conditions provided by the mother hen. Studies have shown that the natural incubation occurs at an approximate temperature of 37^{o}C and average humidity of 55%. The turning of egg is also done to prevent solidification of the yolk. To control these factors, a stable power supply to the incubator system is required. Most rural communities are faced with the challenge of power supply from the national grid, as such an alternative means of powering the proposed incubator becomes a necessity. Solar energy was use to power the developed incubator. The choice of solar energy as a means of powering the incubator stems from the fact that Nigeria is blessed with abundant solar radiation. Also, the target populations also include the rural population. The photovoltaic (PV) system is costly due to the fact that the components are not locally manufactured. This has a direct high cost implication given that the target population is weak financially. These are the challenges this work resolved.

1.1 The State of Arts

Incubation temperature has a significant effect on the hatching rate of fertilized eggs. Therefore, the major goal of increasing poultry production may be achieved with the aid of hatching equipment with more accurately controlled temperatures, thereby ensuring a high hatching rate and maintaining immunity (Wei *et al*., 2016). Bone formation and growth plate formation are crucial for embryo development and a temperature deviation of 1°C above optimum may increase the incidence of skeletal disorders and leg problems in broiler chickens (Oznurlu *et al*., 2016).

Since from the days of old, many methods have been used to supply warmth to an incubator; kerosene lamp, conventional grid power (Mohd *et al*., 2015), biogas (Ogunwande *et al*., 2015), coal, generating set (Adegbulugbe *et al.*, 2013). Of recent is the budding renewable energy sources especially photovoltaic (PV) commonly solar (Nithin *et al*., 2014).

The role energy plays in human existence can never be overemphasized. Without energy there is no economy (Oseni, 2012). Maintaining optimum temperature and humidity implies an incubator must simulate the natural conditions provided by the mother hen. Studies have shown that the natural incubation occurs at an approximate temperature of 37^oC and average humidity of 55% (Benjamin and Oye 2012). The turning of egg is also done occasionally to prevent solidification of the yolk and nutrient distribution around the shell. The effect of epileptic power supply on an incubator was well pronounced when Umar *et al*. 2016 incubated some eggs that refused to hatch. They cited unstable power supply as the cause.

For modern incubators, stable power supply is not an option. However, the country is faced with the challenge of stable power supply from the national grid and most rural communities are not even connected to the grid. Nigeria experiences about “six (6) hours” of solar radiation per day. The solar radiation intensities range from 3.5-7.0 kWh per square meter per day increasing from the South to the North, (Oseni, 2012). This energy source could be available for 26% of the day (9.00am-4.00pm). These facts and figures regarding Nigeria’s geographical location clearly shows that Nigeria has very high potential to generate significant amount of electrical energy from solar energy (Bayar, 2013).

Breakthroughs in the field of semiconductor technology have handled the ‘baton’ of logic control to sensors and programmable microchips. These chips (microprocessors), in various forms, shapes and names (PIC as used by Benjamin and Oye (2012) and ATMEGA used by Radhakrishnan *et al*., (2014) in their respective works) come in handy as far as systems’ control are concerned.

(Wu *et al*., 2008) revealed that the expectations of relative humidity during incubating cycle of chicken eggs are; from 1st to 3rd day relative humidity is 53%, from 4th to 6th day relative humidity is 58%, from 7th to 18th day relative humidity is 55%, in 19th day relative humidity is 65%, in 20th day relative humidity is 70%, and in 21st day relative humidity is 65%. For this reason, resetting buttons have been incorporated into the microcontroller to allow for proper readjustment settings for both temperature and humidity. A relatively simple and cost effective egg turning mechanism is one of the notable features of this work. Taking into consideration power and economic challenges being faced, the work addresses these challenges by powering the incubator with a PV system and also tactically removing inverter to witter down the cost of power supply to the incubator.

2. MATERIALS AND METHOD

2.1 The Construction of the Incubator

2.1.1 Mechanical Design

The project construction began with the mechanical components which consist of the incubator frame, casing and the egg shaker (turning) tray.

2.1.2 Incubator Casing

The construction of the incubator began with using hard wood to construct the main body of the incubator as shown in figure 2.1. Plywood and glass were used to create the side boards to give the aesthetic carved out shape. They were chosen due to their good thermal insulation, ease of construction, durability and availability.

Figure 2.1: The casing of the prototype incubator

2.1.3 Heating Element

Halogen bulb shown in figure 2.2 (use in motorcycle headlights) was made the heat source of the incubator. Reason? It is dc powered and can generate more than enough heat to incubate the eggs.

Figure 2.2: Halogen Bulb

2.1.4 Water Pan

The function of the water pan is to aid humidity inside the incubator’s chamber. The dimension of the water pan used is shown in figure 2.3.

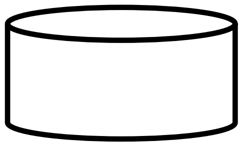

Figure 2.3: Water pan

2.1.5 Circulating Fan

A Central Processing Unit (CPU) fan was fixed inside the incubator to eliminate the challenge of temperature gradient from the heat source point to other areas inside the chamber. In other words, the circulating fan distributes heated air uniformly around the incubator's chamber and so also humidity.

2.1.6 Ventilation

Three 0.5cm diameter holes (as shown in figure 2.4) were bored on top of the incubator. This is to pave way for the escape of excess heat. There is also the need for oxygen exchange by the eggs. The bored holes take care of that.

Figure 2.4: Oxygen/humidity control holes

2.1.7 The Egg Turning Mechanism

In order for a cell to grow, it needs oxygen and nutrients that requires shaking so that they can be distributed evenly around the shell. The conventional method (used in modern incubators) of ensuring oxygen exchange and distribution of nutrients around the shell is by tilting the eggs' tray. This work looked away by exploiting tray shaker for more effective nutrient distribution and a comparatively simpler mechanism.

The heart 'beat' of the shaker (turner) is the two dc motors. The motors are fastened to a plastic material with uneven bodies attached to their rotors (figure 2.5). Once the motors are activated, the rotors cause vibration of the plastic material which carries the eggs' tray. The vibration is invariably transmitted to the eggs' tray. In this manner the sticking to shell of the eggs is prevented and nutrients are evenly distributed within the shells.

Figure 2.5: The egg shaker

2.2 The Design of Photovoltaic (PV) System

The power source to the incubator is from a PV system due to the fact that most rural communities are not connected to the national grid. The proposed PV system will contain solar panel, deep cycle battery and a charge controller. The heating element is dc powered as such the need for an inverter was eliminated. Figure 2.6 shows the block diagram of the PV system for the incubator.

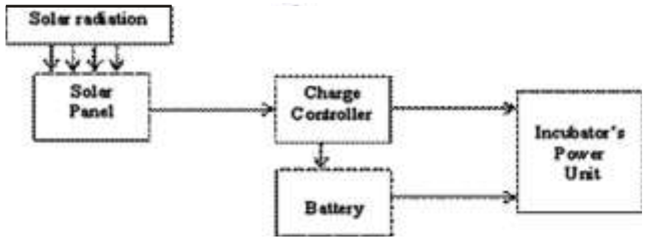

Figure 2.6: The block diagram of the PV system for the incubator

From figure 2.6 above, on the top block is the radiant energy emitted by the sun (solar radiation). This radiation which is in the form of light is trap by the solar panel which converts it to electricity (direct current) using semiconductor technology. This direct current charges the battery through the charge controller that prevents overcharging or undercharging of the battery ensuring it safety. During the day, the electricity generated is fed directly to the incubator's power unit when the battery is fully charged. At night, when there is no solar radiation the battery takes over the supply of power to the incubator's power unit. This process ensures constant supply of power.

2.3 The Control Unit

The control unit defines the success of an incubating system. Here, the temperature, humidity and egg turning mechanism are manipulated tactically to create hatchability environment for the eggs. The full control unit is represented in figure 2.7 below. The sensors (temperature and humidity) sense change in the incubator and send the response to the microcontroller via analogue to digital converter (ADC). The microcontroller based on the programmed logic activates or deactivates (as desired) the bulbs and/or the fan via relay. Also, every eight hours, the controller also send signal to activate the dc motor that shakes the egg tray.

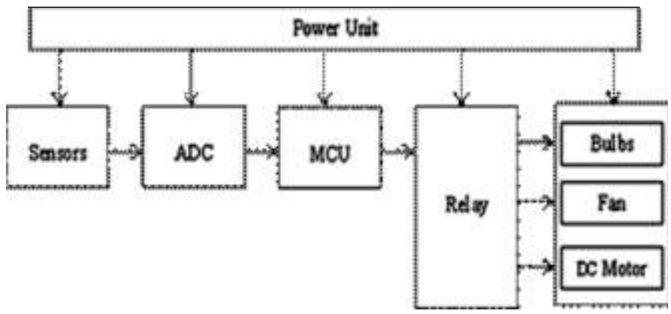

Figure2.7: The block diagram of the control unit

2.3.1 Temperature and Humidity Control

DHT11 monitors the change in heat and moisture inside the incubator's chamber and relates it to the microcontroller (Arduino Uno) via the analogue-to-digital (ADC) converter. The microcontroller sends signals to the relays to switch ON/OFF the bulb and circulating fan to a 12V supply. The reason for the circulating fan is to; eliminate the challenge of temperature gradient from the heat source point to other areas inside the chamber and aid in moistening the chamber by blowing on the water inside the water pan. In other words, the circulating fan distributes heated air uniformly and moisture around the incubator's chamber. The constructed control circuit is shown in figure 2.8.

Figure 2.8: The constructed control circuit

2.3.2 DC Motor Control

The DC motor is the ‘heart’ of the tray shaker. However, it will only run at intervals of 8hrs. The egg tuning is not perpetual. The dc motor was interfaced to the microcontroller via relay and switching transistors. The microcontroller sends a signal between the intervals of 8hrs to activate the relay which set the motor running for 1minute and deactivate. The block diagram of the egg turning mechanism is captured in figure 2.9.

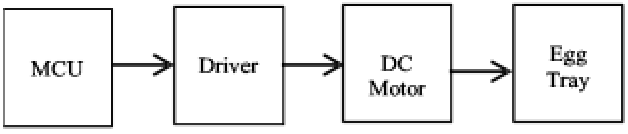

Figure 2.9: The block diagram of the egg turning mechanism

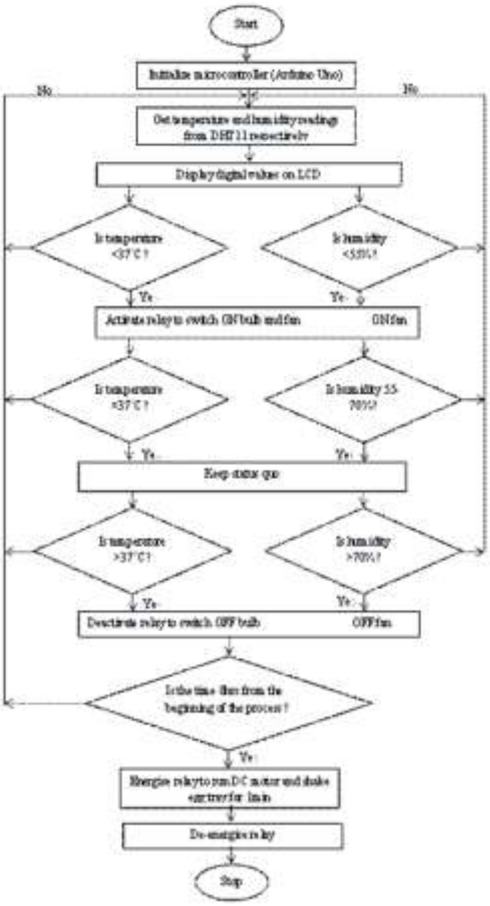

Figure 2.10 Flowchart of the control logic

2.3.3 The Control Logic

A program in C language was written and burnt into the microcontroller (Arduino Uno) to harmonise the control functions. The summary of the control logic is vividly captured in the flowchart (Figure 2.10) follows by the circuit diagram (Figure 2.11) of the design and finally Figure 2.12 shows the developed prototype.

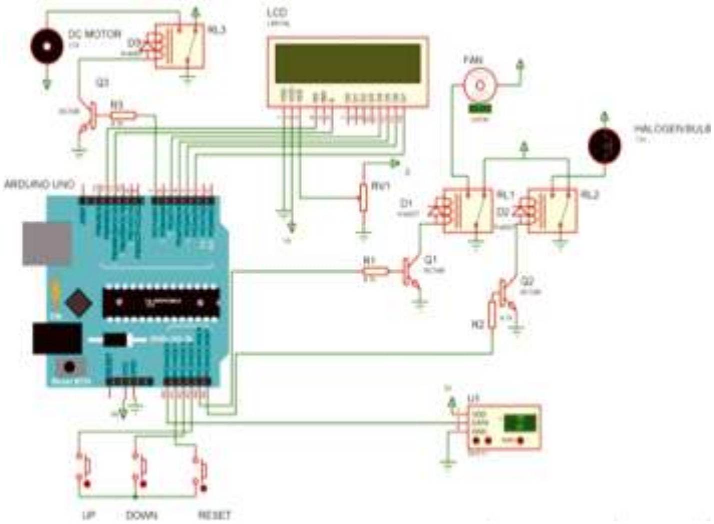

Figure 2.11: Circuit diagram

Figure 2.12: The prototype

3. RESULTS AND DISCUSSION

Several tests were carried out on the prototype under four different weather conditions and the following data were generated.

•Day 1, the test was between the hours of 4am to 7am when it was expected to experience morning dew.

•Day 2, the test was carried out between the hours of 12pm to 3pm when the sun was at its peak.

•Day 3, between the hours of 7pm to 10pm when there was no solar irradiation.

•Day 4, when it was raining.

•Day 5 captures the functionality of the eggs’ tray shaker.

Tables 1 – 5 present the results of tests conducted on the developed prototype.

TABLE 1: RESULTS OF DAY 1 EVALUATION

Hours (am)	Temperature (^{0}C) (set at 37^{0}C)	Humidity (%) (Set at 55%)	Duration of deviation from the set temperature value (Minutes)	Duration of deviation from the set humidity value (Minutes)
4:00	36	57	0.66	0.72
5:00	36	56	0.71	0.80
6:00	37	56	0.53	0.17
7:00	37	55	0.71	0.20

TABLE 2: RESULTS OF DAY 2 EVALUATION

Hours (pm)	Temperature (^{0}C) (set at 37^{0}C)	Humidity (%) (Set at 55%)	Duration of deviation from the set temperature value (Minutes)	Duration of deviation from the set humidity value (Minutes)
12:00	37	54	0.58	0.51
01:00	36	54	0.47	0.80
02:00	37	52	0.22	0.45
03:00	37	53	0.20	0.22

TABLE 3: RESULTS OF DAY 3 EVALUATION

Hours (pm)	Temperature (^{0}C) (set at 37^{0}C)	Humidity (%) (Set at 55%)	Duration of deviation from the set temperature value (Minutes)	Duration of deviation from the set humidity value (Minutes)
07:00	37	57	0.20	0.50
08:00	36	55	0.48	0.12
09:00	37	56	0.13	0.45
10:00	37	55	0.31	0.11

TABLE 4: RESULTS OF DAY 4 EVALUATION

Hours (pm)	Temperature (^{0}C) (set at 37^{0}C)	Humidity (%) (Set at 55%)	Duration of deviation from the set temperature value (Minutes)	Duration of deviation from the set humidity value (Minutes)
1:12 (shower)	34	65	1.02	1.50
1:33 (heavy)	32	67	1.44	2.01
1:51 (shower)	35	66	1.17	1.81
2:05 (after rain)	32	66	1.12	1.22

TABLE 5: RESULT OF DAY 5 EVALUATION

Hours	Shaker activated?	Duration (Minutes)
08:00	Yes	1
16:00	Yes	1
24:00	Yes	1

From Table 1 to Table 4, it can be seen that humidity and temperature tend to overshoot or go below the pre-set values in the incubator's chamber due to external weather conditions. However, the effective control system put in place was able to restore stability within a very short period of time. In other words, the results show the effectiveness of the built control system.

A novel egg shaking mechanism was developed and programmed to be activated 8 hours apart to prevent the yolks from sticking to the shells. Table 5 shows that the egg shaker mechanism was successfully achieved.

The results also show that the time taken for the temperature and humidity to bounce back to the set values differ for different weather conditions. Table 1 shows that it takes average time of 0.37 minutes for temperature and 0.47 minutes for humidity to bounce back to the set values after disruptions. In Table 2, the time was 0.65 minutes for temperature and 0.49 minutes for humidity. While in table 3, 0.28 minutes and 0.30 minutes were the average bounce-back times of temperature and humidity respectively and table 4 has 1.19 minutes as average recovery time of temperature and 1.64 for humidity.

Finally, the results show the effect of external environmental conditions on the incubator's chamber. The higher the humidity the lower the temperature in the incubator chamber and vice versa. System disruption was successfully monitored and desired control achieved.

CONCLUSION

A successful incubator is one that has it optimal environmental conditions under excellent control with little human monitoring and interference. The set objectives of this work were toward realizing a robust incubator. The methods employed in realizing these objectives were well studied for efficient and cost effective system keeping in mind the average financial status of the rural dwellers. A modular approach was favoured in this work. The work was developed in three modules: the physical incubator, the PV system that power the system and the control system that keeps the controlled parameters (temperature, humidity and egg turning) at optimal points. The modules were then coupled to give the robust incubating system. The results indicated that the time taken for the temperature and humidity to bounce back to the set values differ for different weather conditions. The average time recorded for both temperature and humidity to bounce back to set values (after upset) in dewy weather were 0.37

minutes and 0.47 minutes respectively. For sunny weather the values read 0.65 minutes for temperature and 0.49 minutes for humidity. While in calm atmosphere (devoid of rain or sun influence), values of 0.28 minutes and 0.30 minutes were obtained for the average bounce-back times of temperature and humidity respectively. In a raining weather, the system's response indicated temperature took 1.19 minutes to go back to the desired (set) value while for humidity the time recorded was1.64minutes. The economy advantages of this work can never be overemphasized, especially during this period where government is looking away from the petroleum resources to diversify the economy.

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