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Sustainable poultry farming: A concept of IoT-based poultry management system for small-scale farmers

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ORIGINAL STUDY

Sustainable Poultry Farming: A Concept of IoT-based Poultry Management System for Small-scale Farmers

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Abstract

Conventional poultry management techniques are failing to meet increased demand for poultry products as the population continues to grow. As a result, this issue has become a major concern for small-scale farmers, particularly those in low-income areas, in terms of food security. One of the main reasons for this is that the farmers rely on intensive farming methods which are inefficient for automating daily poultry operations. However, intensive farming methods pose major environmental concerns to ecosystems and poultry health. Also, the environmental conditions, welfare, and productivity of poultry operations may be harmed by the global climate crisis and poultry waste products can be disastrous to poultry health and need to be managed effectively. This demands for enhanced poultry management systems to alleviate the environmental conditions and boost optimal poultry well-being. This paper presents a compact, low-cost internet of things-based poultry management system for a small −scale farmer. The system employs a synergistic combination of cloud and Internet of Things technologies to monitor and regulate temperature, humidity, water level, ammonia gas concentration, and lighting systems in real time. The hardware prototype was successfully implemented and tested at the Obasanjo poultry farm home in Nigeria. The experimental results demonstrate that the daily temperature is maintained between 27 °C and 32 °C. The relative humidity ranges from 71 % to 72 %, and the ammonia gas (NH3) level increased intermittently for the first three days before remaining steady, reaching a maximum of 30 ppm. The illumination is optimally adjusted using a pre-configured algorithm to promote maximum egg production and poultry health.

Keywords: Poultry health, Internet of Things, Smart sensors, Lighting strategy, Environmental parameters

1. Introduction

Smart technology has long been a primary focus of sustainable agriculture future [1]. Agriculture sector has substantially enhanced the world's economy growth in terms of food security [2−4], job creation [5−7], raw materials [8−10] and poverty alleviation [11−13]. In addition, this sector accounts for nearly 4 % global GDP, with about 1.4 % attributed to poultry production [14]. The poultry farming is a major contributor to economy especially in developing countries, where majority rely on livestock production for livelihood and nutritional value. The high demand for poultry products such as eggs and meat in this region is driven by its affordability, nutritional value, and sustainability. Poultry farming in Nigeria holds significant potential for economy growth and food security but faces several challenges that hinders its growth and sustainability. Currently, small-scale farmers rely on

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manual processes for various operations such as feeding, watering, egg collection, health management, disease control, and waste management which are inefficient to enhance productivity and efficiency. Also, the growing population and increasing demand for nutritious food further increases the burden of agricultural systems, which calls for urgent attention for smart agriculture such as smart irrigation system [15], nutrient management [16], smart technology and renewable energy [17], livestock monitoring using agricultural drones and robots [18], and food waste management [19] to enhance food security and preserve environmental integrity. For these reasons, agripreneurs and farmers have begun to focus on strategies to promote poultry sustainability with special emphasis on smart poultry management system and Internet of Things (IoT).

The IoT is an emerging smart technology, which is gaining prominence in wide range of applications including smart farming. The internet of Things is a network of interconnected devices, sensors and other technologies that are used to automate a variety of applications via internet. Similar technologies proposed in the literature for intensive and medium scale poultry farming includes smart sensor [20], 5G cellular network [21,22], radio frequency identification [23], Zig-Bee [24], computer vision and imaging [25,26], blockchain [27], robotic [28] and drones [29,30]. An IoT-based poultry management system seeks to remotely monitor and automate various environmental parameters that directly impact the health and productivity of the birds. Due to the inhospitable climate, it imperious to ensure optimal conditions of poultry house parameters such as temperature, humidity, lighting, air quality and water intake level. Increased temperature levels in poultry houses increase mortality rates and reduce growth performance, eggs production, feed efficiency and survival rates of the chickens. The welfare of layers rely heavily on various ecological variables that may adversely influence the bird egg weight, incubation time and hatching time [31,32]. Unhygienic poultry house may cause accumulation of toxic gasses (NH_3 and CO_2), increase resources competition among the birds and may also increase the chances of spread of infections [33]. The proposed poultry scheme focuses mainly on layers breeding i.e., eggs production for small-scale farmers. United Nations (UN) highlights the need for investing in smart agriculture [34] which includes food shortage mitigation, provision of nutrition for all by 2030 and enhancing of food security. Alongside, the Sustainable Development Goals 2 (SDGs-2) emphasizes the need to end hunger, improve nutrition, and prioritize sustainable agriculture. Also, this study contributes to some the SDGs including access to sufficient and nutritious food, foster individual health and well-being and investment in sustainable agriculture. The motivation of this study lies in meeting the nutritional needs of a growing population while also addressing the challenges of inefficient poultry management caused by conventional practices, as well as exploring smart technology as a solution for profitable and sustainable poultry farming. The research emphasizes on environmental monitoring in poultry farming. This includes boosting egg production with the use of a lighting scheduling system.

The main focus is to ensure sustainable food production system via sustainable agricultural practices with smart technology, which ensure access to nutritious food and improve production of poultry products. This study proposes a cheap and portable IoT-based poultry management system that enables farmers to remotely track, and regulate various environmental parameters that can affect the poultry's health and productivity. Furthermore, the proposed scheme seeks to enhance productivity, reduce losses, and improve overall management of poultry through real-time monitoring for small-scale farmers in developing country like Nigeria. The novel contributions of this paper are summarized as follows.

Nomenclature

Ag	Ammonia gas sensor
EPP32SOC	Wireless Enable System on Chip Microcontroller
LED	Light Emitting Diode
Lg	Light sensor
IoT	Internet of Things
SDG	Sustainable Development Goal
Tp	Temperature sensor
HC-SR04	Ultrasonic sensor
UN	United Nation
Wl	Water Level sensor
SonEx	Switching on Extractor
SoffEx	Switching off Extractor
SonFan	Switching on Electric Fan
SoffFan	Switching off Electric Fan
SonHm	Switching on Humidifier
SoffHm	Switching off Humidifier
SonHx	Switching on Heater
SoffHx	Switching off Heater
NH_3	Ammonia gas
CO_2	Carbondioxide
CH_4	Methane
C2-C3	Light hydrocarbon
H_2S	Hydrogen sulfide

- The paper utilizes IoT, embedded systems, Bylnk cloud, and advanced algorithms to improve egg production and poultry health.
- In real time, the proposed system supervises and manages vital environmental parameters such as temperature, humidity, light, ammonia gas concentration, and water level.
- The proposed system employs cutting-edge sensors, including the DHT11 humidity and temperature sensor, the HC-SR04 water level sensor, the MQ-2 ammonia gas sensor, the LDR light sensor, and the PH sensor. The system uses the Bylnk cloud to improve user interaction by enabling wireless connectivity between devices and poultry users.
- Small-scale farmers can access real-time environmental data via the internet from anywhere in the world as the sensor data transferred in real-time to the Bylnk cloud and App. This features enhances health and production while allowing for more accurate poultry monitoring.
- The study incorporates a lighting scheduling approach to optimize egg production.
- The study utilizes smart water level sensors to regulate water levels in storage tanks, resulting in greater water conservation than manual methods.
- The study highlights the significance of smart sensors for poultry health and well-being, as well as their influence on smart farming techniques.

2. Literature reviews

Poultry refers to domesticated birds raised primarily for meat and egg, making it a key component of global food security. Various environmental variables such as temperature, humidity, ammonia gas concentration, lighting, and water supply influence the survival, production (eggs), growth, and management of poultry birds in many ways. Several studies have been conducted on how to improve the poultry welfare as inefficient poultry management results in prolonged health crisis, decreased productivity, economic losses, and high mortality rate of poultry birds [35]. Many poultry environmental variables of interest describe the health and welfare of poultry but only a few variables are of significant of interest.

2.1. Temperature

In poultry, temperature refers to the thermal environment in which poultry is raised. Temperature control is a vital aspect of poultry management as it directly affects the health, growth, and productivity of poultry. Birds are warm-blooded species, and they assume uniform internal body temperature [36]. Physiological processes such as respiration, feeding, metabolism, egg production, growth and general behaviour are affected by the temperature [37]. Maintaining optimal temperature level is essential for the well-being of poultry, for instance, broiler chicks typically require a temperature of about 32–35 °C during the first week of life, gradually decreasing as they grow. Layers, generally thrive in a temperature between 18 and 24 °C [38–40]. However, poultry birds are sensitive to temperature changes for instance, extreme temperature can significantly affect egg production, shell quality, and egg weight in layers, and low temperature in layers distorts their metabolism process leading to nutritional deficiencies.

2.2. Humidity

Humidity refers to the amount of moisture present in the air within poultry environment. It is a vital environmental parameter that affects poultry welfare. The major source of humidity in poultry facilities is typically poultry manure, which is a composition of Ammonia, NH_3, Carbon dioxide, CO_2, methane, CH_4, light hydrocarbon,C2–C3 and Hydrogen sulfide, H_2S [41]. Other sources includes litter moisture content, air quality, ventilation, and gas concentration. Relative humidity is used to measure humidity level, indicating the amount of moisture in the air relative to the maximum amount of moisture the air can hold at a given temperature. The acceptable humidity level for optimum poultry condition is within the range of 50 %–70 % [42]. Also, the impact of humidity on poultry has different consequences depending on humidity levels, humidity within the optimal range helps to minimize respiratory diseases, increase growth, and enhance cooling mechanisms and lower dehydration. However, high humidity level can breed ground for harmful microorganisms, increased cold stress and often lead to decrease egg quality due to increase stress hormones in eggs [43].

2.3. Lighting

Lighting refers to the use of artificial or natural light to create an optimal environment for poultry growth, health, and productivity. In poultry, proper lighting is a major concern as it affects poultry's behaviour, reproduction, egg shell quality and welfare [44]. It plays a crucial role in regulating the biological rhythms of poultry and also influences behaviour such as feeding, mating and egg-laying. Lighting significantly affects egg production in layer i.e., birds exposure to increase daylight tend to produce more eggs. However, insufficient light may lead to stress and health issues while excessive brightness can result in discomfort [45]. Various types of lighting sources such as incandescent, fluorescent, and light emitting diode (LED) light serve different purposes [44]as presented in Table 1. LED is a preferred choice in poultry facilities due to its energy efficiency and light quality. The effect of varying light intensity in poultry health and growth is shown in Table 2.

2.4. Ammonia gas concentration

Ammonia is a significant by-product in the decomposition of nitrogenous compound such as uric, urea nitrogen, and protein in poultry manure [52]. It is produced when organic matter in poultry litter such as manure and bedding materials, breakdown. The amount of ammonia excreted by poultry is directly proportional to the protein content of their diet. The decomposition of other organic matter such as uric acid, feed spills, dead birds, organic debris also contribute to ammonia accumulation in the poultry. The unused protein level in poultry diet is excreted in feces and later degraded, releasing NH_4^+, which is further converted to NH_3.

$$NH_4^+(g) \Leftrightarrow NH_3(g) + H^+(g) \tag{1}$$

When ammonia accumulates to toxic level, the NH_3 gas reacts with the existing humidity to form corrosive NH_4^+ solution, which affect the respiratory tract of the birds. However, if the ammonia concentration is not controlled, the poultry can ultimately cause inflammation in the lungs or air sac, leading to severe death [53]. Even at survivable concentrations, excess ammonia can lead to respiratory problem, impaired immune function, reduce growth and egg production [54,55]. In poultry, the harmless limit for NH_3 is 25 ppm and the litter PH is as metric to measure ammonia concentration of poultry facilities. The ammonia concentration and litter PH with their effect are presented in Tables 3 and 4.

2.5. Water supply

Water, chemically represented as H_2O is an essential nutrient in poultry farming. It is crucial in various physiological and metabolic processes in

Table 1. Different lighting sources for poultry management system.

Color	Effects	Species
Red light	For sexual maturity and egg production	Layers
Blue light	Stress reduction and to improve broiler welfare	Broiler
UV lights	Influence chickens behaviour and well-being	Layer and broiler
Fluorescent light	Enhance egg production and maintain stable environment	Layer
LED light	Enhance production performance and egg quality Improve broiler chicken welfare, feed convention rate and productivity	Layer Broiler
CLF light	Influence poultry behaviour, growth rate and reproductive performance	Layer
Combination of light color	Improve growth and productive performance in broiler	Broiler

Table 2. Poulty light intensity on poultry species.

Species	Duration (hrs./day)	Light intensity (Lux)	References
Broiler	16	10–20	[46,47]
Layers	14–16	10–30	[48,49]
Growing pullets	24 (first week), 9 (after six weeks)	10-15, 30-50	[50,51]

Table 3. Ammonia concentration in poultry house and their effect.

Ammonia concentration	Ammonia level	Effect
<10 ppm	Optimal	Best optimal condition for good growth
<10–25 ppm	Threshold	Optimal condition for bird's growth
>25 ppm	High	Condition that leads to significant health issues such as respiratory distress, decreased growth and increased susceptibility to infections and diseases.
>50 ppm	Critical	Risk of severe respiratory damage and other health complications increase dramatically.

Table 4. Ammonia litter PH level and their effect.

NH_3 PH level	Effect
6.0–7.0	Optimal growth for poultry birds
6.8	Ammonia begins to volatize significantly
7.0–8.5	Increase ammonia emission
>8.5	Respiratory issues and other health concerns for the birds.

poultry. Water is vital for thermoregulation, waste elimination, and also serves as a vehicle for nutritional additives [56]. Birds require a constant supply of fresh, clean water to maintain hydration and health. Water aids in softening feed in crop, facilitating its transit through digestive tract, and ensuring the efficient nutrient uptake. The quality and availability of water directly affect the health and productivity of poultry [57]. In addition, clean and uncontaminated water aids optimal growth rate, egg production and bird reproductive performance [58]. The chemical properties of water, including its PH, mineral content, and the presence of contaminants play a vital role in poultry management. Contaminated water can lead to disease outbreaks, while water with excessive minerals can cause scaling in water system.

2.6. Related works

Numerous researchers have adopted internet of Things in poultry farming. Khairul et al. [59] developed an IoT system for poultry farming. The proposed system used smart sensors to detect temperature, humidity, water level and food and also incorporated an alarm system which notify the farmers on the state of the poultry. However, the system can be enhanced with gas sensors to monitor the toxic gas level in the poultry house. [60], used sensors to determine PH value, yolk index, specific gravity of eggs and nitrogen content. IoT has been reported in literatures to detect poultry diseases [61] and monitor air quality [62], light intensity [63], CO_2 concentration [64], poultry welfare [65], water level [66], chicken behaviour [67], ammonia gas concentration [68], egg production [69,70], chicken cage [71], food quality control [72] and PH level [73]. Chigwada et al. [74] presented an IoT-based poultry system for small-medium scale producer. Their work used various smart sensor to monitor vital environmental conditions that affect poultry health and welfare. The system features a novel light scheduling and automatic switching control. An electric power control strategies for minimizing poultry farming is presented in Ref. [72]. Their proposed strategy utilized a novel algorithm to minimize the power consumption and distributed water supply, and poultry farm's environment. The use of smart sensors [75–77], bid data [78], machine learning [79–81], artificial intelligence [82–84], edge computing [1,85], deep learning [86], and hybrid AI and IoT [87] is currently gaining significant interest in poultry farming. Manshor et al. [88], propose a Raspberry Pi poultry monitoring system. The system not only monitors the temperature and humidity levels of the poultry house but also minimize energy consumption within the poultry. It IS equipped with alarm system which notify the farmers on the potential danger of environmental parameters variation and excess power consumption. [89], presented a poultry management scheme that uses IoT sensors to monitor poultry's house environmental conditions such as temperature, humidity, wind speed, and Co2 emission and minimize energy usage. The scheme uses a programmable logic controller ECM6L45160 as microcontroller to automate the operation of exhaust fans and establish a connection sensors and cloud server. The system is further embedded with an adjustable power control mechanism and gas sensor that minimizes the power consumption and toxic gas level within the poultry facility. Elmoulat et al. [90], presented an hybrid algorithms of edge computing and Artificial intelligence to monitor and predict poultry's air quality. Their work focuses on sensing different gas concentrations with various sensors such as CH_4 (MQ-4), NH_3 (MQ-137), CO (MQ-7), and CO_2 (MG-811). It also features a nutritional sensor such as water level and load cell sensors that monitor the chicken water and feed levels. The various works cited in Table 5 presents the concepts related to Internet of Things and framework in poultry farming.

3. Materials and method

The internet of things based poultry management system (IoT-PMs) is an efficient and budget-friendly cloud enabled scheme that monitor and regulate various poultry environmental variables such as temperature, humidity, water level, and lighting. The IoT-PMs composed of environmental sensors, actuators, wireless enable system on chip microcontroller (EPS 32 SOC), and internet connectivity and Bylnk sever as shown in Fig. 1. Also, the system is equipped with biosecurity, lithium-ion battery, and smart alarm notification system. The use of bylnk IoT platform access via a smartphone facilitated the real-time monitoring and ease of accessibility of the proposed system. The unique features of lighting scheduling and real-time control of poultry ecological parameters enhance the sustainability of poultry welfare and egg production. The IoT-PMs hardware and software components are highlighted as follows:

3.1. System hardware design

As shown in Fig. 1, the proposed IoT-PMs consists of various sensors which have been integrated with

Table 5. Previous related studies on poultry management systems.

S/N	Highlights	Remarks	Citation
1	The study leverages on Artificial Intelligence (AI), edge computing and IoT for prediction of toxic gas concentration in poultry barn	Lacks real-time monitoring of other vital environmental parameters such as temperature, humidity, water level, and lighting.	[91]
2	Proposed an advanced algorithm and IoT system for real-time monitoring of humidity and temperature of poultry farm	Lacks environmental sensors for ammonia gas level monitoring and lacks implementation of remote controller and alert notification system.	[92]
3	Proposed a solution of smart sensor and GSM technology for intelligent poultry system. It also uses GPRS to provide seamless connectivity to the cloud server	Lacks practical integration of the proposed model in real-life setting. Also, farmers lack remote access to vital environmental parameters since sensors for these parameters are not considered.	[93]
4	Proposed integrated solution of wireless sensor, mobile application, and cloud computing for poultry health, Also, it focuses on four sensing parameters (1) temperature, (2) humidity, (3) light intensity, (4) population density.	The model relies on logic controller and cellular network of 3G and $G. Also, lacks practical application of industry 4.0 and IoT platform for real-time visualization and analysis.	[94]
5	Proposed a cloud-based system for poultry farming while highlighting the significant benefit of cloud a wireless technologies such (1) wireless sensor network, (2) sensors, (3) MySQL 5.7, (4) Wi-Fi, and (5) IoT devices.	Lacks real-time monitoring of environmental conditions due to the absence of industry 4.0 and IoT platform for remote data visualization.	[95]
6	Proposed IoT and sensory system for poultry health monitoring. It also, uses mobile Thing speak application for precise data visualization and analytics.	Lacks security measures such as alert/warning notification system to trigger farmers' awareness for.-potential dangers.	[96]
7	Proposed smart sensing technology for efficient poultry management while leveraging on Internet of Things for data sharing, visualization and analysis.	There is no consideration for practical uses. The use of wireless sensor technology raises the danger of radio frequency interference, which could disrupt the data stream.	[97]
8	Proposed an AI-driven automated poultry monitoring system for precise chicken counting. It also uses AI algorithms that enhances resource allocation and operational efficiency.	Scalability issues, latency issues due to real-time detection of large data set. Also, practical usability of the system can be compromised.	[98]
9	Proposed an integrated technology-driven solution of embedded framework and smartphone via internet for poultry health monitoring. The study also, highlights smart distribution and environmental monitoring of poultry farming.	Lacks real-time graphical display of data for visualization and analysis.	[99]
10	Proposed IoT, wireless sensor networks and Artificial Intelligence system for enhancing food sustainability and maintaining environmental integrity.	Lacks lighting scheduling strategy	[100]
11	Proposed GSM-based system for efficient poultry while emphasizing on the benefit of (1) GSM. (2) smart sensors, (3) energy storage system	Lacks industry 4.0's real application and visual, graphical, and numerical display of real-time poultry data for precise monitoring and control.	[101]
12	Proposed an integrated systems for poultry health monitoring while exploring innovative technologies such as (1) smart sensors (2) internet of things, (3) bio sensors	Sensor and IoT device interoperability concerns, as well as scalability	[75]

the EPS32 microcontroller, Wi-Fi connectivity, and programmed to provide an economic, reliable sustainable means of monitoring and controlling poultry birds remotely. The e-MHs hardware and software components are highlighted as follows:

3.2. IoT input sensors

A “DHT11 sensor” was deployed to provide accurate readings of both temperature and humidity levels within the poultry facility. A fan is automatically activated to compensate for real-time poultry temperature above 18–24 °C. A relative humidity above 70 % will reduce hens' reproductive performance and may lead to thermal discomfort and chicks behaviour changes. On contrary, a low relative humidity can reduce egg size and quality and also affect egg's moisture content, resulting in cracking problems. In case of extreme humidity level, an extractor serves effective moisture expellant, regulating temperature and improve air quality.

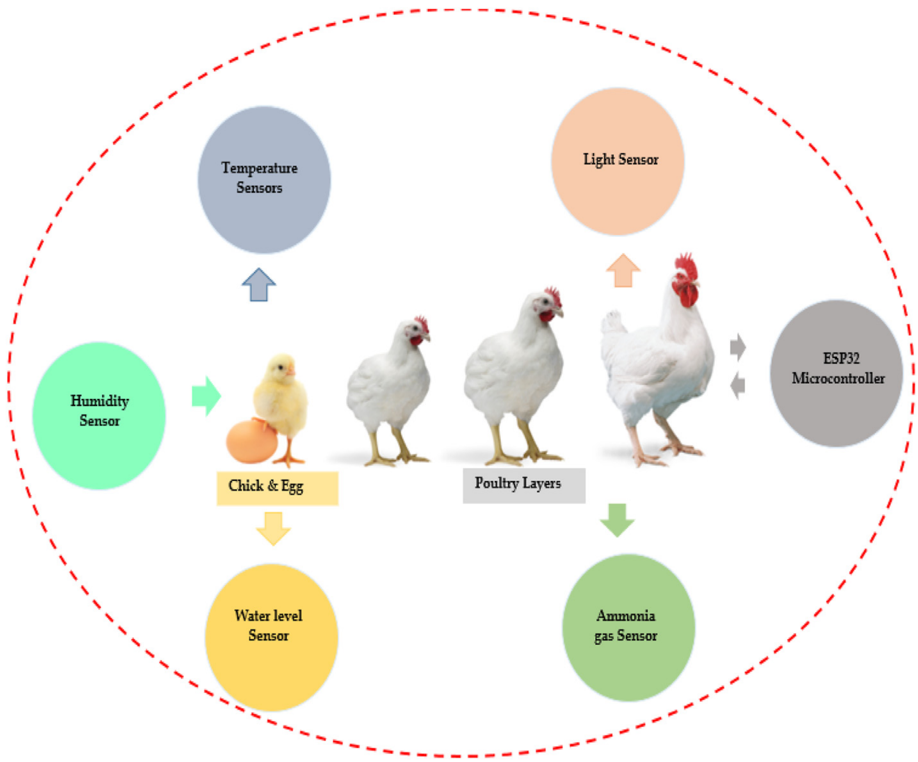

Fig. 1. Hardware sensors integrated with EPS32 SOC Microcontroller.

The “MQ-2 gas sensor” was used to detect and track the poultry's facilities ammonia (NH_3) gas concentration level. Once the ammonia gas level exceeds the threshold limit of 25 pmm, the ESP32 SOC microcontroller automatically energies the relay to switch ON the extractor fan which removes excess ammonia gas from the poultry facilities.

3.3. Light scheduling and power control

Light scheduling plays a crucial role in influencing egg production in poultry layers. Optimal light scheduling can enhance egg production, immune response, feed conversion rate and birds well-being. The proposed scheme has the capability to schedule light timing activities and save energy and costs. The system is programmed to detect the light intensity of the poultry house and regulates it based on the intensity density. The system uses a light dependent resistor (LDR) to monitor and regulate the lighting conditions of poultry layers via a programmable microcontroller. LDR resistance varies in response to light intensity.

3.4. Water supply control

An ultrasonic sensor was utilized to detect water level below 40 cm from the sensor. The system uses a pre-defined commands to activate the pump whenever the water level in the water feed tank goes below the minimum set-point. in addition, the microcontroller is programmed to deactivate the pump when the water level reach the maximum set-point.

3.5. Microcontroller

The “EPS32 SOC” served as a microcontroller for this study and was a preferred candidate due to its Wi-Fi and dual-mode Bluetooth capabilities. The microcontroller provides wide range of functions and capabilities, making it well-suited for IoT-based poultry management systems. The “EPS32” features a dual-core Tensilica Xtensa LX6, CPU, 520 KB of volatile memory, and 802.11 b/g/n Wi-Fi.

3.6. Voltage conversion module and battery

The electronic chip “LM2596” controls voltage in light-emitting diodes, batteries, power supplies, and other devices. The IoT-PM is powered by two 3.5 V 18,650 lithium batteries connected in series.

3.7. Output devices

The poultry scheme consists of different output devices such as pump, extractor fan, fan, buzzer, and lights. The EPS32-microcontroller coordinate and control the switching processes of the output devices based on the pre-defined threshold levels.

3.8. User devices

Smart electronic devices such as smartphones, iPads, computers, notepads, and tablets allow farmers/producers to access, interact with, and monitor environmental conditions and water levels on the bylnk platform in real time over the internet. Fig. 2 depicts the system's hardware components.

3.9. Cloud server

The study employs the freely available Bylnk cloud service for remote monitoring and control of IoT-powered devices. To utilize the Bylnk app (https://play.google.com/store/apps/details?id=cloudblynk domain), first set up your network name and password.

3.10. System hardware design

The Arduino platform was used to generate C++ programming code for the ESP32 microcontroller. All other actuators and input sensors were correctly coded. The platform aims to simplify code and make it less boring. The open-source Arduino software platform consists of two main components: the Integrated Development Environment (IDE) and a core library. The IDE contains a simple editor with a number of tools and features for programming Arduino boards. Programming functions are conveniently accessible via the toolbar.

3.11. Bylnk platform

The Bylnk platform facilitates real-time monitoring and control of poultry facility from anywhere via internet. Bylnk is a powerful low-code platform designed to control and manage connected IoT-PMs devices. Blynk App had to be installed on the smartphones or laptops via Android emulator to establish an interactive environment with the

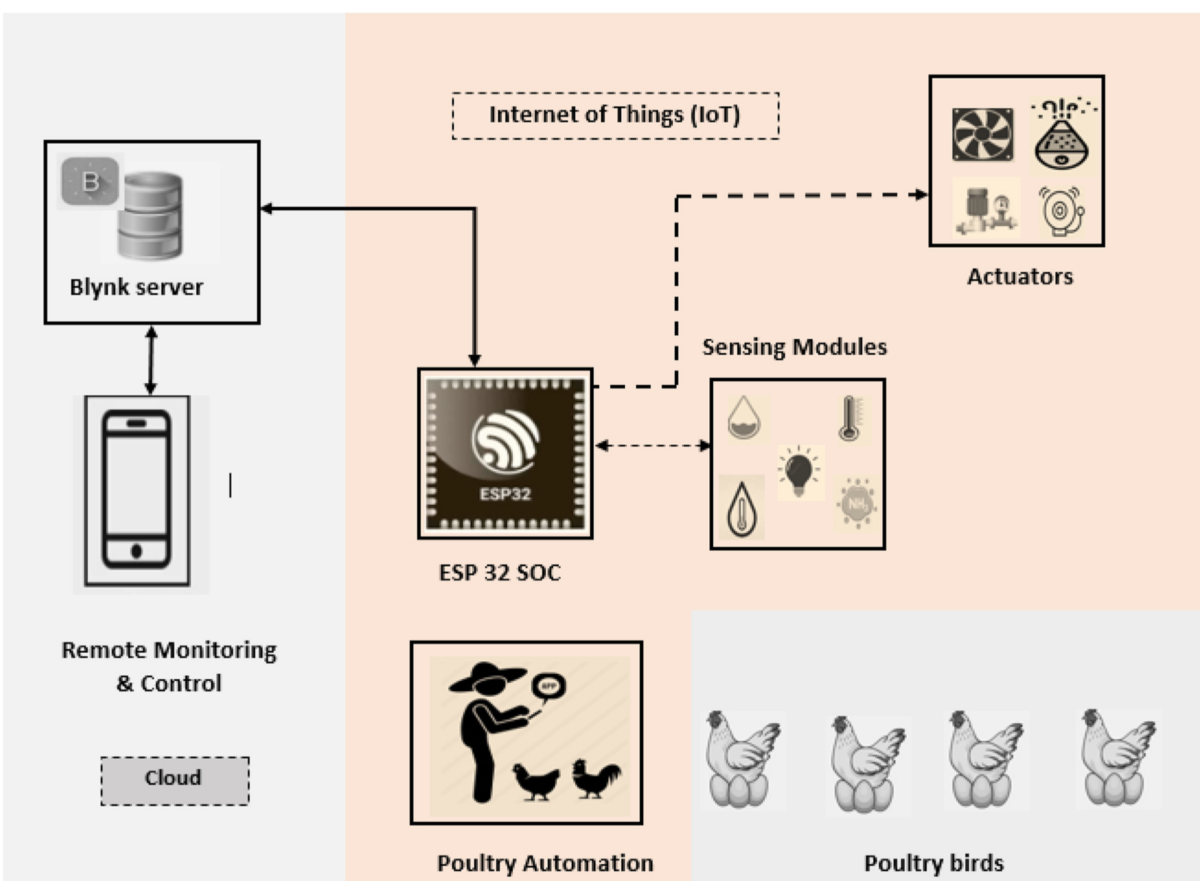

Fig. 2. Proposed system architecture.

dashboard. This App can be installed with mobile/desktop operating systems like iOS/Android, Windows, MacOS, and Linux. It is also compatible with various embedded systems such as Raspberry Pi, Zephyr, particle photon, Zig-Bee and ARN Mbed. The Android mobile OS is selected in this study because it permit farmers/producers easy access to monitor, interact, manage, and control environmental parameters that affect the welfare and productivity of the poultry remotely via smartphones.

3.12. The proposed model concept

The proposed model uses four-tier Internet of Things operational layers (A, B, C, and D). The tier A is the sensing layer (sensing modules), which provides vital data related to the poultry facilities environmental parameters such as temperature, humidity, lighting, water level and ammonia gas level. The tier B is the middleware layer, which establishes a data-sharing link between sensing modules data and the EPS 32 SOC microcontroller as shown in Fig. 2.

The tier C is the network layer that uses wireless technology to establish remote communication between the sensing modules sensors and actuators from system –on –chip microcontroller to cloud database server. The tier D is the application layer, which is responsible for Wi-Fi-enabled IoT cloud platform and to provide farmers with real-time access to graphical charts and instants numeric value of poultry parameters, alert, and updates. In this study, the Bylnk server is hosted on the ESP 32 SOC microcontroller, which also serves as cloud storage accessible via a Wi-Fi connectivity. The visualization of the proposed model requires two main steps, remote connection of the farmer to IoT platform via Bylnk app and data storage on IoT cloud server. The Bylnk stores and read collected data from the database and display the corresponding time series graphs, and instants values as shown in Fig. 3.

3.13. Circuit design and simulation

The experimental model begins with the Arduino frizzing software circuit design and simulation. The circuit schematic for the poultry management system is depicted in Fig. 4. The input sensors are interlinked with the EPS32 microcontroller via internet. The EPS32 controller provides a real-time data sharing and transmission of various input sensor readings to the bylnk server using Wi-Fi connectivity. Also the system makes use of electric-powered fans and extractors to compensate for the poultry facility's severe temperatures and humidity. The system makes use of electric-powered fans and extractors to compensate for the poultry facility's severe temperatures and humidity.

3.14. Coding and Blynk configuration

The second step is to program the EPS32 microcontroller and input sensors, after which the compiled files are transferred to the EPS32 SOC microcontroller via the Arduino IDE 2. The control panel runs on the Bylnk server. The Blynk app was

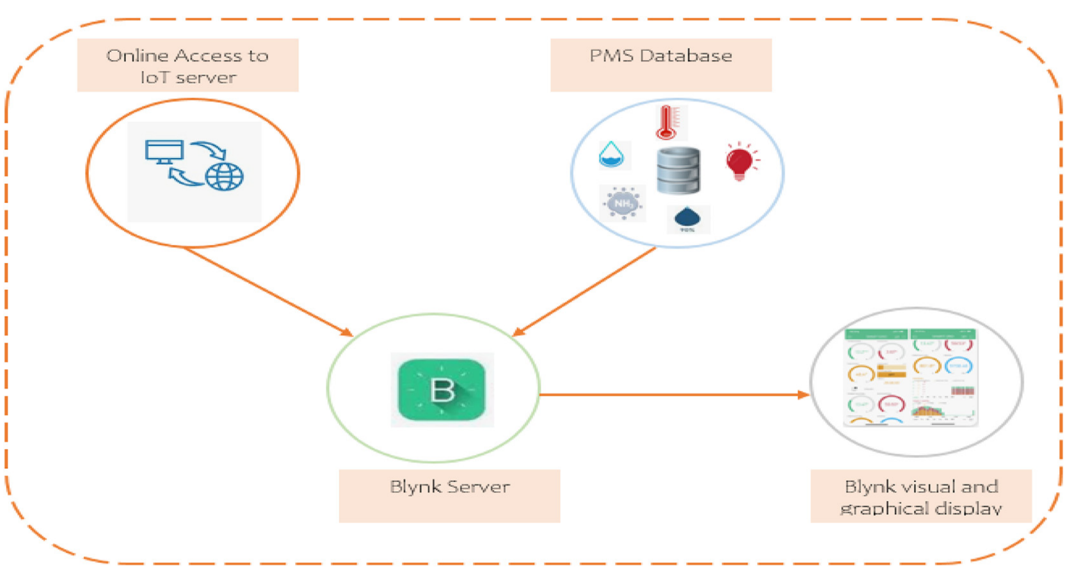

Fig. 3. Steps in proposed model visualization.

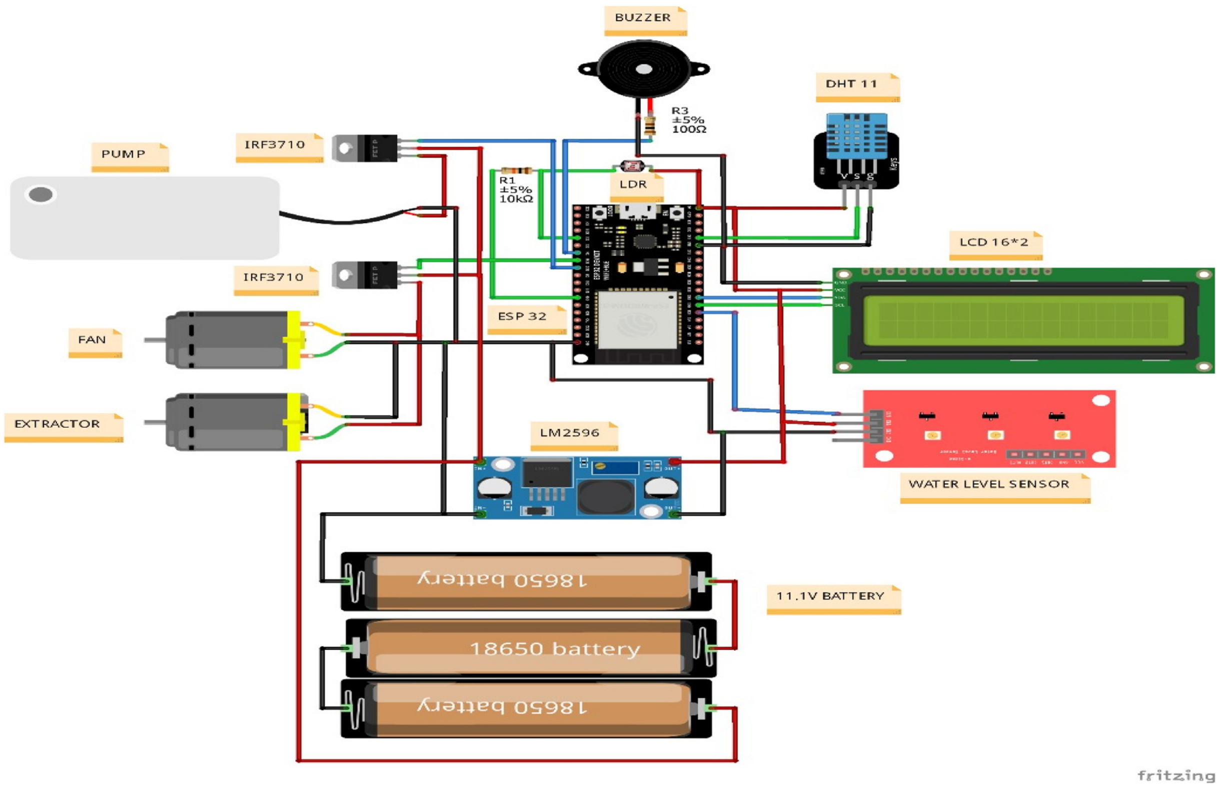

Fig. 4. Proposed system hardware schematic diagram.

installed on the smartphone, and EPS32 was linked to the app's local server via Wi-Fi and a Blynk authentication token. In addition, the "Liquid Crystal" file was uploaded and initialized, and the LCD was connected to the microcontroller via pins.

3.15. Pseudo-code

The pseudo-code in Table 6, explains the functionality of the poultry scheme; it defines the simulation of the smart poultry management system based on an embedded system that monitors environmental conditions, controls pumps, humidifiers, fans, and communication with the cloud (Blynk platform and application). The pseudo-code begins by declaring the minimum threshold for several sensors and then uses variables to indicate sensor reading, pump state, fan state, heater state, and extractor state, as shown in lines 1–18 Lines 18–20 configure the embedded system on chip (ESP32 SOC) and sensors. In lines 21–72, the while loop is executed repeatedly to simulate the proposed system's real-time behaviour. Sensor data is collected continually within the while loop, employing unique sensing algorithms for temperature, humidity, ammonia gas, light, and water level. The collected data is formatted and sent in real time to the Bylnk app and dashboard, allowing for display and analytics. Lines 27–30 create wireless connectivity between the ESP32 SOC and the cloud server (Bylnk Cloud). The lines use special algorithms embedded in the ESP32 SOC establish a secure connection to the cloud. Line 31–54 test the reliability of the pump control, fan control, heater control, and extractor control (actuators) for simulated water level, humidity level, and temperature and ammonia gas sensors. The actuator control flags (SonTp, SoffTp, SonFan, SoffFan, SonHt, SoffHt, SonEx, SoffEx) are configured and simulated using the actuators' switching state (ON/OFF). Lines 55–69 define pre-configured lighting algorithms for poultry layers dependent on their age (week). A 5 s delay is added for loop iterations.

3.16. Integration of the propose poultry model in live poultry farm

The proposed scheme was integrated into the existing poultry facilities of Obasanjo poultry farm, covering an area of 9000 square feet (300 × 30). The farm focusses mostly on the battery cage technique for egg production. The farm infrastructure includes

Table 6. Algorithm.

Pseudo-code of the Proposed Poultry Scheme

```
// Define Constants:
  1:Min_Temperature_Threshold = 30
  2: Min_Humidity_Threshold = 70
  3: Min_Ammonia_Gas_Threshold = 25
  4: Min_Water_Level _threshold = 6
// Variables:
5: Tp                              //Temperature
6: Wl                              //Water level
7: Ag                              //Ammonia gas
8: Lg                              //Light
9: SonTp = false                   //Tank pump ON state
10: SoffTp = false                 //Tank pump OFF state
11:SonHm = false                   //Humidifier ON state
12: SoffHm = false                 //Humidifier OFF state
13: SonFan = false                 //Fan ON state
14: SoffFan = false                //Fan OFF state
15: SonHt = false                  //Electric Heater ON state
16: SoffHt = false                 //Electric Heater OFF state
17: SonEx = false                  //Extractor fan ON state
18: SoffEx = false                 //Extractor fan OFF state
17: Max = 50                       //Maximum distance from the sensor
18: Initialize ESP32 SOC           //System on chip Wi-Fi module
19: Initialize sensors             //initialization of (Tp, Hm.Ag.Lg, Wl)
20: While true
//Simulate sensor readings:
21: Tp = GetTemperature()          //read temperature value (Tp)
22: Hm = GetHumidity()             //read humidity value (Hm)
23: Ag = GetAmmoniaGas()           //read ammonia gas value (Ag)
24: Wl = GetWaterLevel()           //read water level value (Wl)
25: Lg = Getlight()                //read light level value (Lg)
//Simulate Bylnk App and Bylnk web Communication
26: if (ESP32 SOC is connected to Bylnk IoT cloud)
27: print collected data on the laptop
28:send collected data to Bylnk platform
29: else:
30: Try to re-connect
//Control of tank pump based on water level
31: if (WaterLevel ≤ Min_Water_Levet_Threshold)
32: SonTp = true
33: SoffTp = false
34: else:
35: SonTp = false
36: SoffTp = true
//Control of electric fan based on temperature
37: if (Temperature ≥ Min_Temperature_Threshold)
38: SonFan = true
39: SoffFan = false
40: else:
41: SonFan = false
42: SoffFan = true
//Control of electric heater based on temperature
43: if (Temperature ≤ Min_Temperature_threshold)
44: SonHt = true
45: SoffHt = false
46: else:
47: SonHt = false
48: SoffHt = true
//Control of Ammonia gas based on relay
49: if (AmmoniaGas ≥ Min_Ammonia_Gas_Threshold)
50: SonEx = true
51:SoffEx = false
52: else:
```

(*continued on next page*)

Table 6. (continued)

Pseudo-code of the Proposed Poultry Scheme
SonEx = false
SoffEx = true
//Control of lighting based on the age of the layers
if (The age of the Layer ≤ 18 weeks)
Switch ON the light for a period of 19.00−20.00
else:
use the artificial light
if (The age of the Layer ≤ 22 weeks)
Switch ON the light for a period of 19.00−21.00
else:
use the artificial light
if (The age of the Layer ≤ 32 weeks)
Switch ON the light for a period of 19.00−22.00
else:
use the artificial light
if (The age of the Layer ≤ 42 weeks)
Switch ON the light for a period of 19.00−20.00
else:
use the artificial light
Delay (5s) //repeat for each period for 5s
End while

three rows of chicken laying egg cage systems with a 1-m gap for biosecurity precautions. The complete implementation of the poultry scheme includes sensors for temperature, humidity, water level, ammonia gas and real-time IoT cloud based server. Also, 24 h horizon for a period of 1 week was chosen as the testing time. The scheme was installed in the poultry facilities at a distance of 1.5 m on the floor and connected to the cloud server via the internet. This allows farmers to remotely obtain environmental information about poultry farms. The on-site environment of the poultry facilities is presented in Fig. 5. Furthermore, the Blynk server is accessible to farmers via smart devices like smartphones, iPads and tablets and password protected to prevent unauthorized user access to valuable data. Only authorized user to establish an encrypted connection to the cloud server.

In addition, the system helps farmers or agripreneurs to monitor real-time environmental data and the poultry birds' health condition via mobile application. With these information, producers can determine the optimal condition of poultry facilities and make informed decisions about the health of their birds. However, there is an increasing demand for precision agriculture. Recently, significant attention has been focused on sustainable poultry farming solutions [102], such as Radio-frequency

Fig. 5. Live implementation of the proposed system.

identification (RFID) [103], smart sensors for optimal health and livestock well-being have been proposed in Refs. [28,69,84,92,104–107]. Researchers are actively focusing on livestock behaviour monitoring [32,67], Nanosensors for disease detection [108,109], wearable sensors for livestock identification, tracking and health monitoring [20,110], and nanotechnology [111,112]. Future research also tends towards developing data prediction techniques using emerging technology like Artificial intelligence (AI), machine learning (ML), deep learning and Edge computing [79,91,113] to make smart decision on poultry health and welfare based on real-time data and trends.

4. Results and discussions

The Blynk dashboard has been customized to provide a quick overview of poultry management system data value in numerical and graphical formats. Numerical indicators in the form of gauges, as shown in Fig. 6, provide for easy observation of real-time data on temperature, humidity, illumination, ammonia gas level, and water level.

4.1. Temperature and humidity control

In poultry facilities, a "DHT1" is used to measure humidity and temperature. For a week, the temperature and humidity of the poultry facilities are monitored. Each sensor is sampled every 15 min for one week, with a total of 96 sampling intervals (N per 24-h horizon). Temperature and humidity are critical environmental variables that must be continuously monitored. In fact, operating the system above the safe temperature and humidity levels can have a direct impact on the bird's optimal health, egg production, shell quality, and metabolic process. When the temperature reaches the safe limit of 30 °C, as shown in Fig. 7, a fan is activated to cool the poultry facilities and keep the temperature within acceptable limits. Additionally, the electric heater is engaged when the temperature falls below 12 °C, compensating for heat loss. In addition, the system ensures that the humidity is within the acceptable threshold. If the humidity level exceeds 70 %, as indicated in Fig. 7, the extractor fan is activated to remove surplus air. The snapshot in Figs. 6–7 show that the poultry facilities temperature varies from 29.5 °C to 31.8 °C for a period of 168 (24 × 7) hours. The experimental daily average readings of poultry facility temperature and humidity are presented in Tables 7 and 8.

4.2. MQ-2 gas sensor

The experimental set contained a "MQ-2" gas sensor that detected and tracked the levels of ammonia (NH3) in the poultry farmhouse. When the ammonia gas level above the 25 pmm threshold limit, the ESP32 SOC microcontroller activates the relay to turn on the extractor fan, eliminating excess ammonia gas from the poultry facility. Furthermore, the buzzer is activated to produce a sound indication and bring farmers' immediate attention to the prospective threats of stored NH3 gas. When the ammonia gas levels in the poultry facilities reach the recommended (safe) level, the buzzer and extractor fan are turned off. Table 9 shows the daily average ammonia gas readings from the poultry farmhouse.

4.3. Water consumption monitoring and control

Water is one of the main nutrients needed in macro quantity for poultry bird survival. It is an essential ingredient for thermoregulation and waste

Fig. 6. Snapshot of real-time data in the bylnk dashboard.

Fig. 7. Snapshot of graphical and numerical displays of temperature and relative humidity.

Table 7. Poultry facilities temperature readings (experimental).

Sample (in day)	DHT11 (temperature) Date	Degree Celsius (°C)
Day 1	2024:06–30	27.4
Day 2	2024:07–01	31.00
Day 3	2024:07–02	31.02
Day 4	2024:07–03	31.06
Day 5	2024:07–04	31.08
Day 6	2024:07–05	32.00
Day 7	2024:07–06	32.04

Table 8. Poultry facilities humidity readings (experimental).

Sample (in day)	DHT111 (humidity) Date	g/kg (%)
Day 1	2024:06–30	71.06
Day 2	2024:07–01	71.60
Day 3	2024:07–02	71.80
Day 4	2024:07–03	71.96
Day 5	2024:07–04	72.10
Day 6	2024:07–05	72.30
Day 7	2024:07–06	72.50

removal in the metabolic process. Throughout the week, the poultry facilities' water usage was continuously monitored over a 24-h period. The water level in the poultry storage tank is monitored using HC-SR04 ultrasonic sensors. The minimal restriction of 6 % implies “empty tank,” and the optimal limit of 95 % represents “full capacity.” For example, the water pump indicated in Fig. 8 is triggered because the water level is less than the minimal threshold of 6 %. As a result, the ESP 32 SOC microcontroller operates the water pump based on ultrasonic sensor data, filling the water

Table 9. Poultry facilities Ammonia and PH levels.

Sample (in day)	MQ-2 Date	PH level (Scale 0–13)	Ammonia gas level (ppm)
Day 1	2024:06–30	6.0	21
Day 2	2024:07–01	6.0	23
Day 3	2024:07–02	6.0	24
Day 4	2024:07–03	7.0	30
Day 5	2024:07–04	7.0	30
Day 6	2024:07–05	7.0	30
Day 7	2024:07–06	7.0	30

storage tank to capacity. When the water storage tank reaches its full capacity, it will automatically shut off. Fig. 9 depicts real-time temperature and humidity data from the experimental setup.

4.4. Alert notification

Aside from the simple visualization of environmental variables (temperature, humidity, light, ammonia gas concentration, and water level). An alert notification system has been developed to generate warning messages when environmental parameters fall outside of the threshold range. Farmers may now not only respond to significant changes, but also make informed judgements about the health and well-being of poultry birds.

4.5. Light scheduling strategy

The proposed technique is integrated with a lighting scheme to achieve optimal egg production. The ESP32 SOC is pre-configured with a light scheduling strategy that follows Table 10. The experimental approach employs four distinct layer selectors—A, B, C, and D—to represent the chosen week of age for layers 18, 22, 32, and 42, respectively. In addition, the light is automatically turned on and off based on the preconfigured light duration of the selected layers, and the cycle repeats daily until the farmer resets it for new bird selection. When layers are exposed to enough light for at least 15 h per day, they become extremely productive. The sun offers adequate lighting during the day. The lighting scheduling system makes up for low light levels in the evening. Fig. 10 shows the pictorial view of the proposed lighting strategy and Fig. 11 presents graphical representations of the experimental findings of input sensors.

4.6. Performance assessment

Table 11 shows the performance assessment of the proposed system and the existing models. This work proposes an intelligent light scheduling technique for optimum poultry illumination conditions. This work combines IoT, cloud computing. The synergistic integration of these technologies allows for real-time monitoring, remote access, visualization, and analysis of environmental data via the Bylnk dashboard and mobile application.

4.7. Strengths of the proposed system

The main strength of the proposed system lies on the use of hybrid technologies of Internet of Things, IoT-cloud, and advanced algorithms to provide real-

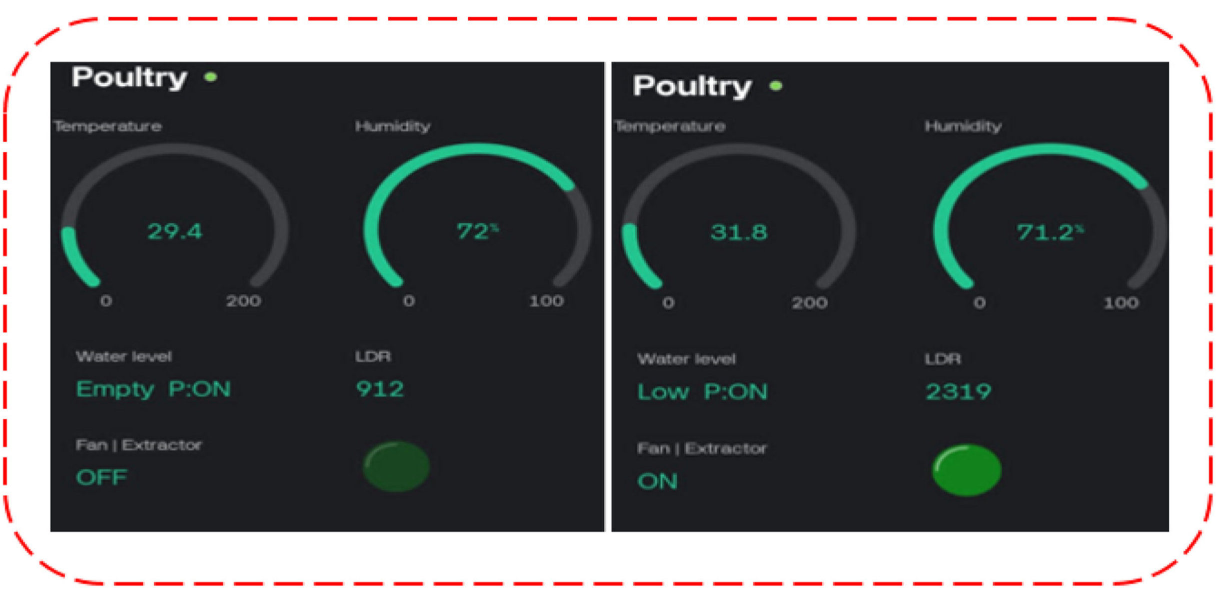

Fig. 8. Snapshot of water level status.

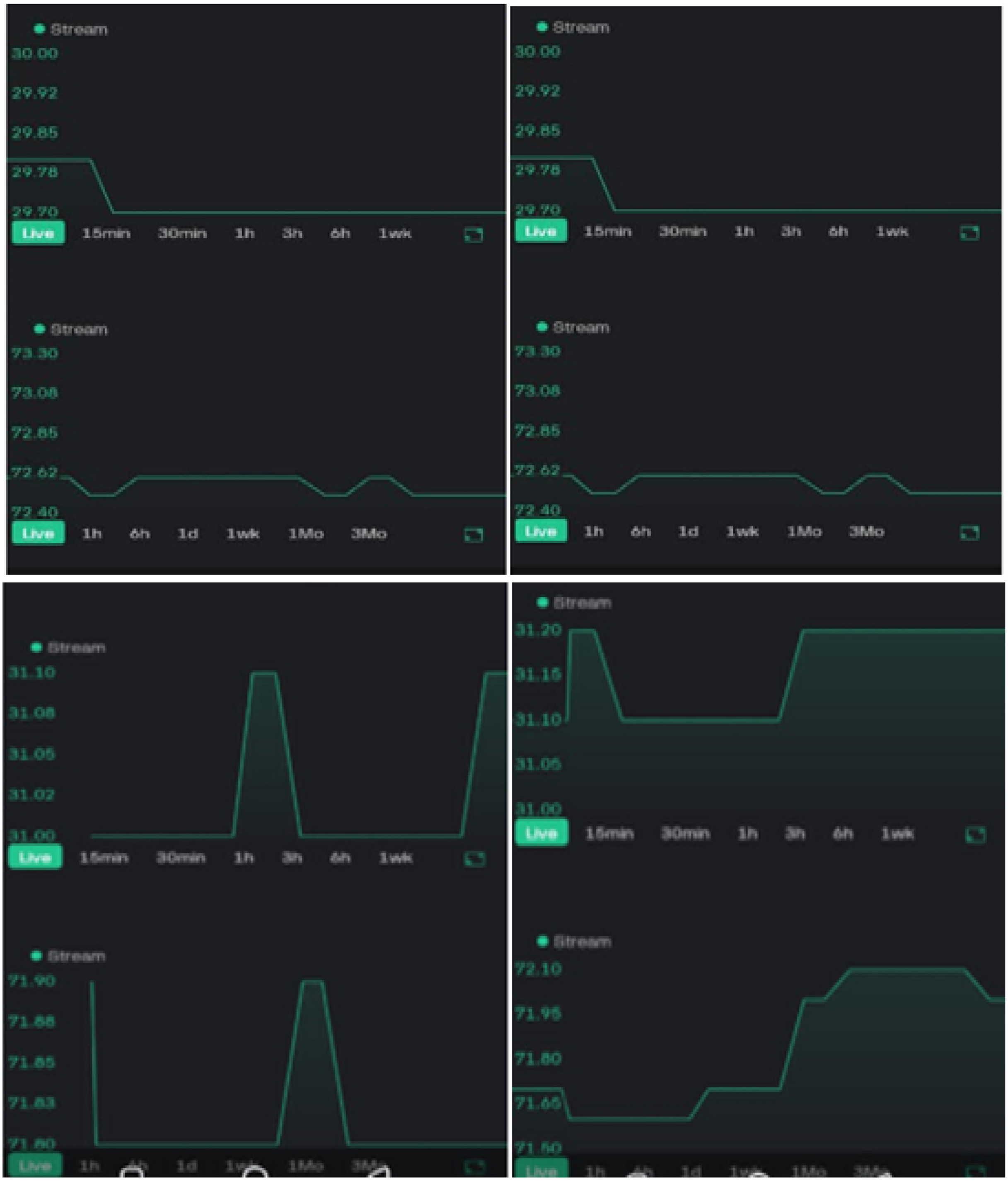

Fig. 9. Graphically display of real-time temperature and humidity data.

Table 10. Light strategy for egg production in layer species.

Layer selector	Age (week)	Light duration of Artificial lighting (hours)	Lighting strategy Peak −time for lighting (hours)
A	18	2	19.00−20.00
B	22	6.0	19.00−21.00
C	32	6.0	19.00−22.00
D	42	7.0	19.00−23.00

time monitoring, remote access and instant alert notification on environmental conditions of poultry farm and health. In addition, the system redefines poultry farming through real time monitoring, rapid response, and remote accessibility, resulting in enhanced productivity and food sustainability. With the Bylnk dashboard, users can monitor environmental data that impact poultry's welfare through

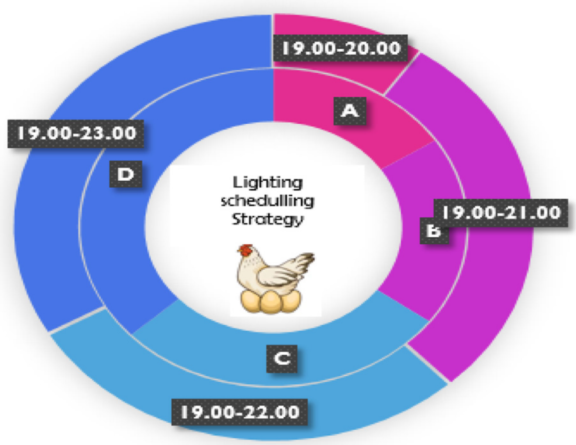

Fig. 10. Pictorial view of the proposed lighting strategy.

mobile application remotely. This eliminates the need for manual checks and provides convenience. Furthermore, the proposed system can detect abnormality in environmental factor or water level and send immediate alerts notification to the users on real-time. The system incorporated lighting scheduling mechanisms to provide an additional layer of safety for layers breeding that might affect their poultry's behaviour, reproduction, egg shell quality, and welfare. Contrary to the previous works, the proposed system seeks to enhance food security and sustainability using a fused internet of things and smart sensors and advanced lighting scheduling algorithms. A novel alert notification, web-based/mobile dashboard mechanism, and IoT cloud platform incorporated to the system to enhance data update and data sustainability.

5. Conclusions

Innovative has become imperative in the poultry industry for increasing productivity, monitoring environmental conditions, and automating poultry tasks for bird welfare. This paper presents a novel smart poultry management systems that uses hybrid smart sensors and Internet of Things technologies to effectively monitor temperature, relative humidity, ammonia gas level, lighting and other critical components of the pouty facility such as water consumption and PH level. The proposed system is connected with Bylnk software and features an interface that allows farmers to

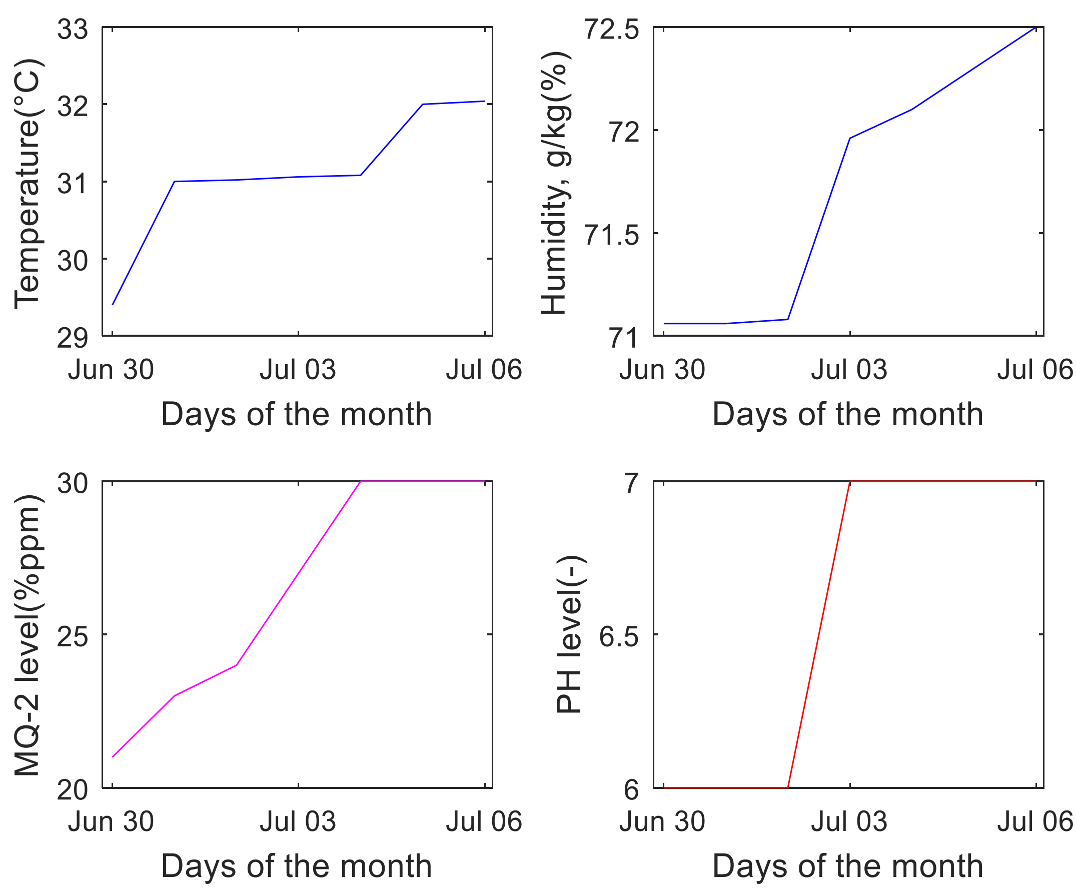

Fig. 11. Graphical display of (a) Temperature sensor (b) Relative humidly sensor (c) Ammonia gas sensor concentration (d) PH level.

Table 11. Performance comparison of the proposed system with existing studies.

No.	Paper	Network	Actuator	Technology	Physiological parameters	Addition features
1	Lufyagilia *et al* [114]	Wi-Fi	28.5	IoT	Temperature, Humidity and Ammonia gas	Web App
2	Orakwue *et al* [115]	Wi-Fi	27.8	IoT	Temperature, Humidity and Air quality	Motion detection
3	Batuto *et al* [116]	Wi-Fi	Servo motor. relay	IoT	Temperature, Humidity, Air quality	Google assistant
4	Mishra *et al* [117]	Wi-Fi	L293D, relay	IoT	Temperature and Humidity	GSM module
5	Syafar *et al* [118]	Wi-Fi	None	IoT	Temperature, Humidity and Air quality	Motion sensor
6	Fernando *et al* [119]	Wi-Fi	None	IoT, Web App	Temperature, Humidity, Ammonia gas and Luminosity	**Web App**
7	**Proposed Scheme**	**Wi-Fi/Cellular (3G/4G/5G)**	**Electric fan, Electric heater, Humidifiers, Water pump, Extractor fan and Relay**	**IoT, Bylnk cloud, GSM, Bylnk mobile App**	**Temperature, Humidity, Lighting, Water level, PH level and Ammonia gas concentration**	**SMS, Alert notification, real-time data interface, lighting scheduling strategy, Water consumption control and**

communicate with it. This module allows farmers to receive notifications, warming alerts, visualize real-time data, perform predictive analyses, and make informed chicken health decisions. Furthermore, the unique feature of the lighting management approach aids in managing the lighting conditions of the birds based on their age, resulting in increased egg production and optimal health. The recommended technique is critical for small-scale farmers in low-income countries like Nigeria, who have limited resources. Furthermore, the system has the ability to boost production while monitoring environmental conditions. The study aims to make a substantial contribution to some of the SDGs, such as improving nutrition and prioritizing sustainable agriculture in underdeveloped nations. As a result, transitioning to a smart poultry management system would not only improve poultry processes, but it would also significantly benefit small-scale farmers in Sub-Saharan Africa, particularly Nigeria, in terms of achieving food security for all by 2030 and encouraging precision agriculture Although the study provided an innovative approach for poultry farming in Nigeria, future research into the integration of nitrogen sensors to reduce nitrogen content in poultry feed can improve the system. Additionally, feed sensors can be added into the system to improve poultry performance, as feed quality has a direct impact on bird performance [52]. Smart biosensors make it easier to detect pollutants and pathogens in poultry products [120]. Disease detection sensors are another promising approach to preventing disease outbreaks in poultry systems.

Ethics information

This research complies with the ethical information for conducting scientific studies.

Source of Funding

This research did not receive any funding.

Conflict of Interest

The authors affirms that there is no conflict of interest regarding this work.

Data Availability

Data is available on request.

Author Contributions

A. A. Okubanjo: Conceptualization, Methodology, Expermentation, Writing- Original draft preparation, artworks design. I.K. Okakwu and N.S. Lawal reviewing the manuscript critically for important context A.A. Babalola. O.P. Alao and A. Olayiwola editing, and draft preparation.

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