

## ORIGINAL ARTICLE



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## Introduction

The area of agriculture has been identified as one of the key areas that are essential in ensuring food security among the rising population in the world. There have been several challenges that have been experienced through the traditional ways of farming, including global warming, less availability of agricultural land, and improper management of agricultural resources. In India, owing to the process of urbanization, the available agricultural land has decreased significantly.

Vertical farming has emerged as a promising solution whereby plants are cultivated in vertical stacks. Vertical farming has been useful in ensuring efficient use of land in agriculture. In addition, vertical farming ensures that plants are cultivated all year long. The environmental conditions such as temperature, humidity, and moisture need to be controlled to ensure that

## A Comprehensive Review of IoT-Based Vertical Farming System for Sustainable Urban Agriculture

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## Abstract

Rapid urbanization and growing demands concerning food production, it is necessary to use sustainable agricultural practices, one of such sustainable practices is represented by vertical farming, where IoT technology offers an efficient approach for Controlled Environment Agriculture (CEA). This paper presents a comprehensive review and design of a low cost IoT-based smart vertical farming using ESP32 microcontroller and Blynk cloud platform. The proposed system integrates multiple sensors including soil, moisture, temperature, humidity, pH and Total Dissolved Solids (TDS) to enable real-time monitoring and automated control of irrigation, nutrient supply and environmental conditions. Unlike existing systems that are largely conceptual or limited to hydroponics, this work emphasizes practical implementation, cost effectiveness, and full automation.

**Keywords:** Vertical Farming, Controlled Environment Agriculture, IoT agriculture, ESP32, Blynk cloud, Automated irrigation

high crop yield is achieved. With recent technological advancements, smart agricultural systems have been developed using the Internet of Things technology.

Furthermore, Internet of Things agricultural systems are useful in automating the farming processes. Internet of Things devices can be used in collecting information on farming. Internet of Things devices can collect information regarding environmental factors.

Hence, the emphasis of the research work would be towards the design and implementation of the vertical farming system based on IoT technology using ESP32 and Blynk IoT cloud services, which would cater to the functions of irrigation, environment sensing, nutrition, and lighting. The vertical farming system designed in this research work would be dependent on the usage of different types of sensors such as

soil moisture sensor, temperature sensor, humidity sensor, pH sensor, and TDS sensor.

## Literature Review

### A. Analysis of Existing Work

Vertical farming is seen as one of the most innovative methods for sustainable farming practices especially in urban settings. With the introduction of Internet of Things (IoT), the measuring of parameters like temperature, humidity, moisture, and nutrition has become possible. There have been quite a few efforts made to bring forth the idea of smart farming using IoT through which different automation techniques and hardware implementations have been tried.

Rathor *et al.*<sup>(1)</sup> have written a review paper in 2024 on the utilization of IoT and artificial intelligence in vertical farming system. This review paper makes no mention of any specific type of sensors and hardware utilized; however, they do discuss the conceptual design of smart automation system in farming practices. While the paper clearly discusses the application of AI in agriculture systems, it does not discuss any aspect of implementation. The paper, though directly relates to vertical farming, also talks about a research gap in the application of IoT.

Oh<sup>(2)</sup> has covered the idea of smart agriculture in urban areas by means of vertical farming in 2023. In general, the article refers to sustainability and land usage optimization. No particular sensors, controller, and cloud technology are mentioned in the article. It is a conceptual work. Even though the article covers a topic very similar to vertical farming, no IoT implementation can be observed in the process.

A comparison analysis of IoT-controlled environmental farming techniques has been conducted by Kaur<sup>(3)</sup> in 2023. The research covers the usage of environmental sensors (temperature, humidity, and light sensors) that have been combined with microcontroller systems for tracking plant growth conditions. Nevertheless, a practical implementation model has not been provided in the research. As far as the system design can be used for vertical farm operations, the study shows the necessity of implementing the system in practice.

The paper by Siregar *et al.*<sup>(4)</sup> provides information about the use of artificial intelligence for precision agriculture and vertical farm systems conducted in 2022. The paper does not give a detailed account of the hardware and sensor used in the system. The paper is relevant in the context of vertical farm systems that use artificial intelligence technology for decision making. Nonetheless, the paper gives evidence of the absence of practical applications using IoT hardware.

The taxonomy of smart hydroponic farming systems has been done by Ahmed *et al.* in 2025<sup>(5)</sup>. In this case, the research paper

provides a framework where pH sensors, electrical conductivity sensors, and temperature sensors will be used in hydroponic farming. Nevertheless, the research paper under discussion is a review paper that does not discuss any practical system. In addition, the paper is related to hydroponics and not the use of vertical farm structures.

In 2025, Awal *et al.* introduced IoT based hydroponic farming technology<sup>(6)</sup>. The proposed model uses temperature, humidity, and pH sensors along with an Arduino-based controller. The proposed model highlights IoT-based monitoring using a dashboard platform and this is a prototype model of IoT-based monitoring in the vertical farming industry. But the proposed system involves hydroponic farming and not vertical farming infrastructure and also lacks details on the implementation of AI-based prediction systems.

In 2021, Halgamuge presented a conceptual framework IoT based autonomous control system for vertical farms<sup>(7)</sup>. This involves environmental sensing and IoT controllers used for environment monitoring and control. But this design uses only an experimental framework, and no intelligent sensing and control frameworks have been involved in the proposed system.

The system design for IoT based automated hydroponic and greenhouse monitoring using temperature, humidity and nutrients sensors with Arduino microcontroller along with cloud monitoring was proposed by Sadek *et al.*<sup>(8)</sup> in 2024. The system, although fully functional, has been utilized for greenhouse farming operations but not in case of vertical farms.

Baraskar *et al.*<sup>(9)</sup> proposed a system design for AI based hydroponic farming using pH, temperature and humidity sensors with a microcontroller platform. This system has been proposed as a combination of data analytics and automation through AI for smart farming operations. The system although completely functional, has been applied only for hydroponic farms and not vertical farm structures.

Sowmya *et al.*<sup>(10)</sup> have discussed about the recent advances in technology in vertical farming systems in 2024. The discussion includes conceptual automation and environment monitoring systems but not any mention of sensors, microcontrollers and cloud platforms.

Analysis of IoT-based Autonomous Hydroponic Farming System by Azmi *et al.*<sup>(11)</sup> in 2024 was conducted, which focused on environmental sensors and IoT controllers with cloud integration for environmental monitoring in agriculture. The analysis is theoretical and does not provide implementation of the actual system.

IoT-Based Vertical Farming Monitoring System by Bhaskar Rao M *et al.*<sup>(12)</sup> is based on temperature and humidity sensors

along with an Arduino controller that works on the IoT platform to monitor farms. The system is design and implemented, but its use is limited to only monitoring without any intelligent decision-making ability.

Review Analysis of Vertical and Hydroponics Farming Systems by Verma *et al.*<sup>(13)</sup> in 2024 discussed the various technologies for growing vegetables but lacked any reference to sensors or any hardware involved or any IoT automation systems.

Anbu Sezhian *et al.*<sup>(14)</sup> conducted a study on review research on automation in vertical farming systems in 2024. The paper elaborates on different sensor-based monitoring systems and automated control systems. The research paper is only at the conceptual stage of implementation, and actual systems have not been implemented yet.

Malabadi *et al.*<sup>(15)</sup> provided a review of IoT technology on greenhouse farming systems in 2024. The review explains environmental sensors and IoT controller technologies using cloud computing. Even though the research paper is related to vertical farming to some extent, it is primarily concerned with greenhouse systems and has nothing about AI-based nutrient optimization techniques.

Meena and Sinha<sup>(17)</sup> suggested an IoT-based hydroponic farming system in 2024. The suggested system is made up of IoT-based sensor technologies such as pH sensor technology, electric conductivity sensor technology, and temperature sensor technology using microcontroller and cloud-based monitoring technologies. The suggested system is partially complete since automated decision-making techniques have not been suggested.

The paper by Rameshkumar *et al.*<sup>(18)</sup> was written in 2018 regarding the application of vertical farming systems in greenhouse environments as future technology. This paper talks about some conceptual models of vertical farming systems as future technology. In vertical farming systems, there are no IoT sensor technologies and automation techniques.

## B. Critical Analysis

It can be seen from the analysis of the above-mentioned studies that all the research works conducted are conceptual models, reviews of research work, and hydroponics monitoring systems. Further, it is also clear that very few research works have been conducted concerning the implementation of IoT-based vertical farming systems. Most importantly, there has been no research work that focuses on low-cost hardware architecture and remote monitoring systems in relation to IoT-based vertical farming systems. This proposed model fulfills the void left in the research of IoT-based vertical farming systems through ESP32 and Blynk cloud technology.

## Research Gap

The available literature on IoT-based vertical farming reveals several key research gaps. First, a large number of studies are theoretical and based on literature review without providing an actual vertical farm prototype. Next, there are many studies dealing with hydroponics or greenhouse farming but no solution for multi-layer vertical farms better suited for implementation in urban areas. The majority of existing vertical farms utilize simple sensors to measure parameters like air humidity and temperature while ignoring critical factors like the concentration of nutrient solutions or acidity and soil moisture levels. Moreover, the vast majority of solutions only collect data from the farm and do not provide control capabilities for irrigation, climate control, and fertilizer delivery. Finally, there is a lack of solutions that are inexpensive and scalable because the existing models do not rely on cost-effective microcontrollers like ESP32. There is a need for an integrated IoT-based solution combining various features in one platform.

## Problem Statement

The existing systems for vertical farming and IoT-based agriculture suffer from the lack of practical deployment, incomplete automation, and poor integration of sensing, controlling, and cloud services technologies. The majority of approaches are theoretical or limited to the development of hydroponics and greenhouses but not actual vertical farms. The significance of such problem lies in the increasing levels of urbanization, shrinking areas dedicated to agriculture, and growing demand for more sustainable and effective food production solutions. For this reason, it is important to create an affordable IoT-based vertical farm system, capable of monitoring and automation of the irrigation and climatic conditions control, thus providing maximum productivity.

## Objectives

- To design and develop a cost-effective IoT-based smart vertical farming system using ESP32 microcontroller.
- To monitor important environmental parameters such as:
  - Soil moisture
  - Temperature and humidity
  - pH level
  - Nutrient concentration (TDS)
- To implement automated irrigation and nutrient delivery system based on real-time sensor data.
- To control environmental conditions such as lighting and ventilation (fan) automatically.
- To integrate the system with Blynk cloud platform for realtime remote monitoring and control via smartphone.

- To optimize water usage, nutrient supply, and energy consumption for efficient plant growth.
- To develop a scalable and low-cost solution suitable for urban and indoor farming applications.

## System Design

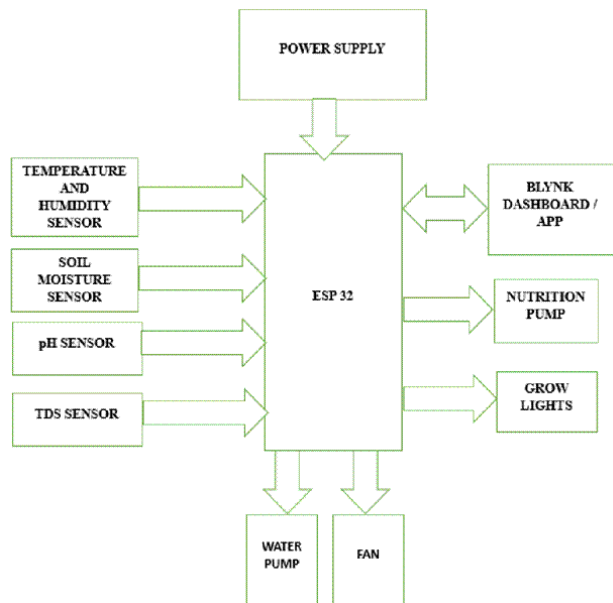


Fig. 1: Block Diagram

The proposed system is a smart vertical farming system based on Internet of Things that helps automate the irrigation process, climatic conditions, nutrient supply, and light. The major controller for this automation process would be ESP32 microcontroller. In this system, various kinds of sensors will be used for monitoring the health condition of the plants continuously. Soil moisture sensors help check the presence of moisture in the soil, DHT sensors measure temperature and humidity levels, pH sensors indicate the acidity or alkalinity of the medium, and TDS sensors measure total dissolved solids, which determine the amount of nutrients available in the water. All readings from various sensors are sent to the ESP32.

All the collected information is processed by the ESP32. ESP32 then analyses the obtained data using the threshold value and controls respective devices accordingly. If soil moisture level is less than the desired value, the water pump is turned ON for water supply. Similarly, if the temperature is too high or the humidity level is low, the fan is turned ON. If the values of pH and TDS do not lie within the set threshold value, the nutrient pump is turned ON.

The relay module is responsible for managing all of the actuators including the water pump, nutrient pump, fan, and

grow lights. The relay module works as a link between the ESP32 and the actuator.

The system is connected to the Blynk cloud service, which will help to upload the sensor data to the cloud server, where users can access real-time data and manage the system via their phones.

On the whole, the system functions automatically through sensing, computing, and acting processes. It assists in providing the best growing environment for plants and saves labor.

## Methodology

### A. Hardware Overview

The suggested approach will be dedicated to developing a smart vertical farm based on the Internet of Things (IoT). It will be capable of automatic irrigation, environmental control, nutrient management, and lighting control. The ESP32 serves as the main processing unit for performing all tasks related to sensing and controlling the process.

As part of the suggested vertical farm, different types of sensors can be installed to ensure continuous control over such parameters as temperature, moisture, humidity, nutrient concentration, and pH value. The first task will be performed by means of a moisture sensor that is responsible for controlling the water content in the growing medium. The DHT sensor can be used to control both temperature and humidity in order to create optimal conditions for growth. The pH sensor is utilized to check whether the medium is acidic or alkaline, while the TDS sensor measures the nutrient levels in the water.

The data collected from the sensors is then provided to the ESP32 controller, where it is analyzed in real-time. According to the results obtained after analyzing the data, the actuator functions are controlled using a relay module. The water pump is turned on when the soil moisture level drops below a certain pre-specified level in order to carry out irrigation. Nutrient solution is provided by the nutrient pump, whenever it becomes necessary, based on pH and TDS levels. A fan can be employed to control the airflow as well as temperature in the system, and grow lights are also installed for lighting. The OLED screen is utilized in the system to facilitate its monitoring.

The architecture of the suggested system is three-tiered:

- Sensor Layer: Data gathering from sensors in real time
- Controller Layer: Data processing through ESP32 and decision-making
- Cloud Layer: Remote monitoring and control

### B. Software Overview

The software realization of the suggested methodology is realized through programming the ESP32 microcontroller through the Arduino IDE, which will monitor continuously and control automatically.

The operation of the proposed system is done through loop, where sensor information is continuously collected and analyzed against preset thresholds. The control function follows by performing the right actions depending on the results obtained from such analysis to ensure ideal conditions for the plant.

A control algorithm that involves threshold functions is used for automation purposes. The water pump is automatically turned ON if the moisture content in the soil becomes less than the minimum value while the fan is automatically turned ON either when temperature rises above a specified maximum threshold or if relative humidity goes below a specified minimum value.

The pH level and TDS sensors are used for nutrient management in the system. In case the pH level deviates from the acceptable range or the level of nutrients drops below the required limit, the nutrient pump turns on. The light fixtures operate according to the set schedule or the set input values.

The presented system uses the Blynk cloud platform for remote monitoring and controlling processes. Data concerning soil moisture level, temperature, humidity, pH level, and TDS sensors are sent to the cloud continuously. The users may control the process via a smartphone app.

## Future Scope

- Artificial Intelligence technology can be introduced in order to predict plant growth and provide optimized watering plans.
- Machine learning algorithms will aid in diagnosing diseases and nutrient deficiency issues in the plants.
- The system can be improved with ESP32-CAM camera modules to enable real-time observation of plants.

## References

1. Rathor AS, Choudhury S, Sharma A, Nautiyal P, Shah G. Empowering vertical farming through IoT and AI-Driven technologies: A comprehensive review. *Heliyon*. 2024;10(15):e34998. Available from: [10.1016/j.heliyon.2024.e34998](https://doi.org/10.1016/j.heliyon.2024.e34998)
2. Oh S, Lu C. Vertical farming - smart urban agriculture for enhancing resilience and sustainability in food security. *The Journal of Horticultural Science and Biotechnology*. 2023;98(2):133-140. Available from: [10.1080/14620316.2022.2141666](https://doi.org/10.1080/14620316.2022.2141666)
3. Kaur G, Upadhyaya P, Chawla P. Comparative analysis of IoT-based controlled environment and uncontrolled environment plant growth monitoring system for hydroponic indoor vertical farm. *Environmental Research*. 2023;222:115313. Available from: [10.1016/j.envres.2023.115313](https://doi.org/10.1016/j.envres.2023.115313)
4. Siregar RRA, Seminar KB, Wahjuni S, Santosa E. Vertical Farming Perspectives in Support of Precision Agriculture Using Artificial Intelligence: A Review. *Computers*. 2022;11(9):135. Available from: [10.3390/computers11090135](https://doi.org/10.3390/computers11090135)
5. Ahmed A, Alnawasrah R, Almadani B, Aliyu, F, Ghaleb M. Contemporary smart hydroponics systems: Taxonomy, enabling technologies, and challenges. *Internet of Things*. 2025;34:101794. Available from: [10.1016/j.iot.2025.101794](https://doi.org/10.1016/j.iot.2025.101794)
6. Awal MA, Pio AS, Mim MJ, Partha PKP, Al Kafi MA, Farha S. A smart IoT-based hydroponics system for small-scale household in Bangladesh. *Smart Agricultural Technology*. 2025;12:101163. Available from: [10.1016/j.atech.2025.101163](https://doi.org/10.1016/j.atech.2025.101163)
7. Halgamuge MN, "IoT and autonomous control for vertical farming systems," *Journal of Agricultural Engineering*. 2021.
8. Sadek N, Das P, Uddin MR, Khan MH, Faruque KFI, Hasan M. IoT Based Automated Greenhouse Hydroponics System. *2024 6th International Conference on Sustainable Technologies for Industry 5.0 (STI)*. 2024;:1-6. Available from: [10.1109/sti64222.2024.10951046](https://doi.org/10.1109/sti64222.2024.10951046)
9. Baraskar T, Khatri V, Kolhe P, Katyarmal M, Khedekar S. AI-powered automated hydroponic system for smart agriculture. *MethodsX*. 2025.

- Solar power systems can be implemented to render the system energy-efficient for sustainable farming applications.
- Sensor types including Electrical Conductivity and CO<sub>2</sub> sensors will contribute to accurate environmental regulation.
- Creation of a smartphone app with a data analytics dashboard for better analysis capabilities.
- Escalating the project to a commercial level of implementation in multi-level vertical farms.
- IoT security protocols can ensure that all cloud communication is safe and reliable.
- Robotic systems will further simplify plant maintenance and minimize human labor input.
- Speech control and smart assistant capabilities can be introduced to enhance ease-of-use.

## Conclusion

Thus, the development of a vertical farming IoT system is a good example of a practical application of IoT in modern agriculture, which shows how effective and affordable it is. Thanks to the use of the ESP32, the system is able to operate several sensors at once, constantly controlling parameters such as soil moisture, air temperature, air humidity, soil pH level, and the presence of nutrients, determined via a TDS sensor. On the basis of this information, irrigation, nutrition, and lighting are adjusted.

The involvement of the Blynk cloud platform allows a person to control the process through the smartphone interface and thus ensures the convenience of using the system. This practical work showed how useful the automation of agriculture could be as it helps to optimize resources and create optimal conditions for plant growth.

Overall, the system proved to be very relevant for today's situation, which calls for innovative ways of implementing agriculture in cities.

Available from: [10.2139/ssrn.5253246](https://doi.org/10.2139/ssrn.5253246)

10. Sowmya C, Anand M, Rani CI, Amuthaselvi G, Janaki P. Recent developments and inventive approaches in vertical farming. *Frontiers in Sustainable Food Systems*. 2024;8. Available from: [10.3389/fsufs.2024.1400787](https://doi.org/10.3389/fsufs.2024.1400787)
11. Azmi KHM, Radzi NABM, Ahmad A. The Future Of Sustainable Agriculture: A Review Of Iot And Autonomous Control In Vertical Hydroponic Farming. *Advances in Electrical and Electronic Engineering*. 2024;22(2). Available from: [10.15598/aeec.v22i2.5321](https://doi.org/10.15598/aeec.v22i2.5321)
12. Bhaskar Rao M, Sindhu S, Reddy VV, Ali A, Amulya S. Vertical Farming System Based on IoT. *International Journal of Innovative Science and Research Technology (IJISRT)*. 2024;:2605-2610. Available from: [10.38124/ijisrt/ijisrt24apr571](https://doi.org/10.38124/ijisrt/ijisrt24apr571)
13. Verma S, Kumar A, Kumari M, Naveen Kumar S. A Review on Hydroponics and Vertical Farming for Vegetable Cultivation: Innovations and Challenges. *Journal of Experimental Agriculture International*. 2024;46(12):801-821. Available from: [10.9734/jeai/2024/v46i123190](https://doi.org/10.9734/jeai/2024/v46i123190)
14. Ambethgar AS, Arumukapraavin I, Alagarsamy RK, Shanthi VP, Ambethgar V, Sundaresan S. Enhancing vertical farming with cutting-edge automation: A comprehensive review. *International Journal of Research in Agronomy*. 2024;7(8):819-831. Available from: [10.33545/2618060x.2024.v7.i8k.1389](https://doi.org/10.33545/2618060x.2024.v7.i8k.1389)
15. Malabadi RB, Kolkar KP, Chalannavar RK, Coronado KVC, Sultan SM, Baijnath H, et al. Greenhouse farming: Hydroponic vertical farming- Internet of Things (IoT) Technologies: An updated review. *World Journal of Advanced Research and Reviews*. 2024;23(2):2634-2686. Available from: [10.30574/wjarr.2024.23.2.2595](https://doi.org/10.30574/wjarr.2024.23.2.2595)
16. Widiyanto MH, Juarto B. Smart Farming Using Robots in IoT to Increase Agriculture Yields: A Systematic Literature Review. *Journal of Robotics and Control (JRC)*. 2023;4(3):330-341. Available from: [10.18196/jrc.v4i3.18368](https://doi.org/10.18196/jrc.v4i3.18368)
17. Farhan M, Meena S, Sinha G. Smart Farming with IoT: A Paradigm Shift in Hydroponic Cultivation of Leafy Greens. *NG Agriculture Insights*. 2025;1(2):34-37. Available from: [10.5281/zenodo.16032445](https://doi.org/10.5281/zenodo.16032445)
18. Rameshkumar D, Jagathjothi N, Easwari S, Rajesh R, Muthuselvi R, Kumar PN, et al. Vertical Farming -Agriculture of the Future. *Indian Farmer*. 2020;7(11):1013-1017. Available from: [https://www.researchgate.net/publication/346097609\\_Vertical\\_Farming\\_-\\_Agriculture\\_of\\_the\\_Future](https://www.researchgate.net/publication/346097609_Vertical_Farming_-_Agriculture_of_the_Future)