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Original Article

Development of an Internet of Things Based Smart Greenhouse

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Abstract *- Agriculture plays a vital role in the development of a country as it not only ensures food availability but could also serve as a major sector in the Gross Domestic Product (GDP) of a country. It has been the primary occupation of man since early civilization. The continued growth of agriculture has, however, been threatened by the continuous change in climatic conditions. Greenhouse farming is one major way to avert the effects of climatic change on crop production; hence, its adoption has been experiencing steady growth in most countries as of today. This method of plant production is designed to maintain the atmospheric conditions within the Greenhouse, as this directly affects the plant growth. This project utilizes a DTH11 sensor to monitor the temperature and humidity, a resistive moisture sensor for soil moisture and LDR for the Light Intensity while keeping the user or farm owner continuously informed of the conditions inside the Greenhouse utilizing cloud-based storage and mobile application while also controlling these parameters to ensure optimal plant production.*

Keywords *- IoT, Greenhouse, Temperature, Humidity, Sensor, Light Intensity.*

1. Introduction

Food production and agriculture, in general, are highly dependent on the climate, which is constantly changing. This factor is a global issue and plays a major role in man's activities and environment, which is now extremely felt in the Nigerian agricultural sector [1]. Some of the biophysical impacts of climatic change include the physiological impact on crops and livestock, changes in the land, soil, and water resources, increased weed and pest challenges, shifts in spatial and temporal distribution effects, changes in ocean salinity, sea levels, and temperature [2].

In a quest to reduce the physiological impact on crop production, the adoption of a controlled environment such as the Greenhouse has been encouraged. Greenhouses, which are structured buildings with walls and roofs usually made of transparent materials, in which plants requiring regulated climatic conditions are grown, can be a major way of combating the effect of climate change as it affects agriculture.

Greenhouse ensures plants no longer depend on weather conditions or patterns since, the atmospheric conditions within the Greenhouse can be controlled. [3] reported that to ensure crop survival irrespective of the hostile ambient environment experienced in Nigeria, the adoption of greenhouse farming needs to be exploited.

Paradoxically, greenhouse plant production has not been widespread in Nigeria due to the difficulty in establishing it by individuals, the lack of adequate greenhouse awareness, as well as high cost of construction [4]. To meet the growing demand for food, new technologies must be adopted in Agriculture. This has been well hindered by the perception of farmers towards new technology, human-specific factors, economic factors, and technological and institutional factors [5]. To enhance productivity and food security using modern technology, the Internet of Things (IoT) is a rapidly expanding and versatile network of smart devices capable of self-organization, information sharing, and adaptive responses to environmental changes. This technology holds great potential for application in agriculture [6]. [7] outlined some of the important roles IoT plays in agriculture, including monitoring farms, reducing human involvement, and getting a more informed weather forecast for farm owners. The IoT-based smart Greenhouse is an automated greenhouse with the capability of running without direct human supervision. It harnesses the ability of sensors to tell the condition or state of the atmosphere within the Greenhouse and make appropriate controls to regulate the conditions to what is required by the plant over a controller. Conditions maintained include the temperature, humidity, light intensity, and water level in the soil. Real-time data is also sent to the cloud and accessed by farm owners over a mobile application.

2. Related Works

Monitoring and automation of a greenhouse with the use of Arduino-based microcontrollers were reviewed in [8]. The importance and challenges facing the use of IoT-based precision farming supervision and automation were studied. The study deduced that while a functional, automated and monitored Greenhouse can bring about the possibility of producing plants in and outside of the season, protect plants from excessive rain, storm, wind, and frost as well as higher yields with space optimization, more efficient irrigation consumption and other highlighted advantages it can also pose the challenge of high initial cost, varied field conditions, complex installations procedures and insufficient understanding of the technology. The deductions from this study are limited to the number of IoT-based methodologies in the scope of this research work.

Ref [9] proposed Smart greenhouse automation utilizing IoT and Arduino-based microcontrollers. Four sensors, which include the LDR light sensor, LM35 temperature sensor, DHT11 humidity sensor, as well as soil moisture sensor, were used to keep track of the greenhouse atmospheric conditions while using the ATmega328 to control the Air vent and sprinkler to meet up with the specified threshold values. This method improves irrigation conservation and keeps the Greenhouse properly ventilated. However, it does not address the light intensity, and it is only a proposed method as it was not used in an actual greenhouse.

In [10], an innovative and scalable intelligent system was implemented to manage and supervise greenhouse temperature using IoT technologies. This System monitors the greenhouse environment and adjusts internal temperature to conserve energy while optimizing conditions for increased productivity.

Utilizing a Petri Nets (PN) model, the System efficiently monitors the greenhouse environment and generates appropriate reference temperatures for regulation, which are then transmitted to a temperature control module. However, the System's functionality currently lacks provisions for monitoring light intensity, humidity, and soil moisture levels.

A prototype for an intelligent Raspberry Pi-based Embedded System and IoT platform for greenhouse monitoring and control was proposed in [11]. This System integrated a Sensor Network (SN) node with a Raspberry Pi-based Embedded System (ES) to actively monitor climatic parameters like air temperature, humidity, soil moisture, carbon dioxide levels, and light intensity in a greenhouse environment. These data were analyzed using IoT analytics (ThingSpeak) and transmitted to gateway nodes placed in the Greenhouse. The gateway then relayed this information to agricultural professionals via a web browser, facilitating remote monitoring and decision-making. The ES, based on the data received, could autonomously regulate climate parameters using devices like pumps, fans, light bulbs, and water sprinklers. It is important to note that this design was a prototype and lacked actual testing to validate its functionality.

[12] proposed an automated monitoring and control system for greenhouses using a combination of sensors and solar power. The System employed temperature, humidity, light, and soil moisture sensors to gather environmental data within the Greenhouse. These sensors were connected to an Arduino Uno R3, which stored and processed the collected data. A GSM module facilitated the transmission of measured values to the user's cell phone via SMS.

The entire setup operated on a solar system with a rechargeable battery, ensuring continuous power supply. Data were also stored on the internet and accessed through an Android application. This cost-effective and efficient System analyzed crucial environmental parameters while utilizing renewable energy sources.

[13] proposed a Wireless Sensor Network (WSN)-based System for monitoring and controlling greenhouse environments. The design utilized the Atmega128L chip and CC2530, a low-power RF chip from TI, to create the sink node and sensor nodes within the WSN. This System enabled the monitoring center to regulate greenhouse temperature and humidity, measure carbon dioxide levels, and assess light intensity.

Multilevel energy memory was implemented to manage energy collection and transfer efficiently, utilizing solar energy batteries effectively. The deployment of nodes and time synchronization were thoroughly analyzed, addressing issues such as complex cabling, low power consumption, cost-effectiveness, robustness, and flexibility. However, it is noted that time accuracy could be affected by frequency offset estimation, as the node estimates it.

A greenhouse monitoring and control system utilizing ZigBee wireless technology was developed in [14]. The System comprised several local stations and a central station. Local stations measured environmental parameters and controlled actuators to maintain climate conditions at predefined set points.

Each local station utilized a PIC microcontroller to store instant parameter values, transmit them to the central station, and receive control signals for actuator operation. ZigBee wireless modules facilitated communication between local and central stations. While effective for greenhouse climate management, this approach necessitates multiple stations, increasing system maintenance costs.

3. Materials and Methods

3.1. System Overview

This work utilizes various sensors to monitor the temperature, humidity, soil moisture and light intensity and keep the user or farm owner continuously informed of the conditions inside the Greenhouse using IoT technology while also controlling these parameters to ensure optimal plant production. The DHT11 sensor continuously records the temperature and humidity of the Greenhouse, its value was used to determine when to switch on the fans for cooling of the Greenhouse. On the other hand, the Soil moisture level was also measured using a capacitive soil moisture level sensor, which was used to control the DC water pump to regulate the flow of water within the Greenhouse. Also, the light intensity available to the Greenhouse was used to determine when to switch on the DC bulb inside the Greenhouse based on the LDR sensor values. All these sensors' readings were sent to Google Firebase cloud storage in real-time. They were automatically synced with the mobile application designed for monitoring and control of the smart Greenhouse. Figures 1 and 2 show the flowchart and block diagram of the System, respectively.

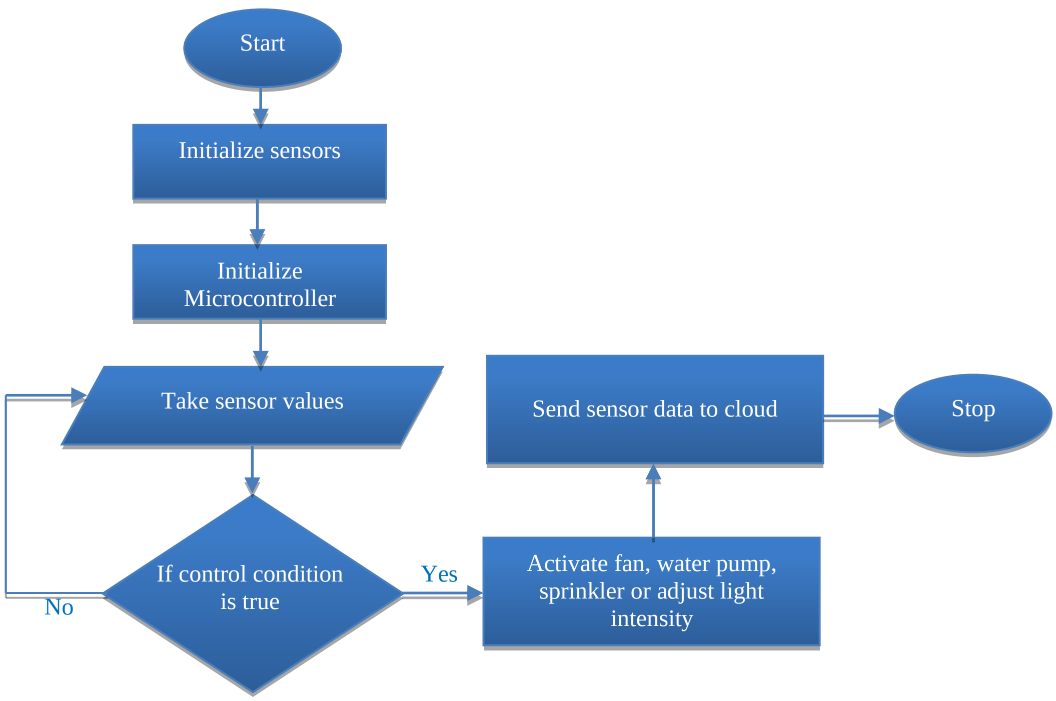

Fig. 1 Flowchart of the Smart IoT-Based System

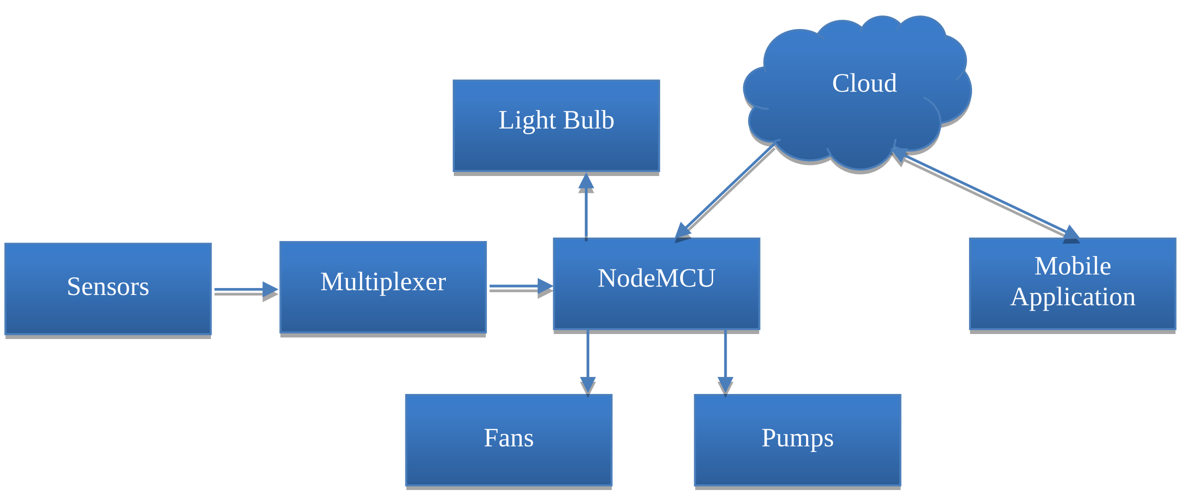

Fig. 2 Block diagram of the smart IoT-Based System

3.2. Hardware Sub-unit

The hardware Sub-unit of this System is made up of the following modules:

3.2.1. Sensor Module

Sensors make up a pivotal part of every smart System as they help to measure physical quantities like the atmospheric conditions within a greenhouse and convert them into appropriate electrical signals that can be interpreted by the controller and used to actuate other components accordingly. This module is made up of the following components:

- Light Sensor (LDR)
- Temperature and Humidity Sensor (DHT11)
- Resistive Soil Moisture Sensor

3.2.2. Conditioning System Module

To maintain the required atmospheric conditions within the Greenhouse. Readings from the sensors are used to adjust the temperature, light intensity, and soil water level in the Greenhouse, making use of the following components:

- 12V cooling fans
- 12V DC Bulb
- DC water pumps
- 6mm Hose/Waterpipe

3.2.3. System Controller Module

For the implementation of this project, the NodeMCU Microcontroller will be utilized. It comes with an embedded ESP8266 Wi-Fi Module to help with internet connections for real-time communication with the end-users over the cloud.

3.2.4. Power Supply Module

The entire System is powered from a 12V battery power source also with the use of a voltage regulation circuit to make available the required power for all the components of the System. Some of these components include:

- Rechargeable 12V Battery.
- 7805 and 7809 Voltage Regulators.
- 10k ohms Resistor.
- 12V AC to DC Adapter.

3.3. Software Sub-unit

The software end of this project is composed of a mobile application and a cloud-based database. The mobile application will be used to monitor and control the Greenhouse from any location with internet access by the farm owner.

This application is built on the VueJs framework utilizing JavaScript programming language, HTML, and CSS. Also, the cloud-based technology used for real-time data storage and control in this project is Firebase Real-Time Database, which is a Google-owned database.

3.4. System Integration

The Firebase Real-Time cloud database serves as the integration point for the hardware and the mobile application, which is used to monitor and control the System. While the ESP8266 Wi-Fi module integrated with the NodeMCU sends data to the cloud the mobile application listens for real-time changes to the stored data and shows the new value to the user.

4. Results and Discussion

Figures 3 and 4 show the inside and side views of the smart Greenhouse, respectively. The System was evaluated based on the IoT response time and the overall system performance using the crop requirements of the tomato plant as the base for the System to maintain.

Fig. 3 Inside of the smart greenhouse

Fig. 4 Side view of the smart greenhouse

Table 1 presents the response time of the smart Greenhouse. The Greenhouse sends data to the cloud every 15 seconds on average. This timing is strongly affected by the network availability as the system calculations and server calls happen in microseconds.

Table 1. Response time of the smart greenhouse

Parameters Sent	Number of Data Packets Sent in 30 Minutes	Average Time Taken to Update Database (In Seconds)
Temperature	122	14.75
Humidity	122	17.75
Soil Moisture Level	109	16.51
Light Intensity	115	15.65

The application works with the Firebase SDK and receives data passed to the cloud in less than 10 seconds, which is largely dependent on network availability as well. Figure 5 shows the mobile application.

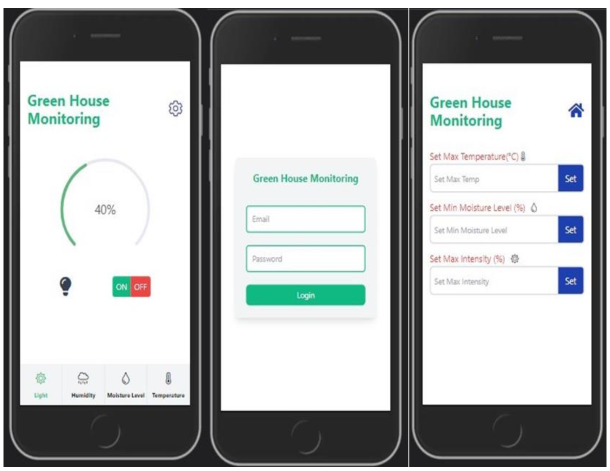

Fig. 5 Mobile application screens

For the evaluation of the smart Greenhouse, the conditions required to produce healthy tomatoes were used to configure the settings for the temperature, humidity, moisture level, and light intensity parameters of the smart Greenhouse. Table 2 shows the performance of the System using atmospheric conditions suitable for tomatoes as a case study.

The smart greenhouse environment stayed within the ideal range for most parameters over the three days with four-hour measurements. While some fluctuations occurred, like humidity exceeding the desired maximum on day three, all readings remained generally favourable for tomato growth. Light intensity showed the most significant variation, exceeding the upper limit slightly on day three, but overall remained within a suitable range.

Table 2. Performance evaluation of the smart greenhouse

Measured Parameter	Required Range for Tomatoes	Minimum and maximum values reached (measured in 3 days, 4 hours for each day)		
		Day 1	Day 2	Day 3
Temperature	18°C to 30°C	21°C to 28°C	19°C to 29°C	22°C to 27°C
Soil Moisture	38% to 46%	42% to 46%	44% to 46%	43% to 46%
Light Intensity	60% to 80%	60% to 75%	60% to 78%	60% to 90%
Humidity	50% to 70%	67% to 85%	69% to 86%	66% to 82%

The evaluation of the smart Greenhouse depicted in Figures 3 and 4, along with the data presented in Tables 1 and 2, showcases a robust system tailored for optimal tomato cultivation. Table 1 outlines the efficient response time of the Greenhouse, with data sent to the cloud every 15 seconds on average, influenced by network availability and swift server operations. The integration of Firebase SDK facilitates rapid data transmission to the cloud in under 10 seconds, contingent upon network stability.

Table 2's performance assessment reflects the Greenhouse's ability to maintain crucial parameters like temperature, soil moisture, light intensity, and humidity within the ideal ranges for tomato growth over three days. Although minor fluctuations occurred, such as elevated humidity on day three, the overall performance remained conducive to healthy tomato cultivation, highlighting the System's effectiveness in maintaining optimal environmental conditions.

5. Conclusion

In this study, an IoT-based smart greenhouse was presented. This analysis of sensor data from the Greenhouse indicates that the System successfully maintained suitable growing conditions for tomatoes within the targeted ranges for most measured parameters over three days. While minor fluctuations occurred, such as light intensity exceeding the recommended level on day three, all readings remained generally favourable for plant health.

This demonstrates the effectiveness of the System in creating a controlled environment for optimal crop growth, independent of external weather conditions. However, it is important to acknowledge that extreme weather events might still cause temperatures to dip below the desired range, requiring additional control measures.

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