Sustainable Agriculture Through IoT-Enabled Vertical Farming

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Abstract— **This study presents an advanced Internet of Things (IoT)-enabled vertical farming system that aims to transform urban sustainable agriculture. The system incorporates web-based technologies for remote crop monitoring and precise environmental data management. Its main features include optimizing soil moisture, efficiently utilizing rainwater, and regulating temperature and humidity. ThingSpeak, an essential system component, is used for data visualization and management. The study details the criteria for selecting high-accuracy sensors and components, highlighting their cost-effectiveness and precision. An OLCD display presents comprehensive farm data, enhancing user management and reducing waste. This innovative VF system contributes to sustainable urban agriculture, increasing food production efficiency and environmental conservation.**

Keywords— Internet of Things, Vertical Farming, Sustainable Agriculture, Urban Farming, Environmental Monitoring

I. INTRODUCTION

Vertical farming is an exciting agricultural technique that includes growing crops vertically inside, typically in warehouses. Due to expanding populations and limited farming space, vertical farming, an innovative agricultural technology, is becoming increasingly important in urban settings. Improving agricultural yields and resource efficiency are the goals of this research work - Internet of Things (IoT)-based vertical farming system. The system tackles important issues in urban agriculture by integrating web-based technology for real-time monitoring and control. This approach provides precise control over climate conditions, significantly increasing crop yields per square foot compared to traditional horizontal farming [1]. Vertical farms use a stacked system without soil, ensuring plant health and protection from external factors. Technologies like LED lighting, climate control, and sensors are employed to manage environmental conditions [2]. The increasing global population, industrialization, climate change, and resource depletion are driving the growth of vertical farming.

Many farmers adopt vertical farming for better crop monitoring, but their limited data management skills often necessitate visual inspections. Thus, an IoT-based vertical agricultural monitoring system has been introduced. It allows data collection and access through web-based dashboards and analysis tools, enhancing agricultural research and development by analyzing real-time operational data [3]. Automation and IoT have transformed traditional farming into "precision agriculture," increasing efficiency.

Sustainable farming is a subset of smart agriculture that encourages urban areas to participate in ecologically friendly food production. [4]. Various urban farming techniques include raised beds, container gardens, hydroponics, geoponics, rooftop farming, vertical farming, and aquaponics. These technologies show promise, but their high initial costs and technical demands hinder individual adoption [5]. Vertical and rooftop farming are popular in large cities but require significant investments and are better suited for medium-scale property owners.

In residential apartments, container gardens are often used for small-scale farming. Urban farming is embraced in Dubai to combat high living costs. When done correctly, it enhances aesthetics, strengthens social bonds, and provides nutritious food [6]. However, the fast-paced urban lifestyle can discourage urban farming due to the time needed for maintenance. IoT-based smart farming is gaining popularity, allowing growers to optimize productivity by managing resources and automating irrigation. Field conditions can be monitored remotely, offering flexibility [7]. However, IoT-based farming faces constraints, particularly high initial setup costs for sensors and data analysis tools, which can be expensive for the average farmer [8].

As part of SDG-focused program, the fundamental components of IoT-based smart agricultural system are sensor systems, communication infrastructure, and data analytics. These components play a pivotal role in improving agricultural practices while aligning with our sustainability objectives [9].

In recent years, urban agriculture has garnered considerable interest as a means to tackle the concerns of food security and sustainability in densely populated regions. The use of IoT-enabled vertical farming, as suggested in this research, is in accordance with the wider phenomenon of smart agriculture [10], which utilizes technology to improve the efficiency of crop production and resource allocation. Numerous urban farming methodologies, such as hydroponics and aquaponics [11], have been investigated, offering valuable perspectives on the practice of controlled environment agriculture.

The technique of vertical farming has garnered recognition for its ability to enhance crop yields and maximize spatial efficiency [12]. Nevertheless, the adoption of urban farming has been impeded by substantial barriers, such as the considerable upfront expenses and technical requirements, particularly for individual farmers in metropolitan areas [13]. This emphasizes the significance of cost-effective Internet of Things (IoT) technologies and user interfaces that are easily accessible [14] in order to address these constraints.

IoT solutions, such as Thingspeak, have been significant in facilitating data administration and visualization within the context of smart agricultural systems [15]. They facilitate the monitoring and decision-making processes in real time by offering extensive insights derived from data. In order to optimize the efficacy of IoT-enabled vertical farming, it is imperative to carefully choose sensors and components that offer precise and reliable measurements [16]. The accurate monitoring of elements such as temperature, humidity, and soil moisture is crucial for achieving optimal crop development [17].

First and foremost, our sensing systems consist of specialized sensors strategically deployed within vertical farms or pots above ground. These sensors serve the critical function of monitoring essential environmental humidity, temperature, and brightness, which are examples of variables. They also communicate with a variety of devices or actuators, such as water pumps, electrical systems, and fans [18]. These sensors and actuators collaborate seamlessly to optimize resource utilization and crop health.

Fig. 1 Depicts a plan for an indoor farm

II. METHODOLOGY

The study technique is centered on the creation of an Internet of Things (IoT) integrated vertical farming system designed particularly for urban agricultural settings. The primary objective of the system's design is to prioritize the accurate monitoring and management of crucial environmental factors, including temperature, humidity, and soil moisture, which play a pivotal role in facilitating optimal plant development. The choice of sensors and other hardware components was determined by many factors, such as precision, cost-efficiency, and dependability. The selection of the soil moisture sensor was based on its superior accuracy in detecting moisture levels, which is crucial for achieving appropriate irrigation techniques.

Furthermore, the system integrates a temperature sensor and a heating mechanism to regulate and sustain the optimal temperature within the vertical farming infrastructure. Potentiometers are incorporated within the system to provide modifications in soil moisture parameters, hence accommodating the individual requirements of various crops. The system as a whole has been intentionally built to prioritize user-friendliness, hence reducing the level of technical skill necessary for its operation.

The gathering and processing of data play crucial roles in this technique. The Internet of Things (IoT) platform known as Thingspeak is widely employed due to its strong capabilities in data visualization and administration. The utilization of this technology allows for the efficient analysis and visualization of data collected from sensors, hence supporting informed decision-making within the context of urban farming methodologies. The aforementioned strategy not only effectively tackles the existing obstacles in urban agriculture but also establishes a basis for forthcoming advancements in sustainable farming technology.

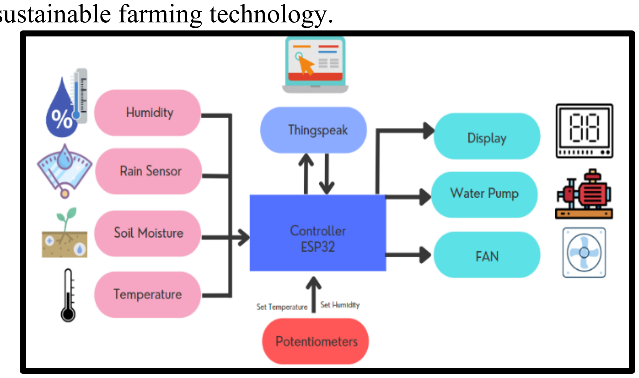

Fig. 2 System Flow Diagram

III. WORKING

3.1.1. Low Soil Moisture

When the soil moisture detector detects a low hydration level, the controller operates the water pump, irrigating the soil until the moisture content rises above 90%.

3.1.2. High Soil Moisture

The water pump will deactivate when the soil moisture exceeds 90%. Conversely, if the moisture level surpasses the set threshold, the water pump will remain inactive and not start.

3.1.3 High Temperature

When the temperature in the agricultural area surpasses the preset level, the PTC fan kicks on to cool it down. The PTC fan will switch off once the temperature recovers to the set range.

3.1.4 Raining

The water pump will remain inactive during rainy conditions.

3.1.5 No Raining

In the absence of rainfall, the standard operating procedure outlined in sections 2.1.1 and 2.1.2 will be adhered to by the water level sensor.

3.1.6 Data sending to Thingspeak

All project data will be transmitted to the Thingspeak platform, where it will be displayed in a graphical format.

3.1.7 Data sent to LCD

The LCD screen will showcase all sensor data to enhance the user experience.

3.1.8 Fire Alert

When a fire is detected, the buzzer will activate, and it will be deactivated once the fire is extinguished.

Table 1 Components selection

Component	Description	Role in the Model	Criteria for Selection
IoT Sensors	Measure temperature, humidity, soil moisture, etc.	Monitor environmental parameters such as temperature, humidity, and soil moisture levels.	Accuracy, reliability, compatibility, and cost-effectiveness.
IoT Gateway	Microcontroller unit (e.g., ESP32)	Acts as the central hub for data aggregation and communication with the IoT platform.	Compatibility with sensors, data transmission capabilities, processing power, and energy efficiency.
IoT Platform (Thingspeak)	Cloud-based platform for data management and analytics.	Data storage, visualization, and remote access.	Compatibility with the gateway, scalability, and security features.
Water Pump	Water supply and irrigation system.	Controls water supply based on soil moisture levels.	Flow rate, energy efficiency, reliability, and maintenance.
PTC Fan	Temperature regulation system.	Regulates temperature inside the vertical farming system.	Cooling capacity, energy efficiency, and noise levels.
LCD Display	User interface and data visualization.	Presents real-time data and information to the user.	Visibility, resolution, and compatibility with user needs.
Software (Firmware)	Embedded software for microcontroller and IoT platform integration.	Manages sensor data, communication with the IoT platform, and control actions.	Customizability, data processing, and remote access capabilities.

IV. IOT PLATFORM

Thingspeak is the official IoT platform for transmitting sensor data in the context of this research project. The platform's strength is in its visualization capabilities, which can dynamically depict this data in understandable graphical representations, making even the most complicated information accessible. In addition, the project has a thorough system for keeping track of data. For each data source, certain cutoffs that act as quality controls have been rigorously set. When these limits are exceeded, a warning LED on the ThingSpeak dashboard lights up, much like a traffic light. This adaptive function quickly detects and flags any outliers from the typical data distribution.

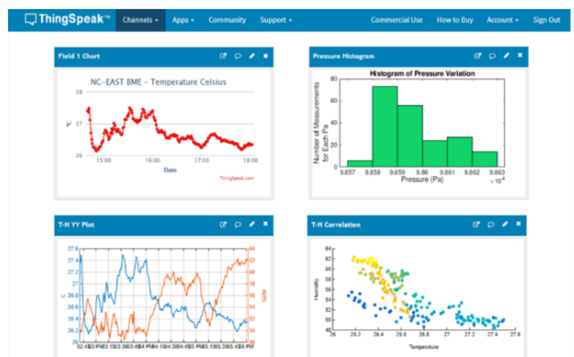

Fig. 3 Thingspeak

4.1 Software Implementation

- Look up Thingspeak and select "Sign in."
- Go to the ThingSpeak page and create a new account.
- Select "Create a new channel" on the Thingspeak platform to establish a new channel.
- In this case, seven fields are utilized for data reception.

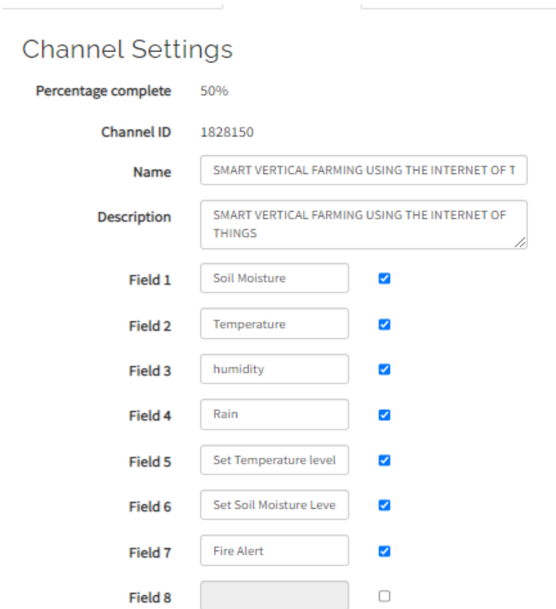

Fig. 4 Adding new fields.

- The channel has been successfully created.

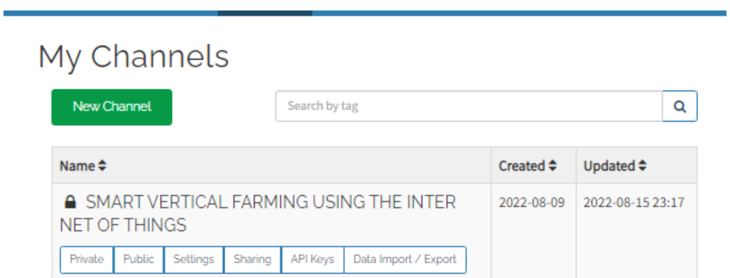

Fig. 5 Complete channel

- Using the channel identification and its related API, the ESP32 uploads information to Thingspeak.
- The data is received and presented in graphical format.

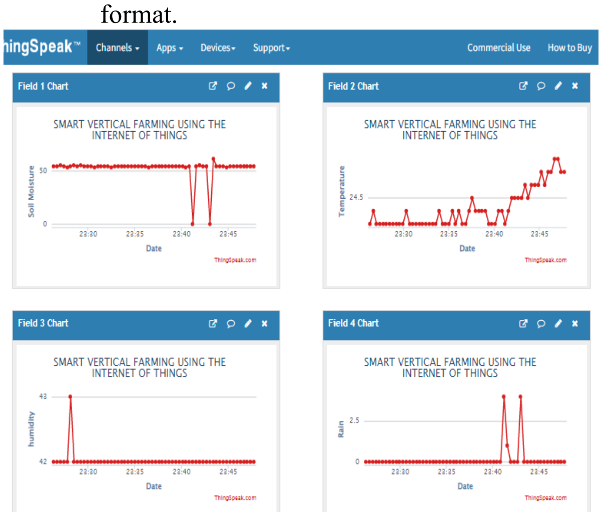

Fig. 6 Graphs

4.2 Hardware Implementation

The hardware components are interconnected on a breadboard, and the entire setup is positioned within a vertical farming environment. Inside the container, there is a PTC fan responsible for regulating the temperature. The temperature adjustment potentiometers are located outside the container, allowing for external temperature control. The circuit is illustrated in the diagram below. The diagram shows an OLED display connected with esp32 SCL SDA pins, while dht 11 and fire sensors are also attached. There are two potentiometers used to control the set level for temperature and humidity. The PTC fan is on the left upper side of the esp32. The buzzer and LED are also attached to provide alerts.

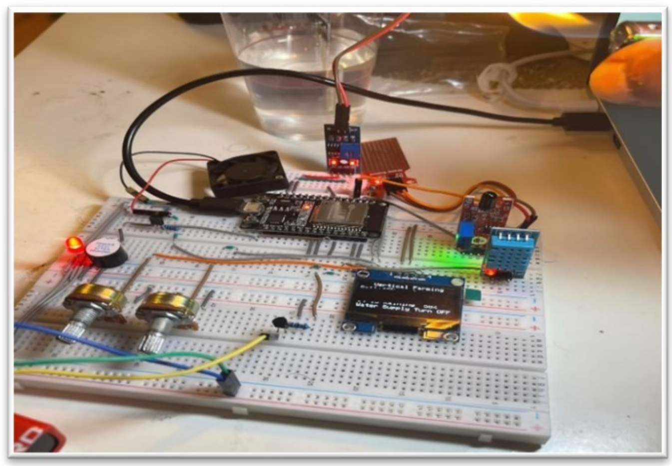

Fig. 7 Circuit Diagram

The ideal temperature is maintained with the help of a PTC heater fan. The moisture level and temperature level are set by the potentiometer. Following the full assembly, jumper wires are utilized to extend the circuit pins, enhancing the overall appearance.

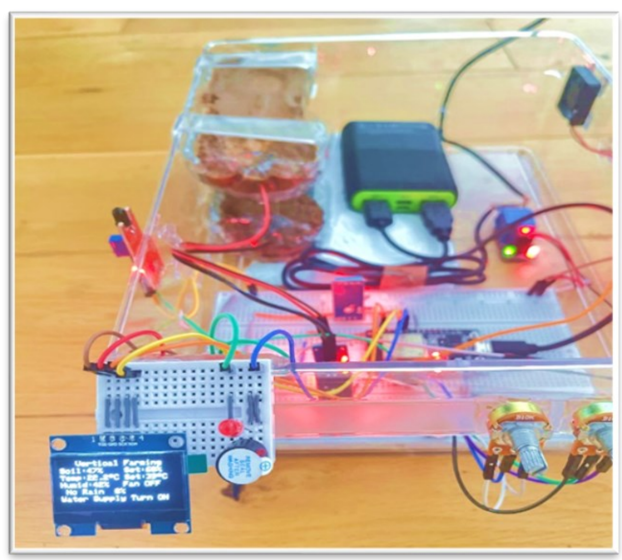

Fig. 8 Vertical Farming Area

V. RESULT

ESP32 gets the data from the sensors, and using the http protocol, it transfers the data to ThingSpeak, where it gets processed and is available for visualization in graphs. The esp32 also compares the data with thresholds and performs preset tasks like turning ON the water supply, turning ON the fan, or giving some alerts. Certainly, the controller promptly reacts to a fire detection by turning on a red LED light and starting a siren to signal an emergency. This vital information is sent to the IoT platform at the same time, and an LED light provides visible confirmation. ThingSpeak will show the results on the display to monitor the parameters remotely, as shown in Figure 6.

Table 2 Results

Event	State	Explained
Fire detected	HIGH	If fire is detected, the Alarm is turned ON, and the alert is sent to the Thingspeak platform as well.
Fire not detected	LOW	In the absence of a fire, the Red LED and buzzer remain inactive, and the fire alarm does not activate.
Water supply	OFF	When the soil moisture detector detects a level that exceeds the set point value, the motor is turned off.
Water supply	ON	The water pump is engaged when the soil moisture detector reports a level below the specified threshold.
Rain detection	Detected	In all cases, when rain is detected, the motor will not turn ON even if the water level is lower.
Rain detection	Not detected	In the absence of rain, the LED should display the moisture percentage, and the pump should operate based on the moisture level.
Fan Activate	HIGH	The PTC fan is activated when the temperature surpasses a certain level
Fan inactive	LOW	When the temperature falls below the established threshold, the PTC fan is turned off.

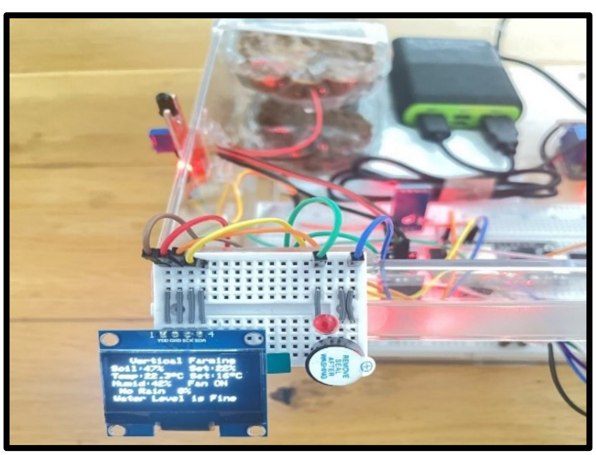

Fig. 9 PTC Fan and pump OFF

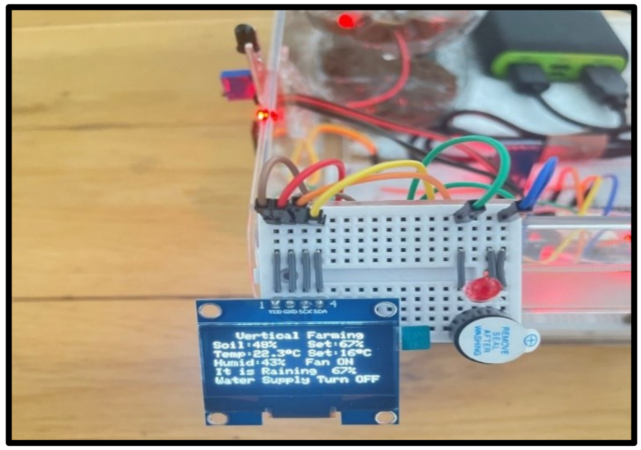

Fig. 10 Raining

VI. CONCLUSION

The vertical farming project was a success, effectively addressing farming space and water management challenges. It autonomously managed the water supply, activating the pump when water levels dropped. The temperature sensor regulated the fan based on environmental conditions. The project also featured a fire sensor for alerts using a buzzer and LED. Data was sent to the ThingSpeak platform and displayed there. High accuracy is also achieved by improving the sensor quality.

In this study, the main goal is the selection of low-price and precise equipment for smart farming devices that monitor both humidity and temperature. Setting up the fundamental IoT platform. Costs would rise if more sensors and actuators were added. A minimal setup is provided for monitoring temperature and humidity in a residential apartment. Properly timed plant watering depends on these two parameters, making them essential for a smart farming system.

The vertical farming system, which incorporates IoT technology, offers a potentially effective solution for sustainable urban agriculture. However, it is important to acknowledge that this system has some limits that necessitate further investigation and advancement in the field. One significant limitation is the considerable upfront investment required for establishing the Internet of Things (IoT) infrastructure, a factor that may provide a barrier for several prospective users, especially those situated in metropolitan environments. Moreover, the intricate nature of the system necessitates a certain degree of proficiency in order to properly install and maintain it, thereby restricting its accessibility. One of the challenges faced by the IoT platform is the dependence on reliable internet connectivity for efficient functioning, especially in areas where internet access is sporadic. Potential future avenues for this study include investigating economically viable alternatives for system components, streamlining the user interface to enhance accessibility across a wider range of users, and devising offline capabilities or solutions that can function well in low-connectivity environments. Additional progress might also prioritize the integration of renewable energy sources to bolster sustainability and broaden the system's adaptation to a broader array of crops, augmenting its application and influence in urban farming practices.

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Selecting the Smart Vertical Farming project using the Internet of Things was a significant decision for me, one that felt somewhat overwhelming due to its complexity and being outside my expertise. Therefore, I'd like to thank my supervisor, Dr. Fahad Hassan, and my co-supervisor, Dr. Abdulwahid Farooq. They guided me in choosing this project and provided invaluable support throughout the entire process, assisting me with every crucial detail. Their direction and assistance have been instrumental in helping me work toward the ultimate goal of the research study.

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