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IoT-Based Greenhouse Monitoring and Control System

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Abstract: In conventional farming, farmers have to go around the farmland physically frequently to estimate the various environmental parameters like temperature, humidity, light intensity and soil moisture to harvest the ready crops at the appropriate time in the best soil possible. Although this conventional farming technique has been utilized for many years, it is irregular and fails to exhibit a high productivity rate because farmers sometimes cannot precisely assess all of the environmental parameters. Greenhouse farming, on the other hand, is a technique whereby the farmers grow crops in ecosystem habitats where all environmental factors are modified to suit the crop type. Automation in a greenhouse is a technology through which farmers may monitor and regulate the greenhouse environment automatically from anywhere in the globe at any time. This work aims to develop an automated greenhouse monitoring and controlling system, which integrates multiple sensors such as a temperature sensor, humidity sensor, light-dependent resistor sensor, and soil moisture sensor to obtain potential environmental parameters of the greenhouse, as well as integrate ESP32 development board, to store, process data and provide WiFi functionality. With the help of the Light Dependent Resistor (LDR), Temperature and humidity sensor and soil moisture sensor, the lighting of the bulb, fan activation and pump triggering can be controlled, respectively, whenever the environmental parameters are below the threshold value. Furthermore, with the help of the WiFi capability of the ESP32 development board, the Internet of Things (IoT) is utilized to store data in a database, process the acquired data, and eventually deliver the information to a user's web application for monitoring the environmental parameters in the greenhouse..

Keywords: IoT, Greenhouse, Web Application, Control System, Smart Agriculture

1. INTRODUCTION

Agriculture is one of the most critical sectors, providing a living for a great number of people [1] and contributing to climate change [2]. Agriculture is one of the main fields that sustain a country's economy [3]. Agriculture has been the lifeblood of all living things because it is the most important source of food and raw materials. Agriculture constituted 22.35% of Nigeria's overall Gross Domestic Product between January and March 2021. Over 70% of Nigerians work in agriculture, mainly at a subsistence level. Despite the importance of crude oil exports, the agricultural sector remains the foundation of the Nigerian economy since it is the primary source of subsistence for most Nigerians. Despite contributing to the economy, Nigeria's agricultural industry suffers various obstacles that hamper its output. These include poor land tenure, insufficient irrigated farming, climate change, and land degradation. Other factors include low technology, high production costs and inadequate input distribution, restricted finance, substantial post-harvest losses, and limited market access [4]. This work will focus on the challenges experienced due to climate change and its irregularities. In line with this, the greenhouse is brought into the equation.

The greenhouse provides the needed conditions for the plants to flourish by monitoring the environmental conditions within the structure. Monitoring is just the collection of data, though this definition is changing with the advancement of technology [5]. Monitoring evolves into a system that collects data and generates information. The monitoring process is carried out by using sensors, which are devices that measure an event or change in an environment and convert it into an electrical signal that can be read and analyzed.

Advancement in technology has created means by which the monitoring of the conditions can be done more effectively and remotely; this can be achieved by leveraging objects, protocols and technologies used for the IoT. The Internet of Things (IoT) has been incorporated in many sectors, such as the medical sector, home automation, smart cities and the industrial sector. It is only appropriate for it to be incorporated into the agricultural sector, the backbone

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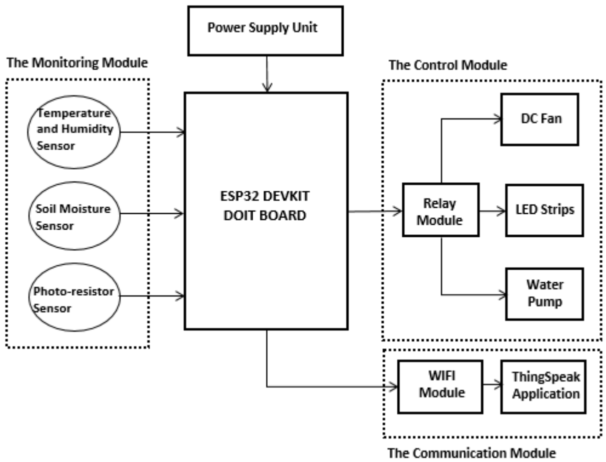


Figure 1. Block Diagram of the System [7]

of Nigeria's economy. The Internet of Things (IoT) is a collection of interconnected devices connected to a network and/or one another and exchanging data without needing human-machine interaction [6]. It is also the network of physical things, gadgets, and other items integrated with electronics, sensors, and network connectivity, permitting them to gather and exchange data. For the greenhouse system to be very effective and have less human intervention, there has to be the automation of the actuators, which are fans, lights, etc. This automation can be done via many means and control algorithms.

Farming on any scale is a task that is not trivial. Various plants and crops have different requirements for quantities like soil water-content level, temperature, fertilizers, light intensity, etc. A prevalent problem is the inability of farmers to provide the required quantities in an adequate amount; they either do not provide enough or provide more than necessary. Hence, incorporating an automated greenhouse using Internet of Things technology has the significance of making the farming process less strenuous and better control of the environmental parameter fluctuations, thereby leading to an increased crop yield level. The significance of this study includes the elimination of time spent on monotonous tasks and channelling the time to more important tasks; improvement in crop yield by ensuring plants are available in and out of season; management of resources more effective and efficient; improvement in the research process carried out in agriculture more efficient and make data provision readily available on the cloud.

Due to the changing climatic conditions and the fact that the traditional system for greenhouse monitoring requires manpower for watering the plants and some other monotonous process, crop yield has been really low, and this is because the traditional method of agriculture is time-consuming and prone to human error [2]. Hence, the need for an automated greenhouse where the irrigation, lighting, and many other processes are automated is necessary. It eliminates man errors and promotes high harvest generation.

This work aims to develop an automated greenhouse monitoring and control system for better crop yield. The objectives of this work are to Construct a prototype greenhouse structure; Monitor the environmental conditions in the greenhouse system using temperature, soil moisture, and photo-resistor (LDR); Control the environmental conditions in the greenhouse structure through the use of a fan, an LED strip and a water pump; Visualize the sensor data on the ThingSpeak platform [6] through the integration of Internet of Things (IoT). This work comprises three modules: the monitoring, controlling and communication module. Figure 1 gives an illustration of the block diagram of the system.

- Monitoring Module: Monitoring is defined as gathering data, but as technology advances, monitoring has evolved into a system that collects data and produces information [3]. Different types of sensors are used to retrieve data. The following sensors were used: The temperature and humidity inside the greenhouse are measured using a DHT22 sensor [8]. The LDR sensor is used in the greenhouse to detect the intensity of sunlight. The moisture in the soil is measured using a Soil Moisture Sensor.

- Control Module: The work of this module is to render a control action based on the data obtained from the sensors. The ESP32 DEVKIT DOIT board has a microcontroller that will control the processes. The sensors in the monitoring module as well as the actuators (fan, LED strips and water pump), are connected to the microcontroller for the control action of regulating the temperature/humidity, light intensity and soil moisture respectively.

- Communication module: This module ensures the IoT feature of the greenhouse system is enabled. It uses the Wi-Fi module of the ESP32 DEVKIT DOIT development board to send the status of the greenhouse structure to the ThingSpeak web application [6]. The WiFi communication protocol is preferred over communication protocols as it enables communication of large amounts of data to the internet.

The scope of this study is on creating a stable environment for the effective growth of Greenleaf plants. This study focuses on monitoring the environmental conditions in a model greenhouse through the use of the Internet of Things for research purposes. It also focuses on the provision of an effective means of controlling the environmental conditions in the greenhouse for effective growth of the plants through the automation of three main actuators, thereby leading to a high harvest rate at any time, in any season.

The organization of the work is discussed as follows: Section one contains the background overview of the work. It contains background information on the work and the motivation for the proposed solution. It also goes over the framework's goals, objectives, and methods of development, and the significance and scope of the study are outlined. Section two consists of a review of previous literature on greenhouse monitoring systems using IoT. Section three discusses the methodology used in this study. It covers the system description, data collection and analysis, the system simulation and the web application development process used for monitoring the plants in the greenhouse. Section four covers the development and testing of the work, the results and its significance to the real world. Section five is the concluding section.

2. LITERATURE REVIEW

A greenhouse is a glass-encased building that provides a regulated environment for plant development [2]. It protects crops from pests, illnesses, and harsh environmental conditions. It functions as a shield between nature and what you are developing, which permits the growth season to be elongated and perhaps improved. Some benefits of the greenhouse are; the production of fresh greens, vegetables and fruits, and the effective use of water and nutrients as opposed to open-field agriculture, thus the return on investment in the greenhouse is often higher than in open-field farming. With the support of the regulated climate within the greenhouse, the greenhouse is an ideal alternative for effective harvest generation, seed generation, and transplantation [5].

The greenhouse is a system for controlling and regulating climatic conditions that allow plants to flourish in otherwise unsuitable climates for their growth and development. However, the productivity and efficiency of the greenhouse technology are fully dependent on the type of greenhouse structure used for production [9]. The design of a greenhouse is determined by the location's latitude and the crop's requirements [10]. The Types of Greenhouses Based on Cost Investment are Low-technology, medium-technology, and High-level greenhouses. The Types of Greenhouses Based on The Shape include Lean-to-type greenhouses, even span-type greenhouses, uneven span-type greenhouses, Saw-tooth type greenhouses, and Quonset greenhouses. The Types of Greenhouses Based on Utility are Active heating systems of greenhouses and Active cooling systems of greenhouses. The Types of Greenhouses Based on Construction are Wooden framed structures, Pipe-framed structures and Truss-framed structures. The Types of Greenhouses Based on Covering Materials are Glass greenhouses, Plastic film greenhouses and Rigid panel greenhouses [9].

Since the climatic conditions outside are inconsistent, it is important to adjust the environmental conditions within the greenhouse to produce greater crop production at the lowest possible cost. Hence, the greenhouses are constructed to provide these regulated climatic conditions; the parameters needed for plant growth must be monitored, controlled, and maintained. In the greenhouse, the monitoring system helps monitor various parameters such as temperature, humidity, light, pH level, soil moisture, etc.

Typically, greenhouse farmers use sunlight to grow their plants. However, the sun is unpredictable. The need for a substitute has become necessary. In previous years greenhouse farmers have used high-pressure sodium (HPS) light as a substitute, but these lights do have a drawback. They consume a lot of power and dissipate a huge amount of heat. In the past 20 years, the development of Light Emitting Diodes (LEDs) has offered greenhouse farmers a better alternative to HPS lights. Initially, the focus on LEDs was its benefits of lower power needs and reduce heat. But recent attention has been shifted to the effects of the colour spectrum on crops. The most significant advantage of LED lighting in greenhouses is the dynamic illumination of crops [11].

Various sensors are used to monitor the lighting condition to detect when artificial lighting is needed in the greenhouse. The light sensor's operation is based on the internal photoelectric effect, a phenomenon in which electrically charged particles are released from or inside a substance when it absorbs electromagnetic radiation. When exposed to light, the phenomenon is commonly described as the ejection of electrons from a metal plate. Quantum detector systems and Thermal detector systems are the two types of light-measuring devices (sensors) employed in the greenhouse. Quantum detector systems use Photo-synthetically Active Radiation (PAR) sensors, Photo-diode Light sensors and Photo-transistors sensors. Thermal detectors use Light-dependent resistors (LDR [12] and Pyranometer sensors.

Temperature is one of the most important factors influencing plant growth. The temperature required for proper growth varies depending on the plant. Some plants require a high-temperature level to grow, while others require a low-temperature level. As a result, it is critical to maintaining the proper temperature for each variety of plants. In the greenhouse, the majority of its energy expenses (70-85%) are tailored toward temperature control. To measure the temperature in the greenhouse structure, the temperature sensors are to be installed spatially over the plants [13].

Humidity is another significant factor in plant development. As plants develop, they exhale warm, moist oxygen and process CO2, naturally warming and moistening the greenhouse atmosphere. The humidity and temperature in the greenhouse are closely linked; therefore, having both temperature and humidity sensors positioned together is an effective move. Nowadays, some modules have temperature and humidity sensors, which help with system simplicity. Below is a table showing detail of some of the humidity sensors used for humidity monitoring [13].

Providing water to the plants is of great importance as low moisture results in poor yield and destroys the plants; also, excess water can cause root disease and lead to water wastage. Therefore, it is vital to maintain the required water level in the soil precisely. The introduction of soil

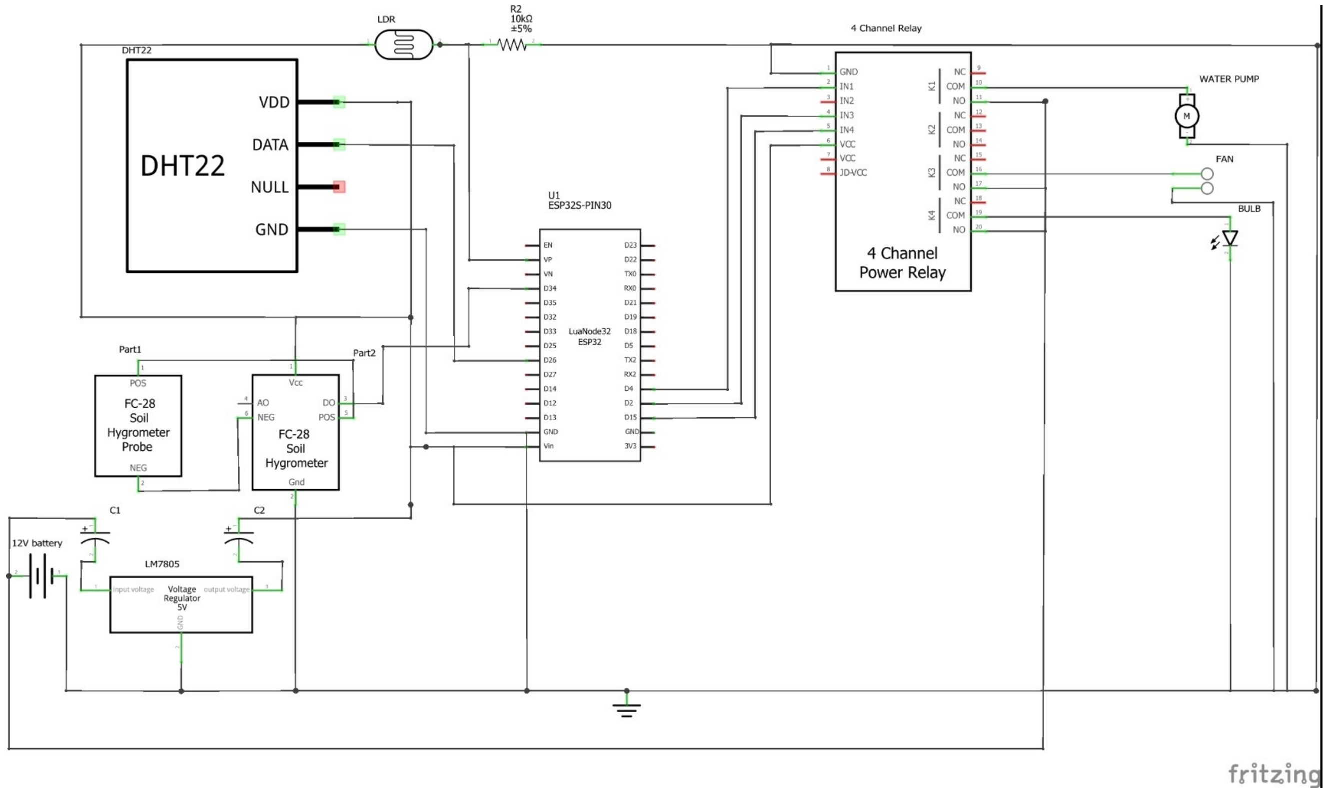


Figure 2. Schematic Diagram

moisture sensor-based irrigation control systems has yielded high-quality and high-quantity crops because the plants are watered when needed. This method has also reduced water wastage. Many types of soil moisture sensors are utilised to detect the amount of water in the soil. Water tension- and content-based sensors are the two types of soil moisture sensors. The water tension sensors are used to measure how firmly water adheres to the soil. This sensor's measurement is represented in pressure units known as bars. It consists of Tensiometers and Granular Matrix sensors (GMS). Water content sensors detect the quantity of water in a known amount of soil; it can be represented as a percentage (%) of water by weight or volume of soil or as inches of water per foot of soil. It consists of the Time Domain Reflectometry (TDR) [14], and Capacitive sensor [13].

In the greenhouse, there could be situations where there could be intruders who come to take some plants and there are also situations where the number of people coming into the greenhouse needs to be known. Various sensors are used to estimate the number of people in the greenhouse or to notify when there is an intruder. Some of these sensors are Passive infra-red (PIR) [15], Grid-EYE sensor [16], [17] and People recognition cameras.

Farmers are unaware of the exact condition of the weather so the activities they carry out are not precise. They perform the activities based on feelings and intuition, as such accurate results cannot be obtained. So, to know the exact amount of resources needed by the plants, a control system is to be used [18]. With the advancement of technology, remote control systems are being implemented in various fields, agriculture inclusive. Control systems are made up of the controllers and the plant to be controlled. Controllers are devices used for the processing of data obtained from sensors and then making decisions based on the analysis carried out. Some of the activities include the activation of actuators or drivers in the system. The controllers are referred to as the "brains" of automated systems [19]. In the greenhouse, various controllers can be used to control the climate conditions in the structure using data obtained from sensors. These controllers range from Microcontrollers to microprocessors and then to Programmable Logic Controllers.

J S Sujin et al [20] in their system used the Arduino Uno as the standard controller to connect all sensors and control the actuators. Yong Wu et al, used a raspberry pi [21] in the remote-control system of their greenhouse environment. In the work, it was used as the control system for the implementation of automatic fertigation and collecting data from the environment monitoring system [22]. In [18], a Programmable Logic Controller is proposed in their system for the control of temperature and soil moisture level to maintain a constant temperature level by frequently turning on and off the light and fan.

The Internet of Things (IoT) idea has been widely used in a variety of industries, including smart homes, health care, and item traceability, as technology has advanced. Internet of things, in simple terms, can be defined as anything that has sensors attached to it, to transmit the measured data over the internet from one computer to another or a person. In IoT, the communication protocol is important in the safeguarding of the network. IoT communication protocols are forms of communication that ensure the data is being transmitted between IoT-linked devices [23]. The communication protocols for IoT are classified into Low Power Wide Area Networks (LPWAN) and short-range networks. MD Jiabul Hoque et al [2], in their system to guarantee effective plant development, the technology they designed sends the measured value to the user's cell phone through text messages using GSM SIM900A Module. In [24], The sensor data were transmitted wirelessly from the ZigBee transmitter to the ZigBee receiver. The ZigBee receiver is linked to a PC to monitor sensor data in real time. BLE and 6LOWPAN are communication protocols that are also used [23]. LORA is another communication protocol that allows for long-range transmission of small packets of data with low power requirements [25].

A greenhouse is often depicted as a highly dynamic intricate multi-input multi-output (MIMO) system, strongly put together, and weather-dependent. It has only recently become feasible to use complex control methods on embedded devices, as the compute functionality of minimal processors has increased to the point where the associated complex algorithms can be processed on them. There are varieties of control methods, which are simple on/off, proportional-integral (PI), proportional integral derivative (PID) [26], adaptive, feed-forward, fuzzy, neuro-fuzzy and optimal control solutions. In [27], a fuzzy control was used because it is a great algorithm for controlling complex systems. It was implemented to control the environmental conditions in the greenhouse intelligently.

MD Jiabul Hoque et al. [2] constructed a greenhouse that automatically monitors and controls different sensors adopted to get possible environmental parameters of the greenhouse. The communication link used in this system is a GSM module to send the measured values to the user's cell phone through a text message. A solar power system is utilized to make sure that the greenhouse has a constant power supply.

Emil Robert Kaburuan, Riyanto Jayadi, and Harisno [28] presented a research paper on a method for monitoring the progress of indoor microclimate horticulture. They used an Internet-of-Things (IoT) board which consists of electrical sensors to monitor the air, water, and soil conditions at the horticulture site to track the growing process. The communication link is an IEEE 802.11 WLAN module.

Rubeena Aafreen, Salwa Yasmeen Neyaz, Raaziyah Shamin, and M. Salim Beg [29] proposed an innovative

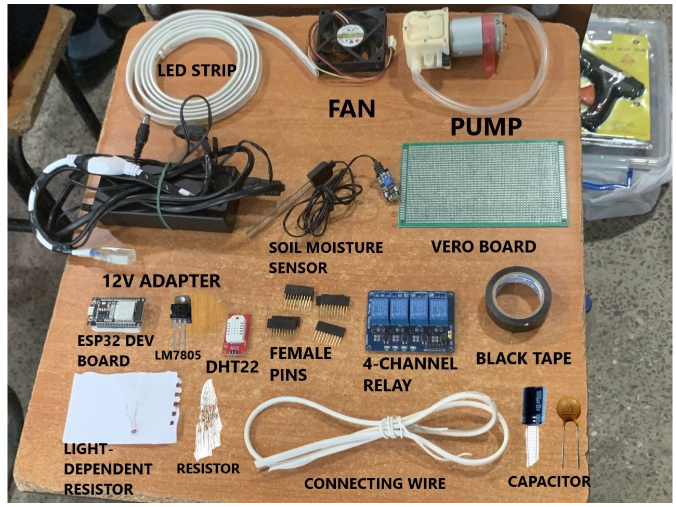


Figure 3. Components used

Internet of Things-based solution for greenhouse telemetry and control. The designed system transmits real-time sensor data, visualizes it, and processes it on the central monitoring server/PC using the ThingSpeak cloud and GSM. The system consists of three parts: Sensor Node, Central Monitoring Server and Monitoring and control unit based on a mobile phone (also known as the actuator node). The sensor node is responsible for processing, packetizing and transmitting the sampled sensor data to the server. The central monitoring server receives, stores, visualises, and analyses live data from the sensor node. Finally, the Actuator Node wirelessly receives and executes control commands found on the Blynk server. It is linked to different fans, irrigation pumps, and other actuators.

TABLE I. COMPONENTS SPECIFICATION

S/N	Components	Specifications
1	LED Strip	Rated Voltage: 12V DC Number of LEDs: 2x32pcs/m Length: 1m Input voltage: 220V – 240V Waterproof rate: waterproof IP65 Colour: Warm white
2	DC Fan	Rated voltage: DC 12V Current: 0.16A Speed (RPM): 3900 (±5%) Airflow (CFM): 5 Color: black Dimension (mm): 40 x 40 x 10 Weight: 16g
3	DC Pump	Operating voltage: 12V Colour: white Motor Phase: Single phase

4	Power Adapter	Input voltage: 100V – 240V AC AC input frequency: 50/60Hz Output voltage: 12V DC Output current: 2.5A Output power: 24W Weight: 0.172kg Dimensions: 91 x 53 x 31 mm
5	Soil Moisture (Driver and Probe)	Operating power: 3mA @ 5VDC Operating temperature: -40^{0}C to +60^{0}C Size: 36*15*7mm Accuracy: ±4% typical
6	Vero Board	
7	ESP32 Development Board	It uses the ESP32-D0WDQ6 chip It uses the Xtense LX6 microprocessor Number of cores: 2 (dual-core) Architecture: 32 bits 4MB flash (some variants go up to 16MB) Operating Current: 80mA Clock Frequency: 80 240MHz Pins: 30 SRAM Memory: 512KB Wi-Fi: 2.4GHz up to 150 Mbits/s Bluetooth: BLE (Bluetooth Low Energy) and Legacy Bluetooth
8	Resistor	Resistance used: 10kΩ
9	Capacitor	1 ceramic capacitor and 2 electrolytic capacitors
10	LM7805	Input voltage: 7 – 35V DC Output voltage: 5V DC Operating current: 5mA Output current: up to 1.5A
11	DHT22	Operating voltage: 3.3-5.5V DC Operating range: humidity 0-100%RH temperature -40 80Celsius Dimension: 58.8 x 26.7 x 13.8 mm Color: white
12	4-channel Relay	Supply voltage: 3.75V to 6V DC Trigger current: 5mA Weight: 61g Maximum switching voltage: 250VAC/30VDC Maximum switching current: 10A Size: 76mm x 56mm x 17mm
13	Light-dependent Resistor	Max power dissipation: 200mW Max voltage @ 0 lux: 200V Peak wavelength: 600nm Dark resistance after 1 sec: 0.03MΩ Dark resistance after 5 sec: 0.25MΩ

Agilesh R, Asrath J, Danish Kumar S, Hariharasuthan N, Santhosh K and Sathya Priyan R [30] proposed a system in which smart GPS-based remote-controlled robots were used to do tasks such as weeding, moisture detecting, animal and bird scaring, spraying, and a variety of other activities. Smart irrigation based on reliable continuous field data is also included. Third, warehouse management which includes temperature control, humidity control, as well as stockroom intrusion detection was proposed as well. Sensors, Wi-Fi or ZigBee modules, cameras, and actuators were integrated with a tiny regulator and a raspberry pi, and they were controlled by smart remote devices or Personal Computers connected to the Internet.

Foughali Karim, Fathalah Karim, and Ali Frihida [31] in their work presented an IoT-based alarm system for controlling water stress tolerance in plants. The first section detailed the procedures involved in developing a decision support system that would allow an agricultural community to estimate the amount of water required. By visualising the differences in soil conditions on a dashboard, the farmers can monitor these in real-time. Also, there is the feature of receiving notifications via SMS.

Abdelhakim Sahour, Farouk Boumehrez, Mohamed Benouaret, and Azzouz Mokhneche [27] in their article provided a smart greenhouse prototype. The fundamental contribution of their work is a unique construction of a micro-climate regulated environment for top-notch plant development that uses IoT technology and incorporates a fuzzy logic controller. The ZigBee wireless network was employed as the communication protocol. They aimed to optimize the usefulness of the proposed system by gathering and analyzing information using an Arduino Uno board.

This review is focused on the technologies that have been adopted for greenhouse monitoring and control. From this review, the focus has not been on controlling the environmental factors in a greenhouse. This work attempts to fill this gap by monitoring the system and controlling the system such that the environmental factors of light, temperature and humidity are at a preset, constant value.

This section focused on the importance of greenhouses in agriculture and the various types of greenhouses worldwide. Secondly, the various monitoring and control systems and algorithms were discussed in this section. In addition, the various IoT communication protocols were discussed. Finally, gaps from various literature were highlighted and discussed.

3. MATERIALS AND METHODS

This section presents a detailed insight into the materials and processes involved in the specification and designing of the greenhouse monitoring and control system while giving reasons for the choice of each component and method used. This prototype is a small model for a large system being implemented in the real world. It is purely for demonstration. The section proceeds with circuit design, a description of the mechanical structure, and Hardware implementation procedure and then concludes with a description of the IoT interface.

A. Hardware Design

Software and physical components comprise the system. The major aim of this system is to produce a productive greenhouse environment that will cut labour costs while also increasing crop availability in all seasons. Sensors, microcontrollers, and actuators are all included in the system. When environmental parameters surpass a safety threshold, the sensor detects a change, and the microcontroller receives the data from its input ports and takes the appropriate action to restore the parameter to its proper level. The microprocessor sends a command to the actuators (fan, water pump, LED strip) to turn them on. The sensor data is sent over the internet to the ThingSpeak Web Application for data logging and inspection by users. Sensors values are sent to the ThingSpeak platform via MQTT. Graphs are used to visualize these numbers.

From Figure 1, the system comprises three major modules; the first is the monitoring module, which comprises the soil moisture sensor, the humidity and DHT22 sensor and a photo-resistor (LDR sensor). This unit measures environmental conditions such as temperature, humidity, soil moisture level and light intensity. The data are visualized on the ThingSpeak Web Application in real time. The second module is the control module, which comprises the ESp32 development kit, which uses the Xtense LX6 microprocessor and actuators: a Fan, Water Pump, and LED Strip. This module is responsible for using the sensor data to determine what the actuators' next action is, whether they are to be activated or not. The third module is the internet module, which uses the ESP32 development board's Wi-Fi module to send the greenhouse structure's status to the ThingSpeak Web Application. Figure 2 is the circuit diagram for the greenhouse monitoring and control system. This system consists of the connection of sensors, a microcontroller unit and actuators. The various units are explained:

1) The power supply and grounding unit: A 12V adapter is used to power the Greenhouse Monitoring and Control System. The 12V is stepped down using an LM7805 IC. This voltage regulator, in conjunction with a capacitor for filtering, is used to step down the voltage to 5V. A heat sink was connected for the LM7805 because of the high heat it dissipated. The 5V output of the LM7805 supplies power to the DHT22 sensor, soil moisture sensor, 4-channel relay module and the ESP32 development board. Common ground is established.
2) The monitoring unit: this unit consists of the soil moisture sensor, Light-dependent Resistor sensor, and DHT22 module (Temperature and Humidity) sensors. The VCC pin of the DHT22 module was connected to the 5V coming from the voltage regulator. Then the DAC pin of the DHT22 was connected to pin 26 of the ESP32 Development board. Finally, the GND pin of the DHT22 module was connected to the common ground. The soil moisture sensor consists of a driver module and a sensor probe. The driver module and the sensor probe were interfaced by connecting positive to positive and negative to negative. The soil moisture driver module's analogue pin (A0) was connected to pin 34 of the ESP32 Development board. The VCC pin of the driver module of the soil moisture sensor was connected to the 5V coming from the voltage regulator (LM7805). The GND pin was connected to the common ground. For the Light-dependent Resistor (LDR) sensor interfacing, one leg of the LDR sensor was connected to a 10k ohms resistor, which served as a pull-down resistor. Then the same end is connected to pin 6 of the ESP32 development board. Then the free end of the resistor is connected to the common ground. The free end of the LDR is connected to the 5V coming from the voltage regulator (LM7805).
3) The actuator unit: this unit consists of the fan, LED strips and water pump. A 4-channel relay module is used to control these actuators. The VCC pin of the relay module is connected to the output pin of the voltage regulator (LM7805), which supplies 5V. Then the GND pin of the relay module is connected to the common ground. The IN1 pin of the relay module is connected to pin 15 of the ESP32 development board, the IN3 pin of the relay module is connected to pin 2 of the ESP32 development board, and the IN4 pin of the relay module is connected to the pin 4 of the ESP32 development board. Channel 1 controls the water pump, channel 3 controls the LED strip, and channel 4 controls the 12V DC fan.

Figure 3 shows all the components used for the construction of the prototype greenhouse monitoring and control system while Table I shows the specification of each component. their application in this work is discussed below.

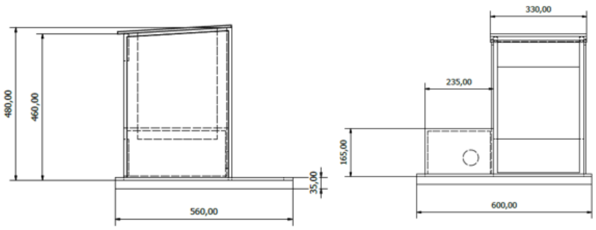


Figure 4. Dimension of the Prototype Greenhouse

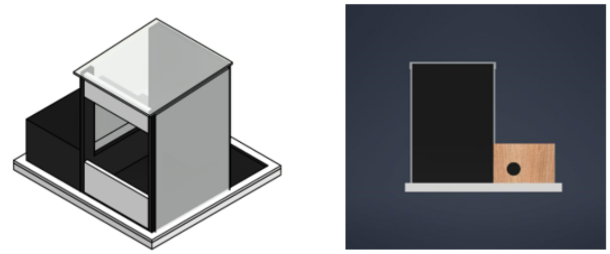


Figure 5. Dimension of the Prototype Greenhouse

1) LED Strip was used to provide illumination for the plant during the nighttime to continue the photosynthesis process.
2) 12V DC fan which is used for regulating the temperature condition of the greenhouse. It is triggered when the temperature level of the greenhouse is higher than the threshold value.
3) DC pump, which is used for the provision of water when the soil moisture level is below the threshold value.
4) 12V Adapter, which is used for powering the system. It is connected to 220V AC and gives out 12V DC.
5) A Soil Moisture Sensor is used for reading the moisture level in the soil.
6) Vero Board, which is where all components are soldered on.
7) ESP32 Development Board, which is the microcontroller board used. It has a WiFi and Bluetooth chip, which makes it suitable for Internet of Things applications. This controls the actuators and sends the temperature, soil moisture level and Light-dependent resistor data value to the ThingSpeak web application.
8) LM7805, which is a voltage regulator. It was used for stepping down the input voltage from 12V to 5V.
9) DHT22 is the temperature sensor used for measuring the temperature level in the greenhouse.
10) Female pins are used for connecting the ESP32 development board to prevent the burning of the component pins.
11) 4-channel Relay, which is used for switching on and off the fan, LED strip and pump.
12) Black tape is used for joining wires where necessary.
13) The light-dependent resistor is used for reading the light intensity in the environment.
14) The resistor was used as a pull-down resistor for the light-dependent resistor.
15) Connecting wires are used for the wiring of the greenhouse structure.
16) Capacitors were used for retaining the current of the power source

B. Software Design

The flowchart for the greenhouse system is shown in Figure 6. It shows the flow sequence of the system. The action taken in this system is in this order:

1) The system is turned on and initializes.
2) The temperature/humidity, Light-dependent resistor and soil moisture sensors start measuring the environmental parameters in the greenhouse.
3) The microcontroller checks the data read if they are above the threshold value for each environmental parameter.
4) If the temperature is too high, the fan is activated and the value is updated on the ThingSpeak platform.
5) If the soil moisture is too low, the water pump is activated and the value is updated on the ThingSpeak platform.
6) If the light intensity is too low, the LED strip is turned on and the value is updated on the ThingSpeak platform.
7) If every parameter is below the threshold, the value is updated on the ThingSpeak platform.
8) This process is repeated as far as the system is powered.

C. Mechanical Structure

The greenhouse structure made was the even span type of greenhouse. These types of greenhouses are easily identifiable by their sloping roofs. The structure made was made up of wood and transparent plastic. The wood acts as the support frame for the greenhouse prototype. The system consists of a glass structure with a wooden frame and a small wooden box-like structure. The box-like structure is the black box which contains all the connections and the microcontroller. Then the glass structure is the greenhouse where the plants are grown and all actuators and sensors can be found here. These two structures are mounted on a flat surface which helps with the mobility of the system. Figure 4 shows the dimension of the prototype greenhouse and figure 5 shows a 3D simulation of the prototype greenhouse.

4. RESULTS AND DISCUSSION

In this section, the outcome of the implementation of the methodology discussed in the previous section and the testing of the various modules that make up the work are discussed. The different units of the work were isolated and tested separately before being integrated. This method

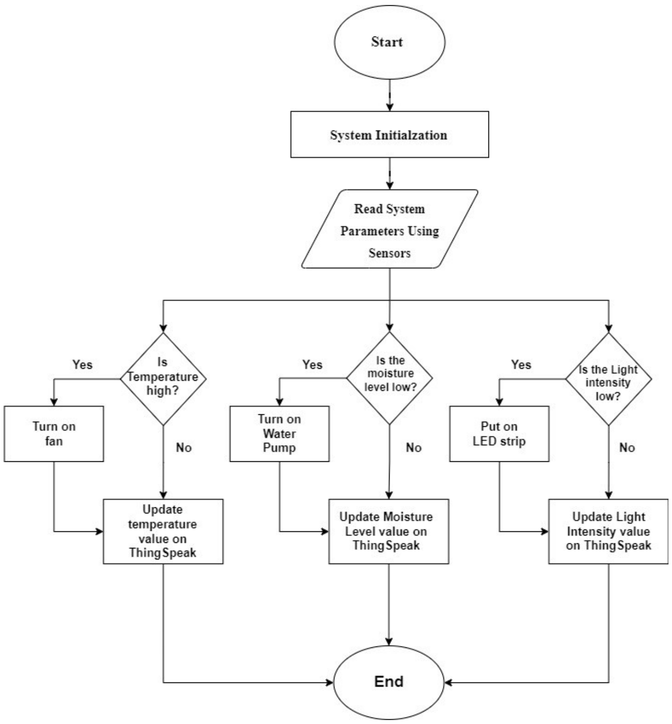


Figure 6. Flowchart of the System

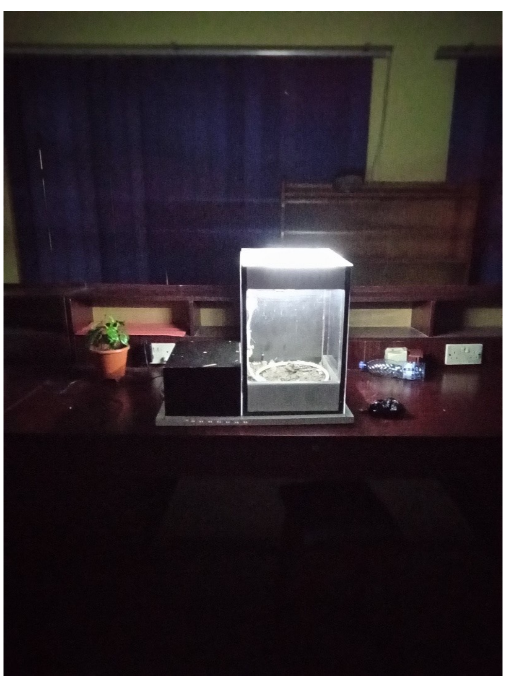


Figure 7. Lighting system illustration

Figure 8. Irrigation system illustration

ensured that the whole system worked smoothly together and aided the identification of errors or problems at different levels of the work. The ‘Bill of Engineering Measurement and Evaluation (BEME) is created in this section.

A. *Modules Testing*

During the construction of the automated greenhouse monitoring and control system the monitoring, control and communication modules were tested and system testing was also carried out to ensure that the aim of the work was achieved.

The sensors were tested individually to ensure that they all measured the environmental parameters. This was achieved with the use of the ESP32 development board. The DHT22, soil moisture and LDR sensors were connected to pins 26, 34, and 36 of the ESP32 development board respectively. The ESP32 was connected to a USB power supply to provide power for initial tests.

After the monitoring module test was carried out, the control module was likewise tested to ensure all actuators responded accurately. To achieve this a 4-channel relay was added to the initial setup by connecting it to the pins 15, 2 and 4 of the ESP32 development board. By this, the 12V adapter was connected as well to provide power for the 12V DC fan, 12 DC pump and the LED strip. The code for this control was successfully uploaded to the ESP32 development board. When the temperature value was above the threshold, the fan was activated. When the soil moisture was low the water pump came on. Finally, when the light intensity was low, the LED strip turned on. The system worked perfectly.

To finalize the testing, the WiFi capability of the ESP32 development board was tested by inputting the WiFi hotspot name and password into the code. A ThingSpeak channel was created and the channel ID was inputted into the software code. The system was then powered on, the sensor values can then be seen on the ThingSpeak platform.

B. System Testing

System testing involves the testing of the overall system functionalities to ensure all components work properly and effectively after final packaging. Figure 7 shows the working of the lighting system when in a dark room. The light-dependent resistor is located on the right side of the black box far from the light of the greenhouse structure.

Figure 8 shows the irrigation system functioning when the moisture level of the soil is low, that is the soil is dry.

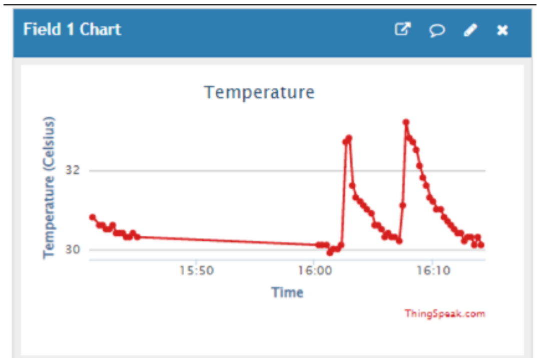
C. Sensor Readings

The soil moisture sensor, DHT22 sensor and the Light-dependent resistor measure the moisture level (water content), temperature and light intensity, respectively. If any of these parameters are below the threshold values, the ESP32 triggers the water pump (when the soil moisture level is low), the fan (when the temperature is high) and the LED strip (when light intensity is low). For temperature, the desired value is 300C, the desired soil moisture level is 4KPa, the desired light intensity value is 2500Candela, and the desired humidity level is 20%.

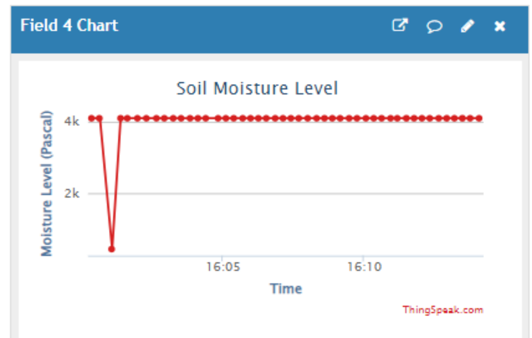
Table II shows some of the experimental values from the sensors on the 14th of June 2022. These sensor values are sent to the ThingSpeak cloud. Hence, the ThingSpeak tools are used to visualize the data.

Figure 9a shows temperature values as a function of the time of operation of the DHT22 sensor. The sudden spikes observed in the graph are due to the testing to ensure the system measures temperature parameters properly. Figure 9b shows the moisture level as a function of time. This graph shows constant values for the parameter being measured. From the graph, the values are somewhat constant. This was because the soil was mostly dry. Then the drop showed that the soil was wet. Figure 9c shows the light intensity as a function of time. From the graph, it can be observed that in some instances, there was a severe drop in the light intensity; this was because of the testing that was being carried out. This was done to test the LED strip's response rate to the absence of light. Figure 9d shows the humidity level as a function of time. The spikes are due to the testing process being carried out to ensure that the system functions properly.

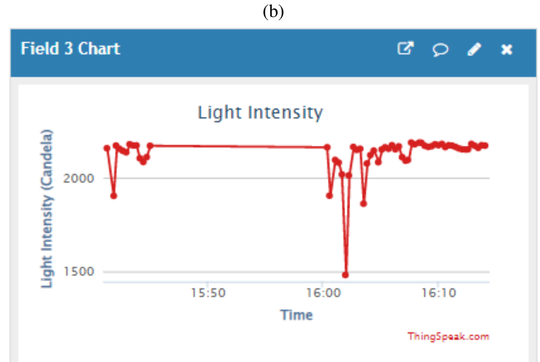
Figure 10 shows a plot of the greenhouse environment parameters from the first test data entry till date. The sudden spike in the light intensity is due to the monitoring unit simulation tests. A high value of the light intensity signifies



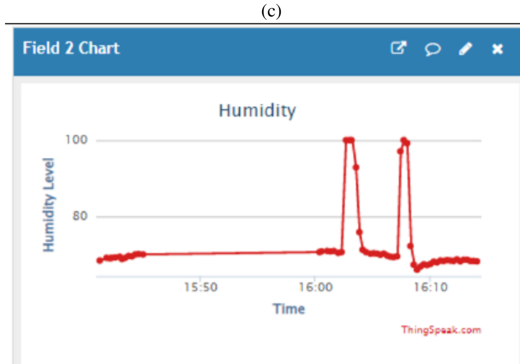
(a)



(b)



(c)



(d)

Figure 9. (a) Temperature as a function of time. (b) Soil moisture level as a function of time (c) Light intensity as a function of time (d) Humidity as a function of time

TABLE II. EXPERIMENTAL RESULT FOR SENSOR PARAMETERS

Created At	Entry Id	Temperature	Humidity	Light Intensity	Soil Moisture Sensor
2022-06-14T14:01:50+00:00	729	28.7	61.2	863	1
2022-06-14T14:02:07+00:00	730	29.3	59.5	2930	1
2022-06-14T14:02:22+00:00	731	29.5	58.6	1617	1
2022-06-14T14:02:37+00:00	732	29.7	58.1	3835	1
2022-06-14T14:02:53+00:00	733	29.8	57.7	3522	1
2022-06-14T14:03:10+00:00	734	29.9	57.6	0	1
2022-06-14T14:03:26+00:00	735	30	57.3	3999	1
2022-06-14T14:03:43+00:00	736	30.1	57.1	3856	1
2022-06-14T14:03:58+00:00	737	30.2	56.6	3019	1
2022-06-14T14:04:14+00:00	738	30.2	56.7	3039	1
2022-06-14T14:04:29+00:00	739	30.3	56.4	2989	1
2022-06-14T14:04:46+00:00	740	30.3	56.5	317	1
2022-06-14T14:05:03+00:00	741	30.3	56.3	2864	1
2022-06-14T14:05:18+00:00	742	30.4	56	2864	1
2022-06-14T14:05:35+00:00	743	30.4	55.9	2945	1
2022-06-14T14:05:57+00:00	744	30.4	55.6	2937	1

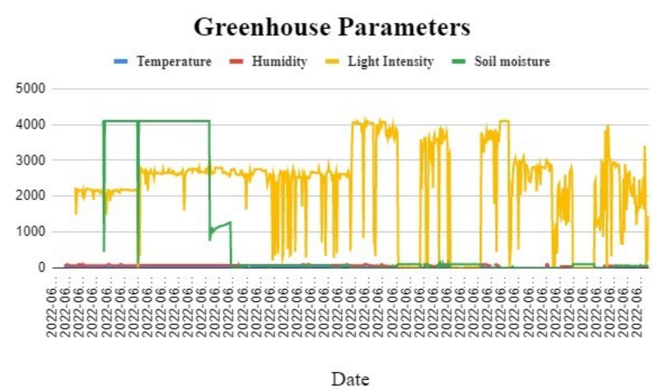


Figure 10. Greenhouse environment parameters as a function of time

that it is still daytime. The initial spikes observed in soil moisture levels were also due to the simulation tests.

A high value of soil moisture signifies that the soil has enough water, and a lower value signifies dry soil. From the graph, the temperature and humidity values have no significant spikes, and high values for them signify that the temperature needs to be regulated and the moisture in the air is too much respectively.

D. Packaging

Figure 11a shows the finished product of the 3D model designed in figure 5. It is a model greenhouse structure with a wooden framework and a glass-like film.

This model greenhouse structure was wired, and the DHT22 sensor, soil moisture sensor and Light-dependent resistor were brought to the surface. The fan and LED strip are located in the greenhouse structure and the water pump is found at the back of the greenhouse structure with the water tank. Then inside the small wooden box is where the Microcontroller, the voltage regulator and the relay module are located. Figures 11b and 11c show the arrangement and placement of the hardware components. Figure 11(d) shows the finished automated greenhouse monitoring and control system.

Table III gives an outline of the price of the components used in the construction of the prototype greenhouse monitoring and control system; the currency is in USD.

These results include successfully operating the automatic greenhouse monitoring and control system. This system monitors the environmental parameters of the greenhouse and then regulates the parameters if they are above the threshold value sufficient for proper plant growth.

For this prototype system to escalate to a real greenhouse, it is recommended that each sensor used in the monitoring module as well as each actuator used should be replicated per square meter of the greenhouse system. For example, a greenhouse system comprising 100 square meters would have one soil moisture sensor, LDR, and DHT sensor per square meter to give a total of 100 of each of the sensors. This will allow for effective monitoring of all sections in the greenhouse system. Likewise, the actuators such as the fan, LED strips and water pump will be replicated per square meter. There will also be one microcontroller per square meter.

5. Conclusions and Future Work

This work takes into consideration the use of embedded systems and the Internet of Things in the practice of agriculture. This work is at the design and construction of a greenhouse system that cannot only monitor the environmental and plant conditions in the structure but also control these conditions to provide an environment to enable plants

(a) (b) (c) (d)

Figure 11. (a) Greenhouse environment parameters as a function of time. (b) Arrangement of the Black box (c) Orientation of the sensors and actuators (d) The finished greenhouse Structure

to thrive. It is designed to save the time spent manually monitoring the plant status and for the betterment of the Nigerian economy and ready provision of food via the constant availability of crops in and out of season. The data gotten from this system is used in the research process for further advancement in agriculture. The achievements of this work are the successful construction of a model greenhouse structure using wood as the framework and a plastic film as the covering sheet for the sides and the top as well as the monitoring and control of environmental conditions. This work offers a monitoring system by designing a circuit that interfaces sensors with the ESP32 microcontroller. This work provides data that can be implemented in research processes to advance agriculture. The construction of the smart greenhouse with the ability to self-regularize the environmental conditions within the structure would help with real-time monitoring of the plants from anywhere in the world as well as the availability of specific crops in and out of season thereby not only improving the Nigerian economy but also improving the ready provision of food.

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TABLE III. BILL OF ENGINEERING MEASUREMENT AND EVALUATION

S/N	Item description	Quantity	Unit Cost ($)	Total ($)
1	Greenhouse structure	1	58.04	58.04
2	ESP32 Development Board	1	13.93	13.93
3	DHT22 Temperature and Humidity Sensor	1	2.76	2.76
4	Jumper Wires	3	1.51	4.53
5	10k ohms Resistor	5	0.12	0.72
6	Vero Board	1	1.28	1.28
7	4-Channel Relay	1	6.50	6.50
8	12V Micro DC Water Pump	1	4.64	4.64
9	Soil Moisture Sensor	1	3.17	3.17
10	Light Dependent Resistor	2	0.12	0.24
11	LED Strips	2	2.32	4.64
12	Fan 12V DC	1	1.39	1.39
13	Watering hose	2	0.58	1.16
14	Plant (Dwarf)	1	1.63	1.63
15	Loamy soil	$\frac{1}{4}$	0.35	0.35
16	12V AC-DC Power Adapter	1	3.50	3.50
17	Electrolytic capacitors	2	1.28	2.56
18	Ceramic capacitor	1	0.035	0.035
19	Resistor	2	0.023	0.046
				110.94

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