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# Environmental Parameters Monitoring for Greenhouse Farming Using Wireless Sensor Networks

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## Article Info

## Abstract

*Successive reforms in agricultural policies have recently created an enabling environment for development and implementation of state-of-the-art, environmentally friendly farming strategies. This permits farmers to intensify production and manage local environment which is crucial for sustainable development of agricultural sector. This paper proposes a wireless sensor network architecture for real-time greenhouse environmental parameters monitoring to achieve scientific cultivation at a low management cost. The greenhouse monitoring system was designed by integrating DHT11 sensor, GSM module to a microcomputer board which is Arduino microcontroller. A real-time observation, monitoring and communication station was built using an android phone. Sensor data are received in near real-time through wireless communication network for analysis and control of targeted area. The proposed model was built and tested. The results obtained shows that automated monitoring of greenhouse farming is promising for enhanced agricultural production.*

## 1. Introduction

Greenhouse climate monitoring and control creates enabling environment for production of crops at low cost and improves the quality of crops. Greenhouse farming can be seen as the art of science and advance technology to boost crop production. The main driving force for the development of greenhouse monitoring is wireless sensor network (WSN). Recent advancement in electronics and wireless communication technology have created an enabling environment for development and production of high communication sensors that are multi-functional at low cost and with low power consumption. These sensors have the ability to communicate at short distances and are portable (small size) in nature [1]. Affordable connected smart sensors via wireless links and installed/connected in large numbers, offers colossal opportunities for automatic monitoring and control of homes, industries, cities and environment [1, 2]. Wireless sensor networks as a present-day technology, has capabilities of exploring the abilities of sensors, control, network transmission, data processing and storage [3]. The creation of WSNs in system platform for data capture, authentication, processing and visualization makes it promising for the enhancement of agricultural production at an affordable cost.

Several quantifiable environmental properties can be measured and stored by a network of distributed measuring sensors available during farming season. Some of these environmental parameters may include: temperature, humidity and soil moisture. WSNs are efficiently capable of providing, near real-time monitoring, capture and storage of measured environmental parameters. These captured and stored data can be explored for development of optimization tools or models for monitoring and control of agricultural crops production. Furthermore, captured data could be analyzed for studying environmental impacts on crop production, production risk avoidance, adjustment of crop production techniques. Hence, the use of wireless sensor networks contributes eminently to crop production.

The concept of greenhouse farming is gaining lots of attention and interest recently despite its existence centuries ago. Greenhouse farming can be seen as a comprehensive system strategy for optimizing production of agricultural crops under a controlled environment. They could either be in the form of permanent or temporary structures covered with glass or plastic, and generally excluding simple high or low tunnels, shade houses, and others to the permanent structure requirement with climate controls, and "with computerized irrigation systems [4]. Greenhouse protects crops from too much heat or cold, shield plants from dust storms and blizzards, and help to keep out pests [5, 6]. Humidity and temperature control allow greenhouse to turn in non-arable land into arable land, thereby improving food production in marginal environments. Figure 1 presents an illustration of greenhouse farming showing climatic control parameters.
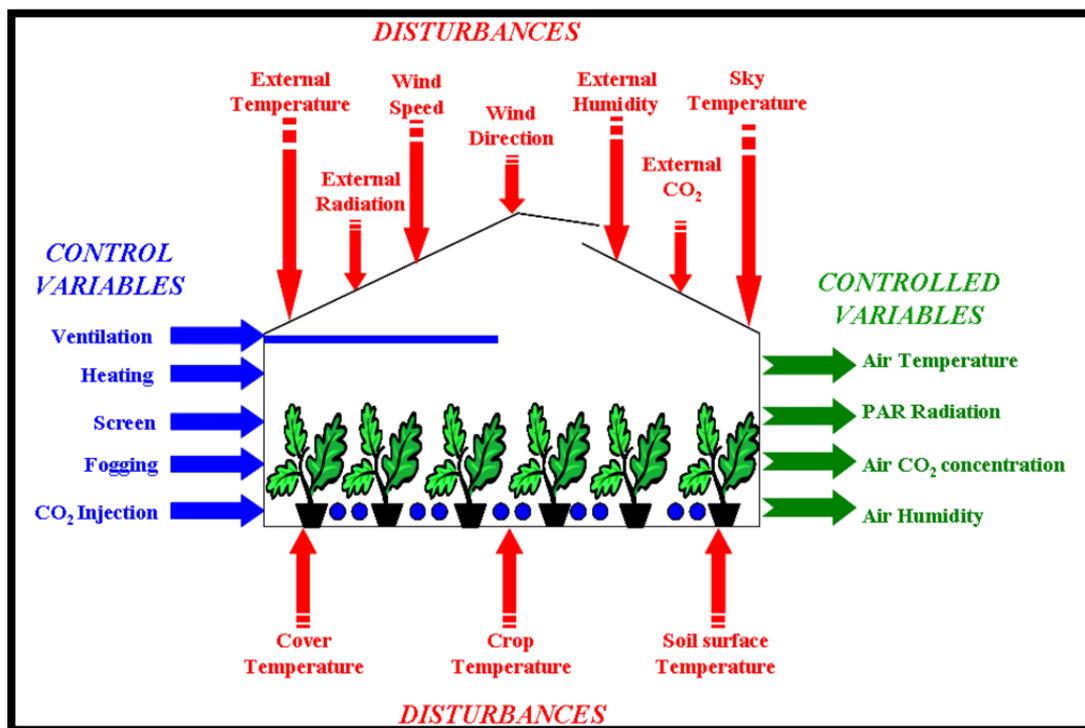


**Figure 1: Climatic Control Variables (Source: [7])**

Several greenhouse monitoring schemes [8, 9, 10, 11, 12] have been previously proposed. These proposals used different approaches towards the achievement of their set objectives. However, there is room for enhancements and also exploration of other strategies for measuring environmental parameters in greenhouse farming. The main objective of this work is to design a simple and affordable automatic monitoring and control system using Arduino microcontroller and GSM module for real time environmental parameters monitoring and control. Furthermore, the contributions of this work can be summarised as follows: development of a microcontroller based

greenhouse monitoring and environmental parameters control; presentation of a comprehensive review of different strategies for greenhouse monitoring systems. A near real time automated alert system for green house monitoring. Highlights of some open research problems in relation to automated greenhouse monitoring and recommendation of proactive steps for development of enhanced greenhouse monitoring techniques to address identified open problems is presented. The remainder of this article is structured as follows: Section 2 presents the state of the art. Section 3 describes the developed system, its architecture and design. Section 4 presents tests and results. Finally, section 5 concludes the work and some future works.

## 2. Related works

Several wireless sensor networks for greenhouse monitoring have been proposed by different researchers. However, these proposals have their shortcomings which creates room for further research. Nikhade and Nalbalwar [13] developed WSAN which had no GSM module and both main system and base station were integrated on a single Arduino. As such results could not be communicated to the user and due to the fact that both main and control system are integrated on a single microcontroller, the load unit had been minimized.

Benzaouia, Tadeo and Nachidi [14] proposed a system to control air temperature and humidity concentration in greenhouses is described by means of simultaneous ventilation and heating systems by using Takagi-Sugeno (T-S) fuzzy models and the Parallel Distributed Compensation (PDC) concept. They showed that robust fuzzy controller effectively achieves the desired climate conditions in a greenhouse. Using this T-S fuzzy model, the stability analysis and control design problems can be reduced to sufficient conditions expressed as Linear Matrix Inequalities (LMIs).

Elmusrati, Virrankoski and Ahonen [15] constructed a wireless sensor network (WSN) consisting of small-size wireless sensor nodes equipped with radio and one or more several sensors, they developed a wireless sensor node for greenhouse monitoring by integrating a sensor platform provided by sensinode.

Khuan, Tik and Palaniappan [16] have proposed an embedded greenhouse monitoring and control system to provide a highly detailed micro-climate data for plants within a greenhouse environment with an innovative method of growing temperate crops in a tropical environment using microclimatic conditions. The greenhouse was equipped with conventional wired sensors that provide readings of the air temperature, light intensity and nutrient solution temperature in the mixing tank. The acidity and concentration of the nutrient solution were manually measured, and adjusted accordingly, and high resolution data collected with the deployment of a network of wireless sensors to provide sufficient data to develop a model for the growth of these crops under Aeroponic conditions. The researcher claimed that the reliability of the star network was relatively high, with many nodes performing with a data transmission rate above 90%, where the minimum data transmission rate for all the nodes was 70%.

Song *et al*. [17] have proposed system based on AVR Single Chip microcontroller and wireless sensor networks. The monitoring and management center can control the temperature and humidity of the greenhouse, measure the carbon dioxide content, and collect the information about intensity of illumination. In addition, the system adopts multilevel energy memory. It combines energy management with energy transfer, which makes the energy collected by solar energy batteries be used reasonably. Therefore, the self-managing energy supply system is established. The system has advantages of low power consumption, low cost, good robustness, extended flexible as well as an effective tool for monitoring and analysis decision-making of the greenhouse environment is provided.

Rodríguez et al. [11] developed a system for monitoring and predicting data in precision agriculture in a controlled environment using wireless sensor networks. Three prediction model was built using linear regression, neural networks and support vector machines (SVM). Simulation results shows that the SVM produced the best predictive model among the three algorithms compared. Some of the weaknesses of this approach include: there is no hardware implementation of the proposed

model. Moreover, the results of the experiments were not prepared in a clear and understandable manner for all readers to see. Also, the absolute mean error generated by the SVM is high, there is need to use more efficient algorithm with relatively low prediction error.

Fang et al. [18] developed a greenhouse acquisition and control system based on ZigBee wireless sensor network (WSN). The ZigBee have temperature and humidity sensors which is used to sense temperature and humidity of the environment. Data from the environment is collected using the sensor nodes. It then transmits the control commands to the controller nodes after processing and analyzing the data, so that the temperature and humidity inside the greenhouse can be adjusted thereby, providing conducive growth environment for crops. The proposed system is advantageous because it is cheap, less labour intensive and have low power consumption. The shortcoming of this approach is that performance of Zigbee protocol on remote multi-hop transmission is poor and the host computer may not always close to the sensor nodes.

Tafa, Ramadani and Cakolli [12] developed a greenhouse monitoring system using general purpose microcontrollers and low power ZigBee communication modules. They also did the performance analysis the greenhouse monitoring wireless sensor module. Experimental results obtained shows that the proposed system have a good performance in terms of functionality, accuracy, and overall cost. The drawback of the system includes lack of benchmark to measure the performance of the system, poor transmission, and lack of standard performance metric to evaluate the performance of the proposed system. The power consumption was not really tested. Also, there is need to use more nodes to increase the coverage of the sensing nodes in the green house.

Sampaio and Motoyama [19] proposed a hierarchical wireless sensor network for monitoring greenhouse. The system has the ability to monitor and control the humidity, temperature, ground moisture and environment lightens a greenhouse. Experimental results showed that all the components of the system are functioning properly. The drawback of the proposed system is that the experiments were carried out on a small scale WSN. Therefore, the performance has not been evaluated on large scale WSN. Moreover, the proposed system has a processing log jam on the serial port of the controller node that can decide the threshold of sensor nodes this system can contain.

Akkaşa and Sokullub [20] developed and IoT-based greenhouse monitoring system. Measurement data have been shared with the help of IoT. With this system farmers can control their greenhouse from their mobile phones or computers which have internet connection. With the system farmers can control their greenhouse from their mobile phones or computers which have internet connection. The deficiency of this system is that it only provides a one-way flow of information from the greenhouse to the end user. Also, the proposed system only monitored and do data analysis, it lacked the capacity to automatically control greenhouse farming.

Kitpo et al. [21] developed an IoT system with a bot notification on tomato growing stages. The tomato dataset was obtained from the tomato greenhouse in Japan. The deep learning model was trained and tested to detect the fruit proposal region. Moreover, the detected regions were classified into 6 stages of fruit growth using the visible wavelength as a feature in SVM classification with the weight accuracy of 91.5%. The limitation of the work is that the IoT solution lack the capacity to automatically control greenhouse farm.

Anish et al. [22] proposed an IoT Based Smart Greenhouse Monitoring System. The proposed system has the ability to compute various changes needed in the greenhouse using a wireless sensor network and a server. It uses the customer's website for controlling and monitoring service. The sensors used in the proposed method measures the soil moisture, humidity, temperature, $CO_2$ and the light intensity. The measurement is used to effect atmospheric changes inside the greenhouse. The advantages of the technique used is that it is fast and easy to install and use. It also has the ability to constantly give warning messages to the user about the condition inside greenhouse using cloud services. The limitation of this approach is that the work was not tested on large scale greenhouse farm and does not have the facility to automatically control greenhouse farm.

Hoque et al. [23] developed an automated greenhouse monitoring and controlling system that uses sensors and solar power. The sensors used for collecting data in the system include temperature

sensor, humidity sensor, light sensor and soil moisture sensor. The Arduino Uno R3 is incorporated to the system to store and process data. While GSM module is used to send SMS notification of the measured value of the various parameters to the user cell phone. A solar power system with rechargeable battery is also incorporated to ensure continuous power supply to the greenhouse system. Furthermore, Internet of Things (IoT) is used to store data to a database. The proposed system is advantageous because it cost effective, efficient and effective by analyzing major environmental parameters. The limitation of the proposed system is that it cannot determine the exact soil texture and amount of fertilizer to use aptly in the farm. Also, the cost of purchasing solar power can be a disadvantage especially for poor farmers in developing countries.

Anire et al [10] developed a wireless sensor network for greenhouse monitoring. The proposed system integrated environmental sensor such as temperature, humidity and soil moisture in a microcomputer Linux board which is the Raspberry Pi 3. Sensor calibration is used to ensure data accuracy for a controlled environment. The WiFi capability of the Raspberry Pi 3 is used to establish the wireless network between the nodes and the data aggregator. The drawback of this approach is that it only collects data and analyse it. It cannot automatically control the green house farm. Also, the developed device was only tested in a lab. Therefore, there is need to test it in an open field and evaluated the performance of the system.

Mekki and Abdallah [8] designed and implemented a wireless sensor network for monitoring and controlling greenhouse. The system has many nodes that is made up of temperature, humidity, moisture light, and $CO_2$ sensors. The limitations of the system include the fact that is not fully automated to control the greenhouse farm without any human intervention. Moreover, the performance of the proposed system was evaluated in a lab only, there is need to practically evaluate its performance in an open field.

The proposed design is to use a wireless sensor network with GSM technology for monitoring and controlling greenhouse climate. The system consists of a number of field stations connected to a central location. The location stations measure environmental parameters, send these parameters to a control station for display and control. It now determines the performance of the actuators based on predefined points. In essence, each local station microcontroller is used to store the value of the parameters, send them to the control station and receive control signals required for the operation of the actuators. The communication between the local station and the base station is done through transceivers.

The Wireless Sensor Network (WSN) was used to gather data from point to point to trace down the local climate parameters in different parts of the big greenhouse to make the greenhouse automation system work properly. This proposed system is a low cost greenhouse monitoring system designed to monitor a greenhouse temperature and humidity parameters. The advantages of this system is that it is easier and cheaper to install and maintain compared to many of the other systems in literature [24].

## 3. Methodology

This section describes the technique used to accomplish the set objectives of this work. First, the microcontroller is integrated on the main system and interfaced with sensors, the GSM module, the transceiver and actuators (water pump, heater and fan). This would enable the regulation of the greenhouse conditions when the conditions are not favorable.

### 3.1 System Architecture

The architecture of the proposed system shown in Figure 2 depicts the behavior and interfacing features of the main system. The Arduino Mega being the heart of the system interfaced with the required components: the display, the switching unit consisting of several relays and transistors, the transceivers and the major sensors.
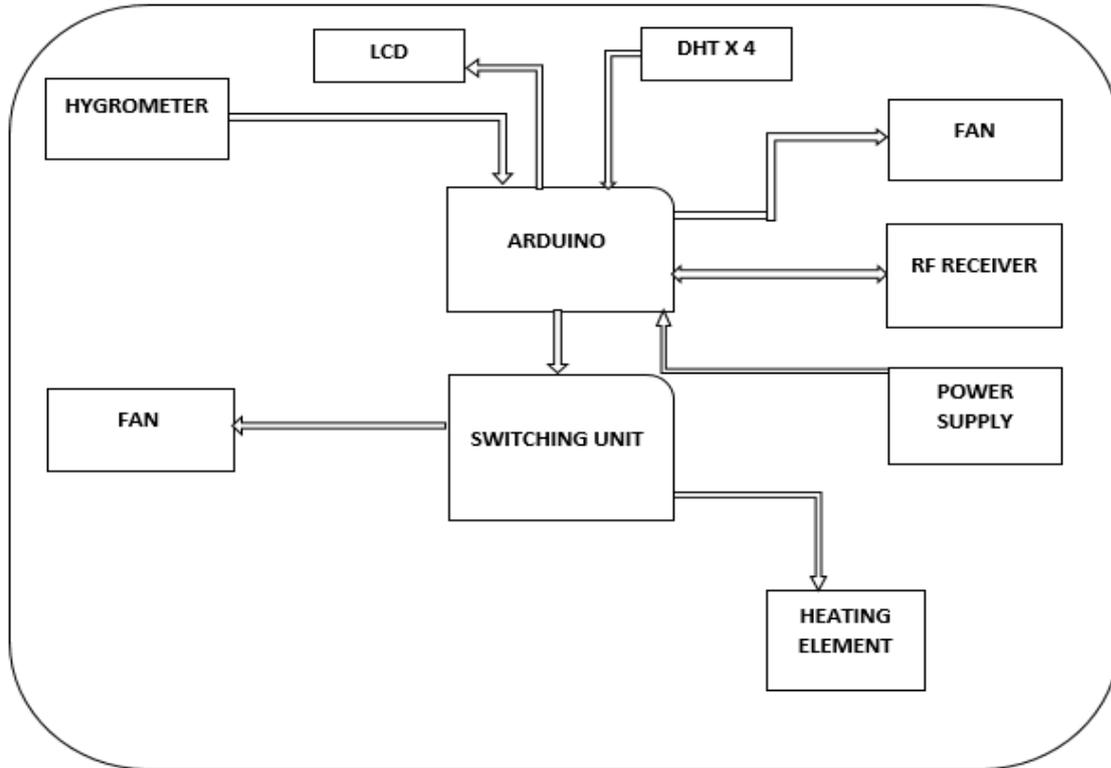
**Figure 2: Block Diagram of Main System**

Figure 3 represents the control system with the second Arduino interfaced with the LCD, the receiver on this section and the input keypad. This section determines the next action or behavior of the actuators.
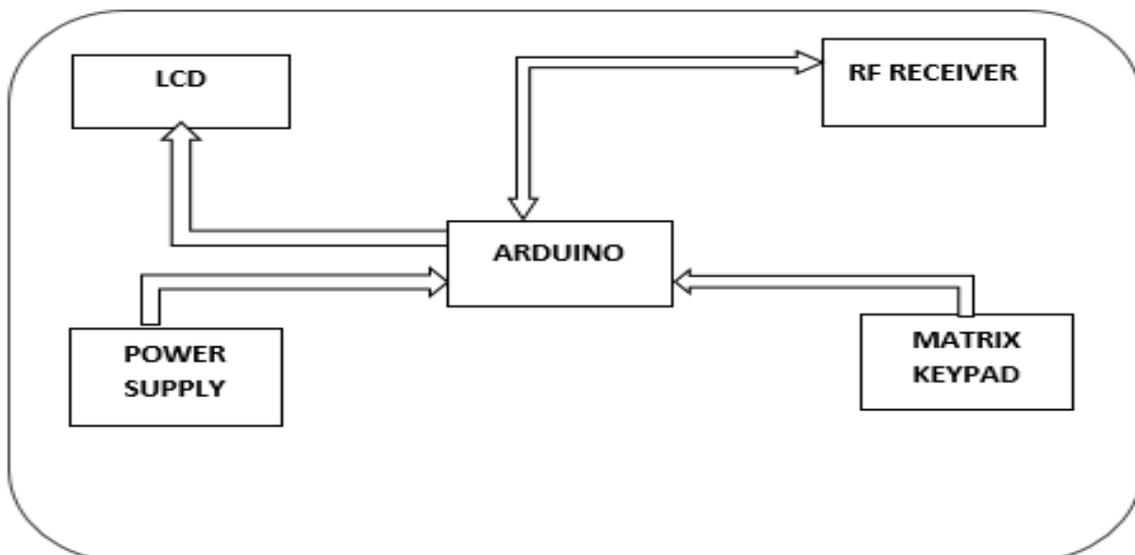


**Figure 3: Block Diagram for Control System**

Depicted in Figure 4 is the internal circuitry and configuration of the main system. The LCD is connected to the data pins of the Arduino (D2-D7), to the Arduino`s serial connectors, the GSM module is connected. The sensors are connected to the analog pins (A0-A3). The transceiver, the power supply and the switching unit are connected to the other end of the Arduino Mega.
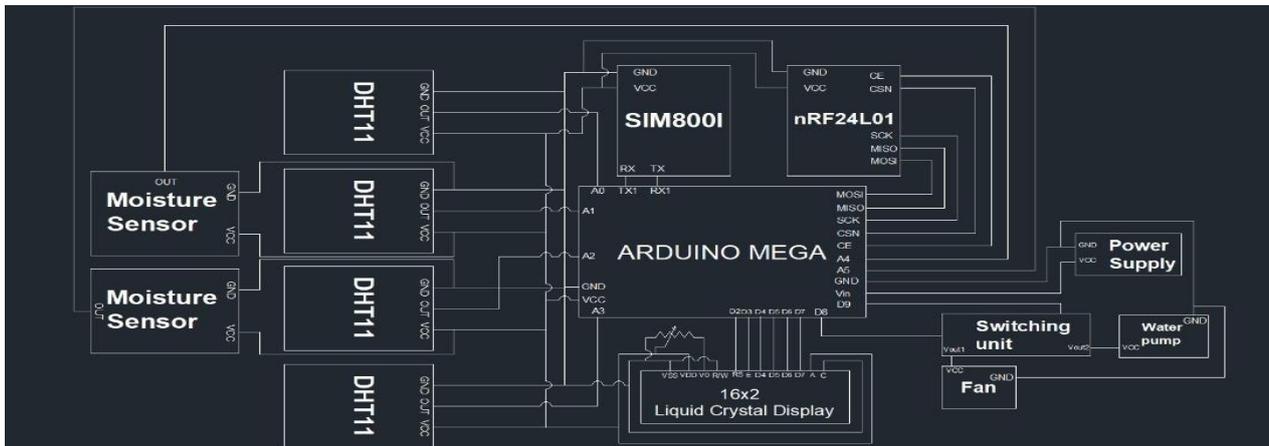


**Figure 4: Circuit Diagram for the Main System**

Figure 5 shows the internal circuitry of the control system with two input devices, i.e. the Dual axis joystick connected to the serial connectors of the Arduino UNO, with the matrix keypad connected to the data pins of the microcontroller and the transceiver interfaced at the other end of the UNO.
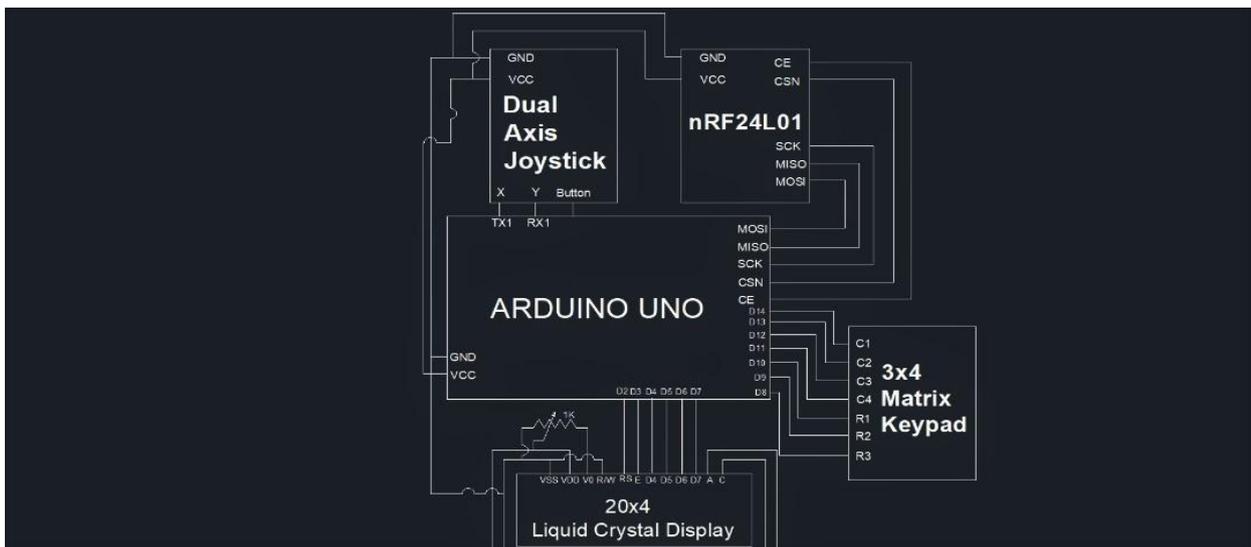


**Figure 5: Circuit Diagram for the Control System**

The values of the greenhouse parameters are predetermined and fixed and these values are uploaded into sensing and response unit for comparing with acquiring values. If the set temperature is greater than the acquired temperature the Arduino send signal to run the fan and the pump, else run the fan. If the set humidity greater than the acquired humidity, the Arduino sends signal to run the pump, fan, else run the fan. If the set of soil measure greater than the acquired soil measure the Arduino send signal to open the valve, else close the valve.

### 3.2 The Control Unit

Arduino is the heart of the intelligent greenhouse. Its boards are able to receive, analyze and send data in order to maximize plant growth and health. Figure 6 shows the basic Arduino board (Mega 2560. Brownout and watchdog help to make the system more reliable and robust. It supports ICSP as well as USB microcontroller programming with PC. The main reason behind choosing this is the additional features that are inbuilt with this board. First feature is the large I/O system design with inbuilt 16 analogue transducers and 54 digital transducers that supports with USART and other communication modes. Secondly, it has inbuilt RTC and other features like analogue comparator, advanced timer, interrupt for controller wakeup mechanism to save more power and fast speed with 16 MHz crystal clock to get 16 MIBS. It has more than 5 pins for Vcc and Gnd to connect other devices to Arduino Mega.

The Arduino Mega 2560 is a replacement of the old Arduino Mega, and so in general reference, it will be called without the '2560' extension. Due to the many numbers of pins, it is not usually used for common projects but you can find them in much more complex ones like Radon detectors, 3D printers, temperature sensing, IOT applications, real-time data monitoring applications and others [25].
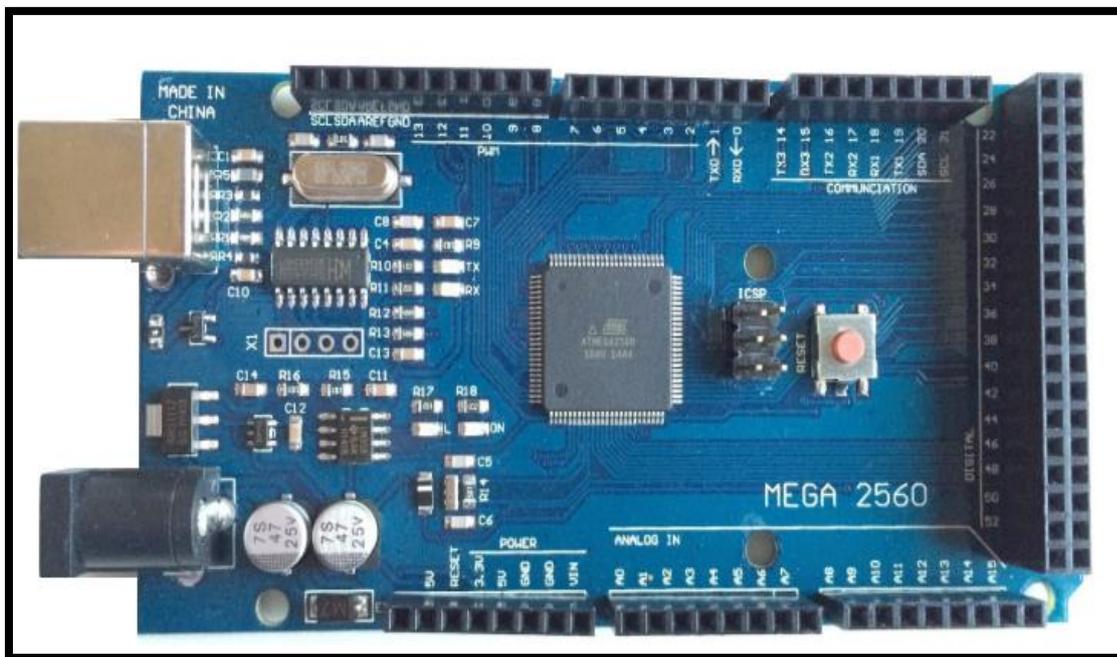


**Figure 6: Arduino Mega 2560**

### 3.3 Sensing and Response Unit

This unit comprises of the sensors that measures the greenhouse parameters and the components responsible for signal transfer and data transfer to the user. The sensing unit determine the conditions of the greenhouse. The sensing unit include the DHTs used to measure the humidity and temperature of the greenhouse, the soil moisture sensor determines the water level in the soil. Both transceivers (transmitter and receiver) are connected with the transceiver being on the main system and the receiver on the control system. With this, the data obtained on the main system would be forwarded to the control system for further action of actuators.

The data gathered from the sensing unit is sent to the control system through the transceiver on the main system to the receiver on the control station. The receiver obtains the data while the control system triggers the actuators from the interfaced microcontrollers. The actuators act on stabilizing the greenhouse conditions. If the temperature rises above a certain threshold value, the fan turns on,

if the temperature falls low, the fan is turned on and if the water level falls below the predefined percentage, the water valve supplies water, the output is then sent to the user through the GSM module. The user is chanced to make enquiries or control the greenhouse directly through GSM.

### 3.3.1 DHT11 Sensors
DHTs are some of the most widely used sensing technologies today. It allows for the detection of temperature in various applications and provides protection from excessive temperature excursions. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and spits out a digital signal on the data pin (no analog input pins needed).

### 3.3.2 Soil Moisture Sensor
YL-69 sensor is a soil moisture sensor. It was needed for reading water level in the soil. The Soil Moisture Sensor is used to measure the volumetric water content based on the dielectric constant of the soil. The sensor is inserted in the soil to sense the existence of water. An electric current can easily pass through if there is moisture and due to the fact that the level of moisture is hard to determine and to make sure that the moisture sensor is very accurate and efficient.

### 3.3.3 GSM Module (SIM800L)
SIM800L GSM/GPRS module is a miniature GSM modem, which can be integrated into a great number of projects. It is used to accomplish almost anything a normal cell phone can; SMS text messages, Make or receive phone calls, connecting to internet through GPRS, TCP/IP, and more! To top it off, the module supports quad-band GSM/GPRS network. In this case, it is used to send message to the user containing the conditions of the greenhouse for instances where the user is away from the greenhouse.

### 3.3.4 NRF24L01 Transceiver Module
The NRF24L01 transceiver module is used in this research in order to make a wireless communication between two Arduino boards where using the push button at the first Arduino will control the LED at the second Arduino. It allows us to remote things wirelessly all through the Wireless sensor network. In other words, it serves as a link between the main system and the control system.

### 3.4 Operation of the System
The construction of the wireless greenhouse controller system consists of major parts which are the hardware that is made up of the microcontroller, voltage supply, LCD display, sensor unit, relays etc. The software on the other hand is a program that runs compatible with the microcontroller that centres the entire paper. The software is a computer program called the source code. Source code is the list of human-readable instructions that a programmer writes - often in a word processing program - when he is developing a program. The source code is run through a compiler to turn it into machine code, also called object code that a computer can understand and execute. The programmable language to be used is Arduino which is compatible and simple with both C and C++ programs, the Arduino integrated development environment.

## 4. Results and Discussion

A comprehensive explanation on the system performance, methods of testing employed and analysis made is presented in this section. During construction of the three stages, each process stage was tested and modified to achieve the overall working device. This was made to ensure that failure rate was reduced to the barest minimum level. The performance, effectiveness and reliability of this paper was tested and verified using the aggregate of four (DHT11) temperature and humidity

sensors, two soil moisture sensors, a Liquid Crystal Display for human reading, GSM module for sending SMS and Radio frequency transceivers for communication with the control system.

Default threshold temperature is 30°C. This variable is not hard-coded; it can be modified from the control system via the matrix pad. When the temperature is greater than the threshold, fan is turned on. Also, if the soil moisture reaches a certain percentage below the threshold value, it automatically turns on the water pump and water flows for the set time period. A short message (SMS) is automatically generated and forwarded to alert the manager through GSM. This automatic generation of SMS is triggered by dialing the GSM number.

The graphs in Figures 7- 18 shows the measurements of three different parameters (temperature, humidity and soil moisture) taken for three days. The values were taken at intervals of 10 minutes each. Each parameter was observed after 10 minutes. The captured data for each of the environmental parameters are saved and plotted to observe the trend. For day 1, readings were first taken at 8pm on Thursday 17th October, 2019 and continuously after an interval of 10 minutes. For day 2, the readings were first taken at 12am on Friday 18th October, 2019 and eventually for day 3, the readings were first taken at 12pm on Saturday 19th October, 2019. The variation in time is to aid further research for enhancement of crop production.

Figure 7 shows a graph of temperature against time. At 8pm the temperature began to fall and it did continuously to sometime in the morning where the temperature began to rise towards noon.
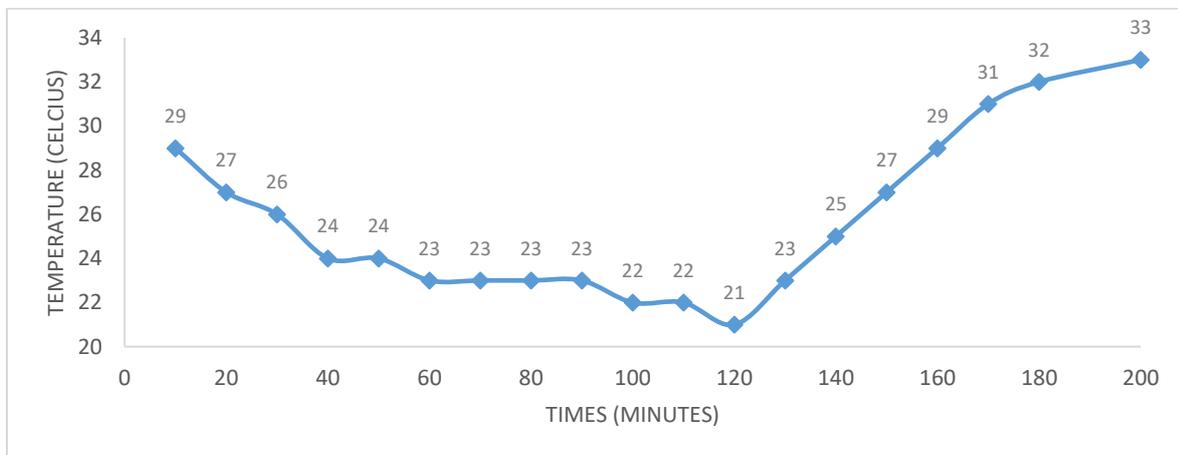


**Figure 7: Day 1, Temperature against Time**

Figure 8 shows the graph of humidity taken at alongside the temperature. For about two hours, it was noticed that the humidity rose and maintained the highest percentage in air, after about two hours, the humidity began to drop and it did continuously without rising.
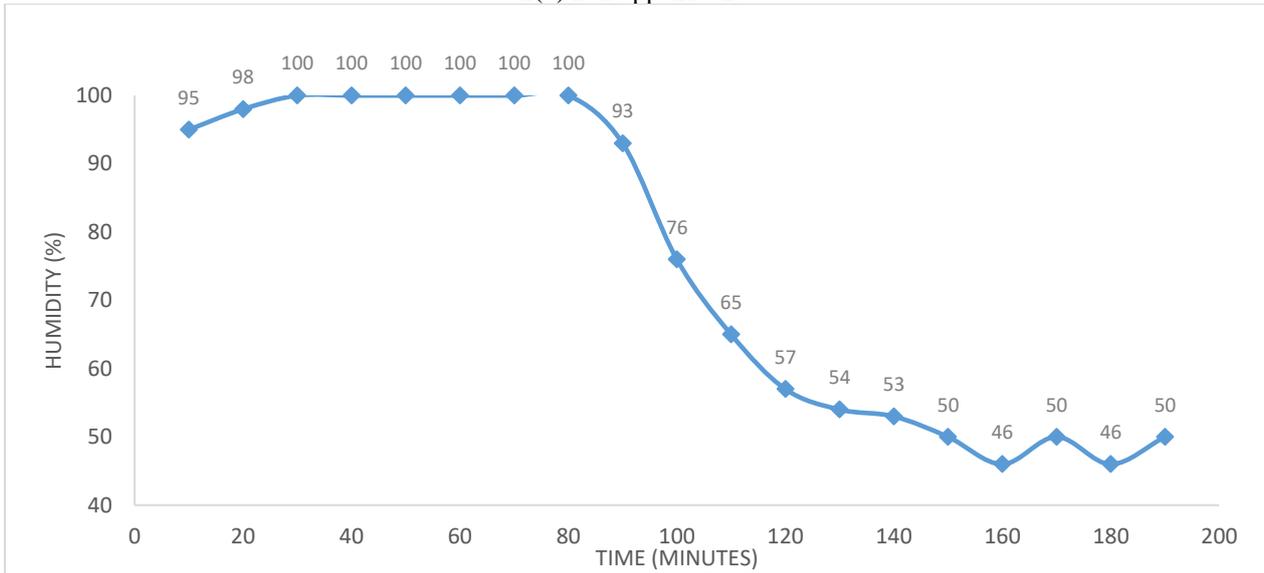
**Figure 8: Day 1, Humidity against Time**

Figure 9 shows the graph of soil moisture against time. Progressively, with passage of time the amount of water in the soil under supervision was noticed to fall low.
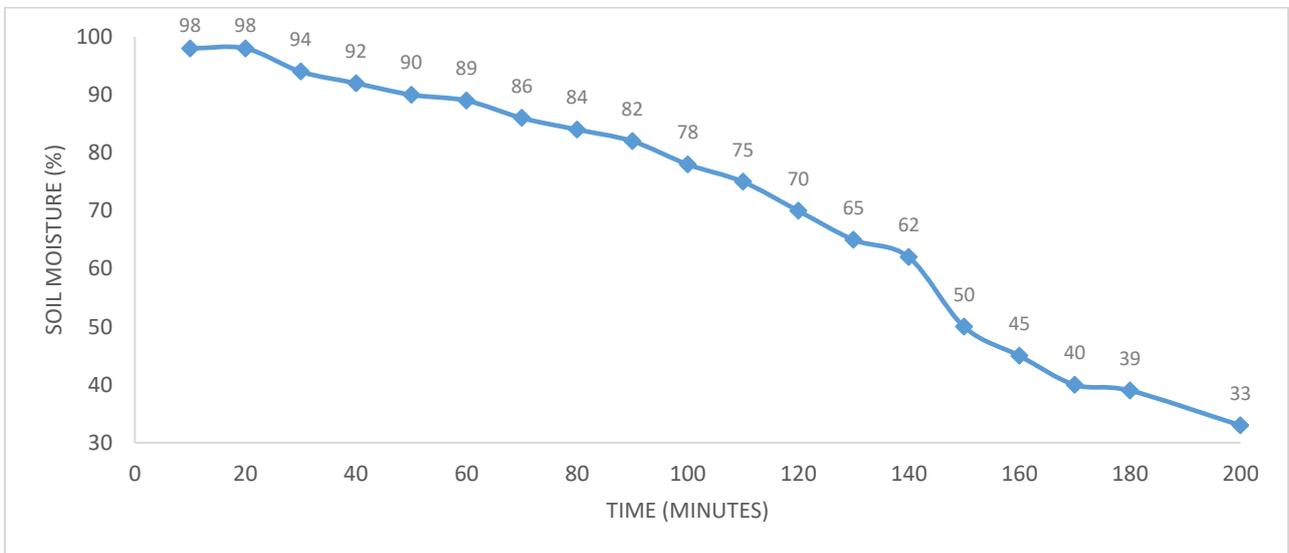


**Figure 9: Day 1, Soil Moisture against Time**

Figure 10 shows the second day`s observation of temperature change. The temperature reading began at about 6am. In the first hour it is observed that the temperature in the 5th and 6th period fall after which it started rising again. Afterwards the temperature began to rise for the next hours. Very close to sunset, the temperature began to fall low again.
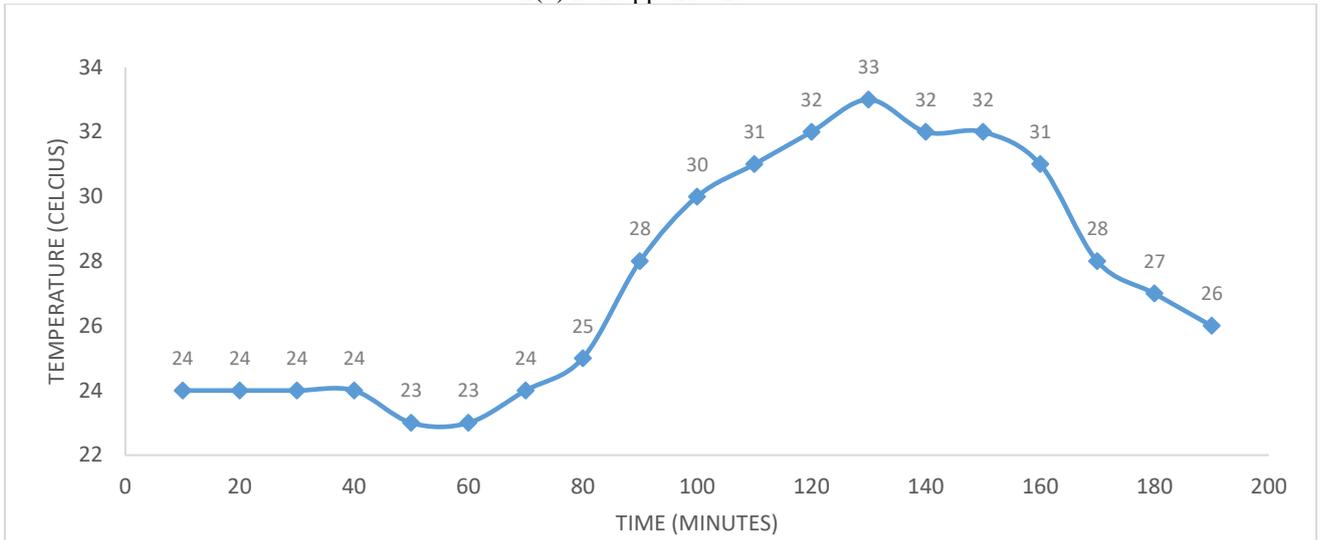
**Figure 10: Day 2, Temperature against Time**

Figure 11 explains the rise and fall of humidity. At first, there was a rise in humidity and suddenly after one hour, the humidity began to fall from 100 to about 52 after two more hours. From then onwards, the humidity began to rise again.
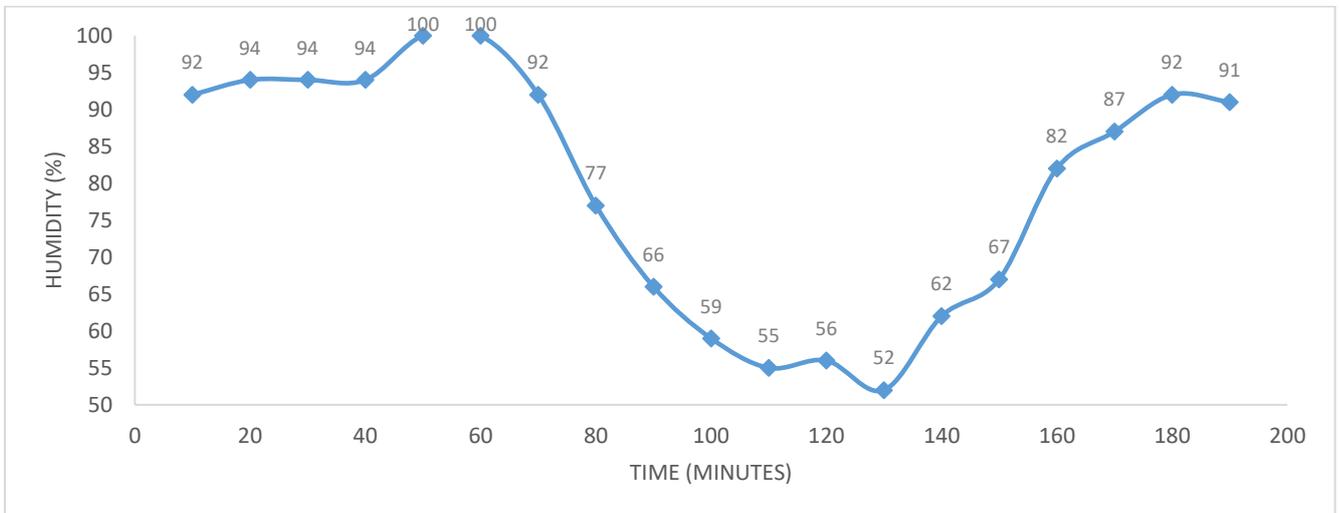


**Figure 11: Day 2: Humidity against Time**

Figure 12 is the third graph observation for day 2. As usual, progressively, with passage of time the amount of water in the soil under supervision was noticed to fall low.
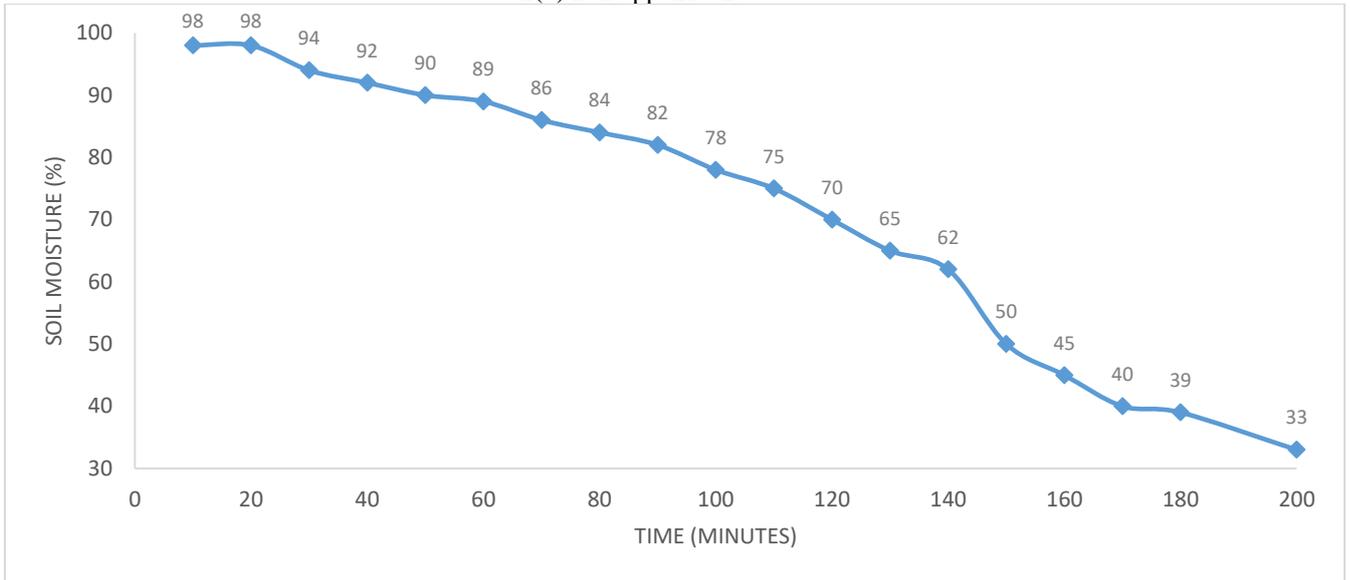
**Figure 12: Day 2, Soil Moisture against Time**

In Figure 13, there was an unstable rise and fall of temperature because some part of the day experienced rainfall and cloud cover, later on the temperature began to rise till evening time when the temperature began to fall at constant pace.
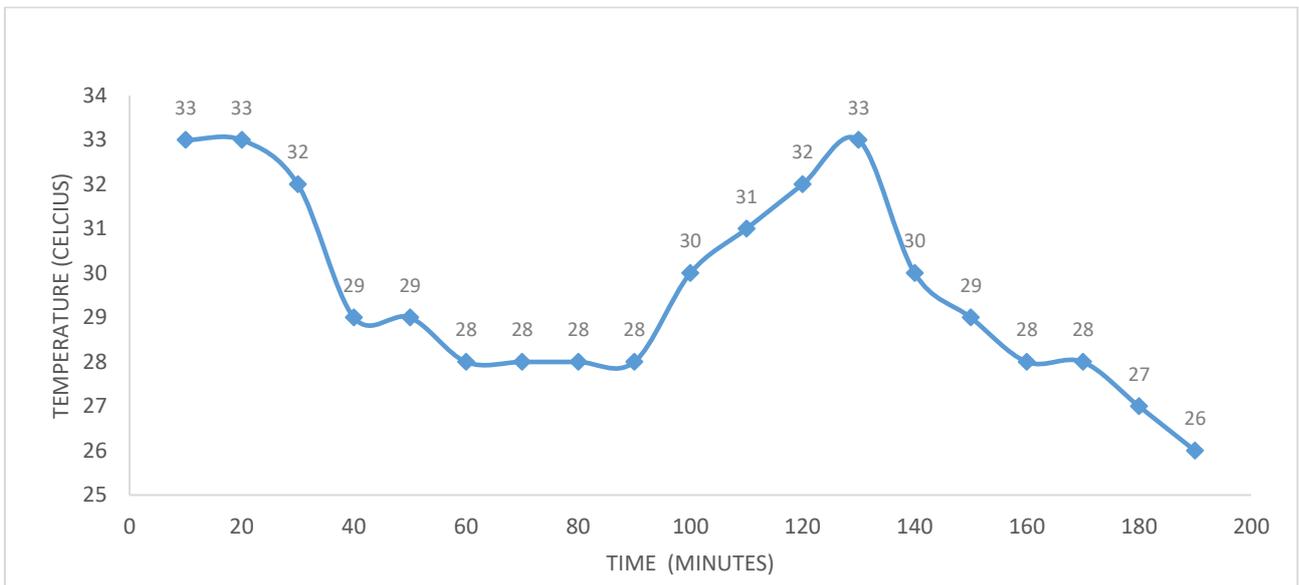


**Figure 13: Day 3, Temperature against Time**

In Figure 14, there was a continuous increase in humidity since early hours till evening period when the sun began to fall.
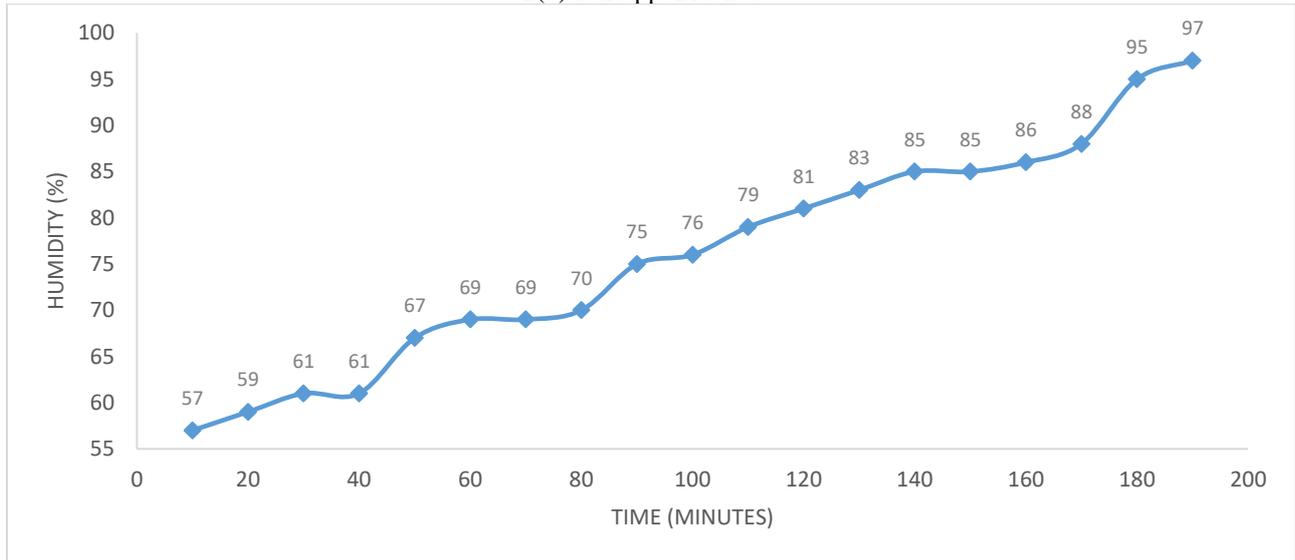
**Figure 14: Day 3, Humidity against Time**

In Figure 15, the soil under observation was left to dry a bit before readings were recorded, water was then added to the soil until it became very moist. After every 10 – 20 minutes, there was a drop in the water level.
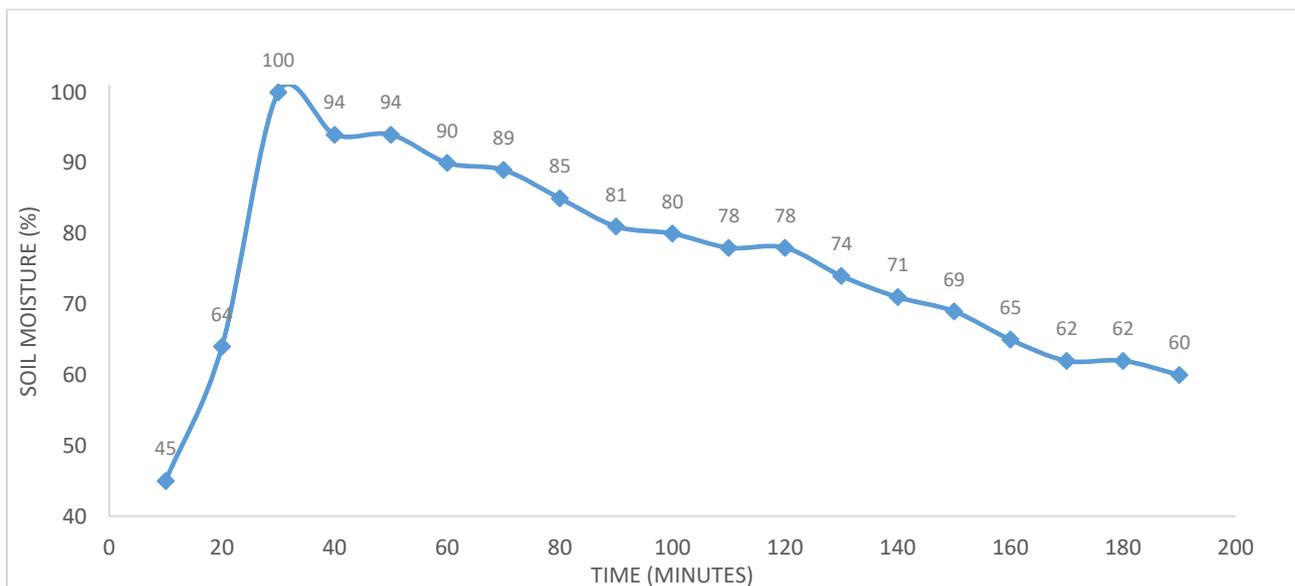


**Figure 15: Day 3: Soil Moisture against Time**

A composite graph is shown in Figure 16 which indicates the different temperature readings observed for all three days.
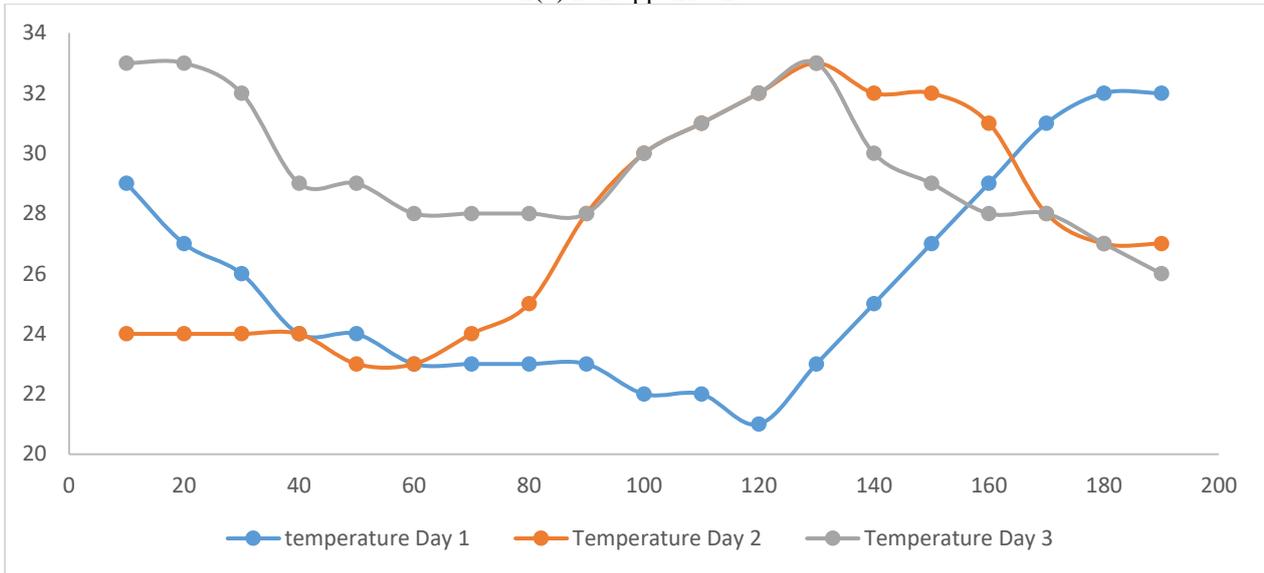
**Figure 16: Composite Graph for Temperature**

Figure 17 shows a composite graph of different humidity readings observed for all three days.
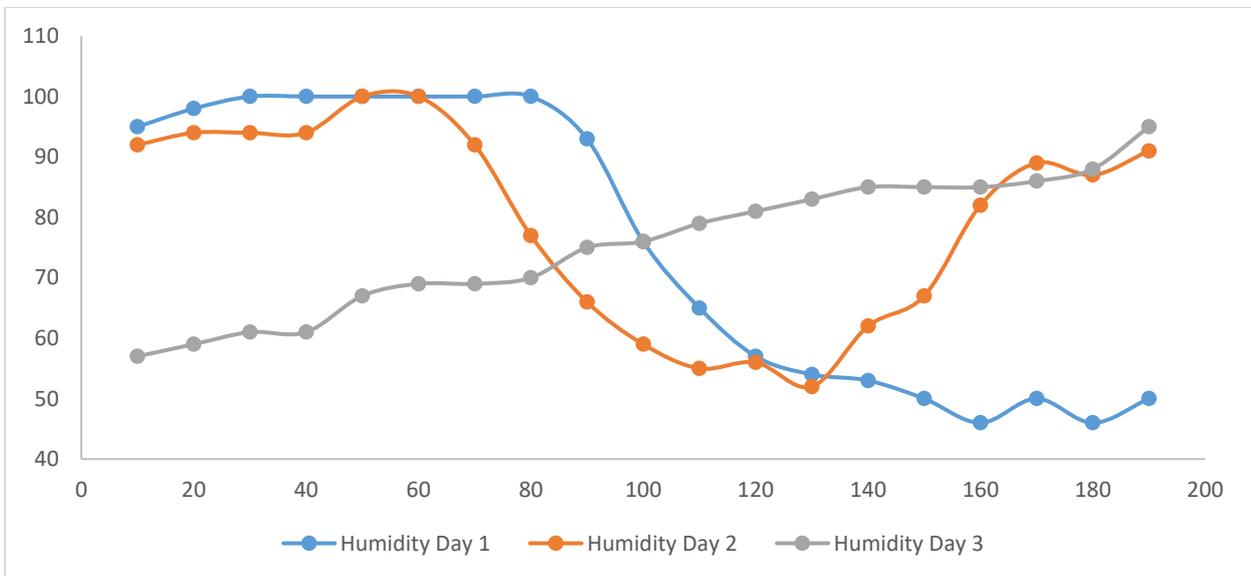


**Figure 17: Composite Graph for Humidity**

Figure 18 shows a composite graph of different moisture readings observed for all three days.
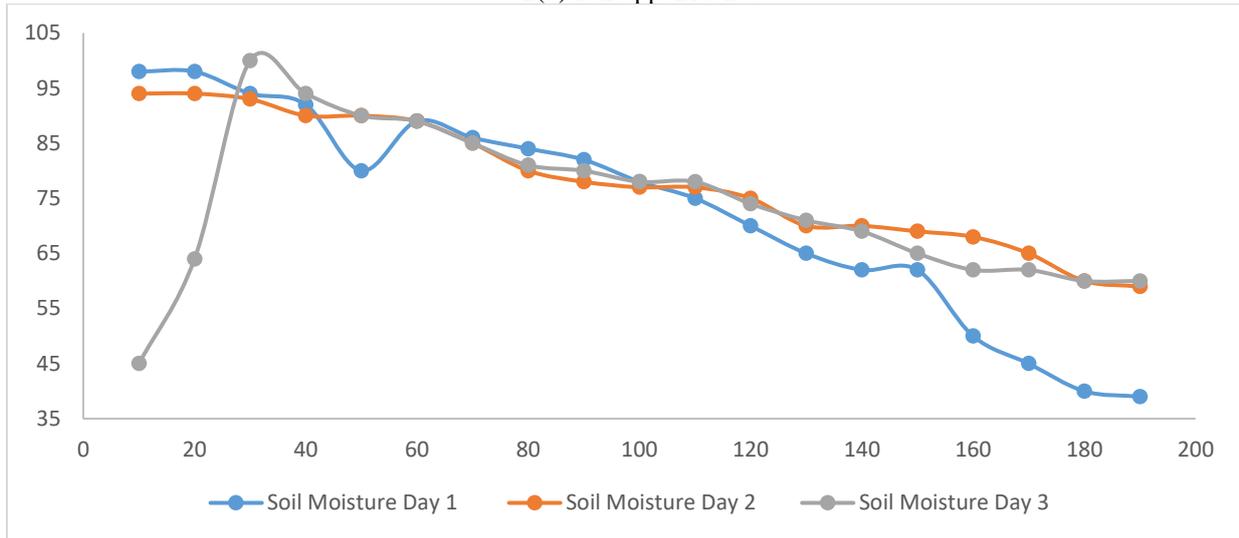
**Figure 18: Composite Graph for Soil Moisture**

Figure 18 shows the rise and fall of the three major parameters: temperature, water level in the soil and humidity. Also, from the charts above it was observed that temperature and humidity are directly proportional. Increase in temperature leads to increase in humidity too. It was also observed that the water level in the soil is lost at faster rate when the temperature is high. The next section concludes the paper and discusses some relevant advancements that can be made on the system which is a limitation to the present proposed methodology.

From the experimental results, it is evident that the proposed system is an effective environmental parameter monitoring of greenhouse farming using wireless sensor networks and Arduino microcontroller. This work provides a low power consumption, low cost, robust and effective greenhouse monitoring system. This is similar to what it obtainable in many of the work cited in previous section [8, 13, 17, 18, 12, 19, 20, 22 and 23]. However, unlike the work of [12 and 23], the power consumption was tested and found to be very economical. The results of the readings of the proposed system can be communicated to user. This overcomes the setback observed in [13 and 20]. Moreover, this present work has a wide coverage area because many nodes were used. This is unlike the drawbacks that characterised the work of [8, 12, 19 and 22]. This proposed system also overcome the challenges associated with the work of [23] where the greenhouse system cannot determine the soil moisture. Also, the limitation inherent in the work of Akkaşa and Sokullub [20] and Anish et al. [22] has been surmounted in this proposed method as the approach is simple and practicable in developing countries. It also has the capacity to automatically control the greenhouse farm from the base station.

## 5. Conclusion

This paper provides a comprehensive report on design process and implementation of wireless sensor networks for greenhouse monitoring with GSM technology. A comprehensive review on greenhouses monitoring strategies was provided. The proposed greenhouse management system has the advantage of lower installation with increased flexibility and reliability. Other advantages that the proposed system is its compatibility, compactness, portability and low power consumption. In conclusion, greenhouse monitoring and control using wireless sensor networks and GSM technology is a promising strategy for enhanced greenhouse management. The following improvements can be effected for possible future work:
   i.   More sensors can be added to the sensing unit to monitor other environmental parameters such as soil pH level, air flow, carbon monoxide and oxygen level.

ii. GPS module can be added to the system for locating the local station and prediction of the parameters depending on region.

iii. Global system for mobile communication and SMS can also be integrated into the system. These features will allow the system to directly alert any abnormal changes in the green house environment through the transmission of a simple short texts messages to the user.

iv. Memory card could also be chipped onto the system to give room for better storage of relevant data (values) through long time analysis of stored data.

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