IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Smart Indoor Vertical Farming using ESP32 and Blynk

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Abstract: Rapid urbanization and increasing demand for food production have made the need for sustainable agriculture practices unavoidable. The concept of vertical farming stands out from among various sustainable agriculture practices, especially if coupled with IoT technology for Controlled Environment Agriculture (CEA), which enables resource optimization and optimal plant growth in indoor settings. Concerning the aims of the research paper, it can be stated that the major purpose of this paper will be to develop a vertical farming model through IoT technology using ESP32 microcontroller and the Blynk application. It will be possible to utilize the developed vertical farming system for monitoring the environment with regard to soil moisture, temperature, and moisture levels. Additionally, during the process of monitoring, it will be possible to monitor the pH and conductivity levels of the soil. Furthermore, it will be possible to utilize the pump and grow lights.

Index Terms - Vertical Farming, IoT agriculture, ESP32, Blynk cloud, automated irrigation.

I. Introduction

Agriculture is among those key fields whose intervention is required to facilitate food security of the rising population of the world. A number of challenges have arisen with the adoption of the traditional methods of agriculture because of the effect of global warming, shortage of farmland and poor management of agricultural resources. In India, with the occurrence of urbanization, there has been reduction in the amount of farmland. Vertical farming is referred to as a new method that is applied in farming whereby crops are cultivated vertically. Vertical farming has been seen as an efficient approach in the utilization of available land in agriculture. Furthermore, in vertical farming, crops are grown throughout the year. It is essential to observe that environment factors such as humidity and moisture need to be regulated to achieve high levels of yield. With the introduction of technology in farming, there has been the development of agricultural systems through the Internet of Things. In addition, Internet of Things agriculture systems have proved to be very helpful in automating agricultural activities. Internet of Things equipment can be employed in collecting agriculture data.

The main aim of the research work will thus be to design and develop an innovative concept of vertical farm system that can be used for the purpose of irrigation, environmental control, nutrient supply, and lighting through IoT technology in conjunction with ESP32 and Blynk IoT cloud server. The development of the vertical farming concept requires the use of different types of sensors such as soil moisture sensor, temperature and humidity sensor and TDS sensor.

II. Literature Survey

The vertical farming technique is considered to be one of the novel methods that can help carry out farming sustainably, especially in cities. With the advent of the Internet of Things technology, it has become possible to measure parameters like temperature, humidity, moisture, and nutrition. Numerous initiatives have been taken by people and institutions to popularize the idea of smart farming through IoT technology, and hence different applications have been created.

Rathor et al.[1] have discussed the utilization of Internet of Things (IoT) and Artificial Intelligence for the vertical farming system. It is important to note here that in the said review paper, there is no discussion on any particular sensor technology and hardware implementation; but rather the authors have provided details about the smart automation system in farming. Though a great deal has been talked about AI applications in agricultural systems, implementation part is not discussed at all.[2] Oh has analyzed intelligent farming in cities via vertical farming in 2023. Sustainability and effective use of land are generally covered in this article. However, no sensors, controllers, and cloud technology have been discussed. It is a conceptual study only. Even though a concept that resembles vertical farming has been described in the article, IoT has not been implemented at all yet.A comparative analysis of IoT-based solutions for environmental farming has been done by Kaur [3] in 2023. Temperature, humidity, and light sensors are included along with other IoT technologies in the design of this article. Even though an actual design for system implementation has not been provided in this article, it seems that the design can be used in vertical farming. Therefore, it becomes necessary to implement the design system practically. On the other hand, Siregar et al. [4] present an overview of the application of artificial intelligence in precision agriculture and vertical farms. However, there is no discussion of the specific sensors and hardware used in the experiment in this paper. This paper is significant to the study of vertical farms because artificial intelligence is applied in decision-making processes. However, this paper presents proof that there are no real-world examples of the practical application of IoT hardware in such systems.

Furthermore, Ahmed et al. [5] have presented a taxonomy for smart hydroponic farming systems. In this case, there is a paper identified for the guidelines for the development of smart hydroponic systems by employing the use of pH sensors, EC sensors, and temperature sensors. Although this paper is significant, it has been noted that it is a review paper which means that no actual system was developed during the course of the research. Additionally, the paper focuses on hydroponics rather than vertical farms. IoT-based hydroponic farming technology was proposed by Awal et al. in 2025 [6]. This paper proposes the use of temperature, humidity, and pH sensors along with the Arduino-based controller. This design offers IoT-based monitoring using the dashboard platform and can be said to be the prototype design of IoT-based monitoring in vertical farming. But the technology proposed here uses only the hydroponic farming technology and does not have any vertical farming technology. In addition to that, there are no details offered by this design concerning AI-based prediction models.In 2021, Halgamuge introduced a framework of an IoT-based autonomous control system for vertical farms [7]. It involves environmental sensors and IoT controllers that allow for monitoring and controlling the environment. However, in this case, only the framework has been proposed for experiments and there were no intelligent sensing or control systems used for this framework. Sadek et al. propose the design of the IoT-based automated hydroponic and greenhouse monitoring system with the temperature, humidity, and nutrient sensors in 2024 [8]. It involves the usage of the Arduino microcontroller. Though the technology used in this paper works well, it was implemented in greenhouse farms and not in vertical farms.

Baraskar et al. [9] have provided Design of an AI Based Hydroponics Farming System Using pH, Temperature & Humidity Sensor & Microcontroller. This system design uses both data analysis as well as automation in hydroponic farming through the use of AI-based technology. While the system designed is fully functional, it is used only in the case of hydroponic farms and not in vertical farms. Sowmya et al. [10] have considered Vertical Farming Technology Advancements for 2024, where the authors consider conceptual automation and environment monitoring systems, without considering the sensors, microcontrollers, and cloud platform aspects in the research work. Azmi et al. [11] have done IoT-Based Autonomous Hydroponic Farming System Analysis, where IoT-based environmental sensors and IoT-based controllers were employed for monitoring the agricultural farms, using the concept of autonomous farming. However, the analysis was purely theoretical in nature and was not implemented in practice. The IoT-Based Vertical Farming Monitoring System by B.R.M. et al. [12] utilizes temperature and humidity sensors along with an IoT-based Arduino controller for the monitoring of farms in terms of temperature and humidity conditions. While describing the entire designing process of the system, it does not consider its application in decision making. A Review Analysis of Vertical and Hydroponics Farming Systems by Verma et al. [13] appeared in 2024, and it analyzed the technological application for vegetable cultivation. However, there was no indication about using sensors or any other physical devices and IoT automation systems.

The research paper titled Review Research of Automation in Vertical Farming Systems by Anbu Sezhian et al. [14] was conducted in 2024. This research article provides useful details about several types of sensor monitoring systems and automated control systems. The research paper is theoretical and conceptual only, but it did not develop the system practically.Malabadi et al. presented a review article on IoT technology for greenhouse farm systems in 2024. This review provides descriptions of different environmental sensors and IoT controller technologies based on cloud computing. Even though this research article may have some relevance to vertical farming, its primary focus is greenhouse farm systems. There is nothing discussed about optimizing nutrient technologies using AI. Meena and Sinha proposed a system of hydroponic agriculture using IoT in 2024. The hydroponic farming system uses pH sensor, electric conductivity sensor and temperature sensor technology using microcontroller & cloud technology. However, the proposed system is incomplete because no auto-mated decision-making technologies were proposed. The paper by Rameshkumar et al. was published in 2018 and involved the concept of vertical farming technology in greenhouse conditions for future technology. Vertical farming technology is covered in conceptual models in this paper for future technology. In vertical farming technology, IoT sensor technology and automation technology are not required.

The analyses of the above-mentioned studies reveal that all the researches mentioned above are either theoretical frameworks or review of research works or hydroponics monitoring system. In addition to that, it is also very clear that only limited number of researches has been done on IoT-based vertical farming systems. What needs to be added further is the fact that none of the studies has been done addressing the problem of designing low-cost hardware and remote monitoring system for IoT-based vertical farming systems. The suggested framework fills this gap in the area of IoT-based vertical farming systems.

III. Research Gap

It would be important to indicate some significant gaps in the literature that can be considered as potential areas for further research. First, it should be highlighted that most of the existing research works have a theoretical nature and rely on literature review for investigating and analyzing the subject matter. Second, it is worth mentioning that most studies focus on hydroponic or greenhouse agriculture, but no proposals are made in relation to vertical multi-layered farming that can prove to be quite valuable in an urban setting. Third, it should be stressed that the majority of existing solutions apply simple sensors that allow measuring the parameters like air humidity and temperature, but they cannot track any other important parameters such as the concentration of nutrients in the solutions and acidity levels. Fourth, it is vital to note that the current solutions are restricted by the monitoring function only, and thus, no tools are provided for controlling and regulating the processes of irrigation, fertilization, and maintaining the right climate conditions.

IV. Problem Statement

The challenges connected to current vertical farming and IoT agriculture are the lack of real application, insufficient automation, and wrong integration of sensor and control technologies, including cloud computing. Most of the studies related to vertical farming are purely theoretical or focus on developing hydroponics and greenhouse systems; however, no actual implementation of vertical farms is involved. This issue becomes especially critical taking into account the rapid pace of urbanization, the reduction in the territory of agriculture, and the necessity of using sustainable and efficient agricultural techniques. Therefore, it is vital to create a cost-effective vertical farming approach using IoT technologies enabling monitoring and automation of irrigation and climatic conditions with the aim of maximizing productivity.

V. Methodology

A. System Architecture

The proposed system is an IoT-based smart vertical farming system designed to automate irrigation, environmental control, and nutrient management using real-time sensing, embedded processing, and cloud-based monitoring.

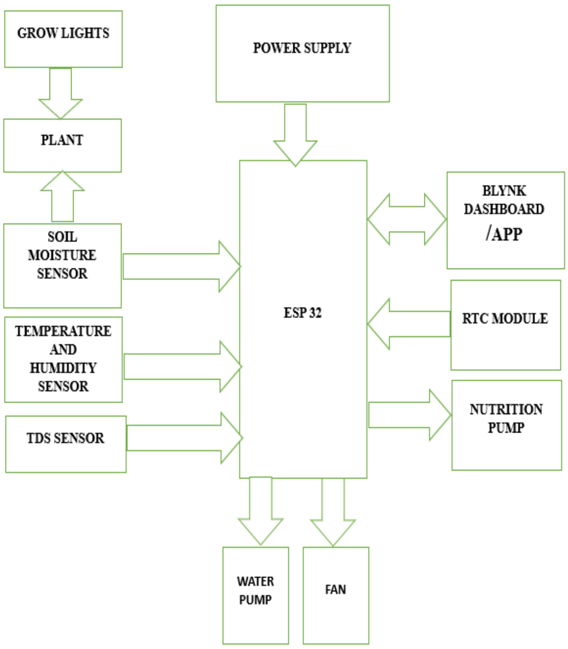

Fig 1: System Architecture

From the block diagram of the system architecture, it can be noted that the system is built on the principle of dividing it into three basic layers: the sensing layer, the control layer, and the cloud monitoring layer.

Sensing Layer

The sensing layer collects all real-time data regarding the vertical farming environment. This includes the following set of sensors:

- Soil moisture sensor: measures the moisture levels in the soil/growing medium and the requirement of irrigation.
- DHT11: temperature and humidity sensors to monitor the environment conditions impacting plants.
- TDS: sensor to measure total dissolved solids present in the irrigation water/nutrient solution. All the data received from the sensors gets fed to the ESP32 microcontroller.

Control Layer (ESP32 with RTC Module)

In this layer, the ESP32 is used as the main processing unit which continuously compares all sensor values with predefined threshold levels to control the operation of actuators accordingly. The system also uses an RTC module to keep track of the plant growth duration. Sowing dates are entered through the Blynk application which keeps track of the day count. The ESP32 uses real-time sensor data and the plant's growth stage to intelligently control the various components: when the soil moisture is ≤ 40%, it turns on the water pump and turns it off when the moisture reaches ≥ 75%. It turns on the fan when the temperature reaches ≥ 30°C or the humidity reaches ≤ 55%, and turns it off at the optimal conditions. Grow lights provide artificial illumination according to predefined schedules, to ensure optimal plant growth conditions and the nutrient pump is turned on only if the plant is >= 8 days old (as recorded by the RTC) and the TDS value is <= 800 ppm.

Cloud Monitoring Layer (Blynk Platform)

This cloud-based application has been designed using Blynk as an Internet of Things (IoT) platform where sensor values including soil moisture, temperature, humidity, total dissolved solids (TDS), and the number of plant growth days will be transmitted into the cloud through the ESP32. In this way, users can manage the system remotely through a smartphone or web portal. Through this application, the users can have visualized data, control actuators remotely, monitor plant growth days, and receive notifications on certain events such as sowing and day 8.

B. IMPLEMENTATION

SOFTWARE SETUP

The software solution is built using the Arduino IDE and integrated with the Blynk IoT framework, which enables monitoring and control from a cloud-based application. The ESP32 microcontroller is configured to collect data from sensors, including soil moisture, temperature, humidity, and TDS values, and convert them to appropriate units for further analysis. Using predefined thresholds, the software solution analyzes sensor data continuously and makes automated decisions regarding actuator control, such as pumps and fans. Real-time data is transmitted to the Blynk cloud server, enabling monitoring and control via the mobile dashboard. The real-time monitoring interface of the system through both web and mobile platforms is shown in Fig. 2.

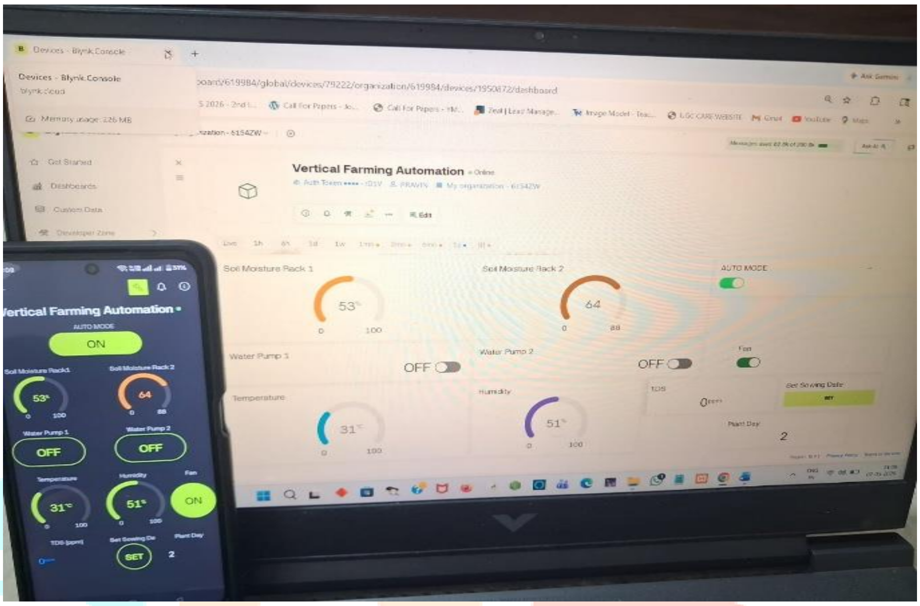

Fig 2. Web and mobile platforms

The control logic of the system uses both threshold and stage-based automation techniques. In the case of irrigation, the system activates the water pump when soil moisture content falls below 40% and deactivates it when it becomes 75% or more. In the climate control section, the system turns on the fan at temperatures exceeding 30°C or at relative humidity lower than 55%. On the other hand, it turns off the fan at temperatures less than 26°C and relative humidity greater than 70%. Nutrient management is done based on stages; thus, the nutrient pump turns ON after Day 8 of plant growth using the RTC module and turns ON when TDS levels fall below 800 ppm. RTC is also used to track days from sowing by setting the starting date using the Blynk button, and the system automatically counts the number of days elapsed. Blynk application also enables real-time visualization and control of system operation, as well as displaying the relevant parameters like soil moisture level, temperature, relative humidity, and days of plant growth. Alerts such as the “Sowing Set” event are triggered when Day 0 is initialized, and a “Day 8 Alert” notifies the user when the plant reaches the nutrient supply stage.

Hardware Setup

The implementation of the proposed system involves the integration of hardware components and software algorithms to achieve an automated vertical farming setup as shown in Fig.3. The ESP32 is the microcontroller that is used to act as the main controller for controlling all sensors and actuators in the system. There are two sensors that are placed in each rack for checking soil moisture levels. Temperature and humidity levels inside the greenhouse are monitored using a DHT11 sensor. A TDS level sensor is used for measuring the nutrient concentration of the nutrient solution, while the RTC DS3231 is used for monitoring time and counting days for plant growth stages. There are a number of actuators that include a pump for irrigation process and another pump that supplies nutrients based on TDS values and plant growth stage, fans to maintain proper temperature and humidity levels, and grow lights for artificial illumination.

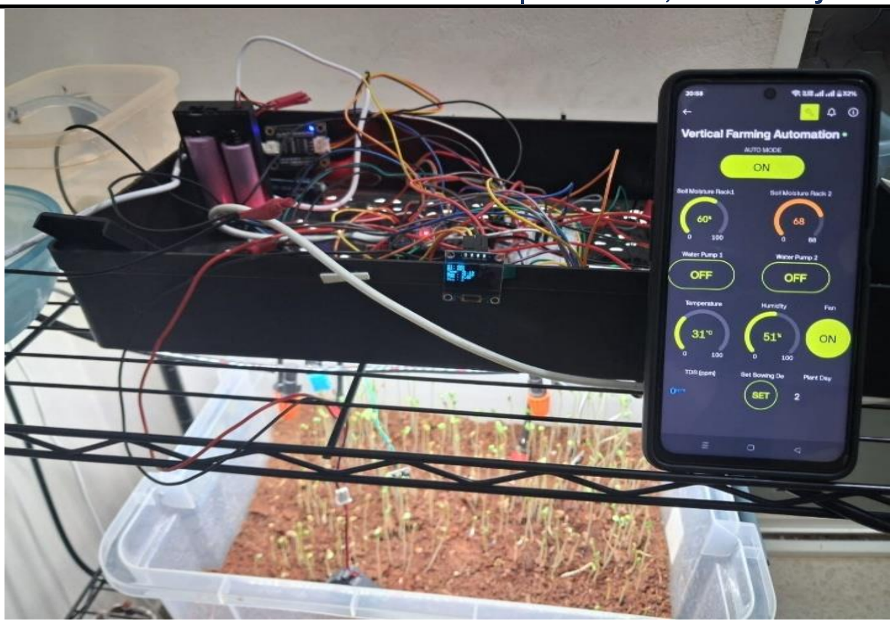

Fig 3. Hardware Setup

Other components like relay modules are required to control the fans, pumps, and lights; while an OLED screen will be utilized to show system data, and a regulated power supply source to power the whole system. Sensors are responsible for continuous monitoring of environmental and nutrient levels in the greenhouse, while the microcontroller will handle these readings to control the actuators based on defined thresholds.

VI. Result And Discussion

Implementation and testing of the proposed IoT-enabled automatic vertical farming system were done successfully in order to achieve automated irrigation, environmental monitoring, and nutrient delivery. The success of the system was evident through the continuous monitoring of the sensors and control of the actuators. Monitoring and interaction with the user took place through the Blynk cloud platform.

A. Soil Moisture-Based Irrigation Control

Soil moisture sensors were employed to monitor the soil moisture level in the growth medium and regulate the irrigation system.

Table 1 Pump Control Thresholds

Moisture Level	Pump Status
≤ 40%	Pump ON
≥ 75%	Pump OFF

The observation was made that water pumping started automatically when soil moisture content fell below 40%, and stopped automatically when soil moisture went above 75%. This helped ensure water utilization efficiency, prevent over-irrigation, and maintain proper soil moisture content levels for plant development.

B. Environmental Monitoring and Fan Control

The temperature and humidity inside the vertical farming facility are measured using DHT Sensor. Table III below presents the DHT sensor used for temperature and humidity detection in the environmental monitoring system. The environmental monitoring system maintains the temperature between 25°C and 30°C, and the humidity levels at 55% to 70%, which is best for plant development.

Table 2 Environmental Conditions

Parameter	Typical Range
Temperature	25 – 32 °C
Humidity	55 – 75 %

Table 3 Fan Control Logic

Condition	Fan Status
Temperature ≥ 30°C or Humidity ≤ 55%	Fan ON
Temperature ≤ 26°C AND Humidity ≥ 70%	Fan OFF

It was noted that the fan functioned automatically to control the climate in the vertical farm. This made it possible to maintain the microclimate at a constant level since the presence of stable microclimate is necessary for proper plant development.

C. Nutrient Control Using TDS and RTC

The operation of the nutrient control system is carried out using both the TDS readings and the growth stage data of the plants using the RTC module. The nutrient pump is OFF for the entire initial growth stage where Day is less than 8. It gets activated only after Day 8, and this helps in achieving stage-based control of nutrient pump operations. The nutrient pump is turned ON only when the TDS reading drops below 800 ppm. In the test conducted, it was found that the nutrient control system did not give any nutrients during the initial growth stage and gave nutrients as needed.

D. Cloud Monitoring and Event Notifications

The proposed cloud monitoring and alerting system was constructed utilizing Blynk IoT platform to monitor and control the functioning of vertical farming. The proposed system offered live visualization of important metrics such as soil moisture content, temperature, humidity, TDS content, and plant day count on a smartphone app interface. Moreover, event-based notifications were provided that included alerts on completion of planting date and another alert at Day 8 for the purpose of activating nutrients. Integration of Blynk IoT made the process easier and more effective by making the system interactive for users. The constructed prototype offers an innovative and efficient system for smart vertical farming by incorporating advanced technologies such as IoT, real-time sensing, and automation. The use of soil moisture content for irrigation saves considerable amounts of water as opposed to traditional methods while ensuring optimal moisture availability for plants. The environmental control system based on the thresholds of temperature and humidity makes it possible to provide a steady micro-climate inside the system. Automatic fan control is employed to avoid overheating. One of the unique features incorporated into the system is the RTC module to activate nutrients depending on growth stages. Unlike conventional systems, which deliver nutrients either constantly or depending on thresholds set for sensors, the system delays the delivery of nutrients until the plant achieves a certain level of growth (from Day 8 onwards). This method minimizes unnecessary consumption of nutrients at early stages of growth. The utilization of the TDS sensor improves the system performance due to the ability of measuring and providing nutrients only when needed.

Moreover, the use of the Blynk cloud platform for data analysis helps ensure that the system is scalable and accessible via notifications and real-time monitoring features. Users can monitor the growth of plants, track system data, and get alerts without being on-site. One limitation in the design of the system is that the threshold levels are hardcoded into the system, and therefore their accuracy can depend on factors like the nature of the crops grown and environmental factors.

VII. Future Scope

Even though the designed solution has high efficiency, there is a lot that could be done to enhance it further and make it scale better. For example, the introduction of an AI component will allow for predictive analytics based on historical data to be used for irrigation and nutrients needs. Moreover, better sensor integration, including light, CO2 levels, and soil PH sensors, can give us more accurate monitoring of the environment. Another possible step would be to add an image analysis capability to the system for the monitoring of the plant status, growth rate, and any diseases present in real-time. The energy aspect can be enhanced by using solar panels in the design to decrease power usage. Also, a way of scaling the proposed solution for industrial purposes can be to build it out in vertical farm capacity.

VIII. Conclusion

To automate the irrigation, environmental and nutrients process, the IoT based smart vertical farming system designed has been effectively developed and implemented. The sensors used are soil moisture, DHT11 and TDS for continuous monitoring of environmental and nutrient status. The ESP32 microcontroller will take action based on the data collected by processing the data.The incorporation of a Real Time Clock (RTC) has made the system grow stage-based by automating the process, i.e., providing the nutrients based on a particular stage after day eight in the growth process of the plants. Nutrients will be supplied at this stage only. This has increased the efficiency of nutrients, preventing over-fertilization during the early stages. Additionally, through the TDS sensor, the supply of nutrients will be based on the requirement of the plants. This will improve the efficiency of the process. The Blynk IoT platform has made the system user-friendly through remote operation and notification.

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