Iot-Based Smart Aeroponics Vertical Farming System for Optimized Plant Growth

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ABSTRACT

This paper presents the design and development of an IoT-based smart aeroponics vertical farming system intended to improve plant growth efficiency through continuous microclimate monitoring, automation, and optimized water–nutrient delivery. The system integrates Arduino Uno as the main controller with sensors including a light-dependent resistor (LDR), DHT11 temperature–humidity sensor, ultrasonic water-level sensor, and electromechanical actuators such as a water pump and solenoid valve. IoT connectivity is enabled through the ESP8266 Wi-Fi module, interfacing with the Blynk platform for real-time monitoring, data logging, and remote operation. The vertical tower design incorporates a multi-layered aeroponic structure allowing 7 plants per column while minimizing land usage, water consumption, and human intervention. Hardware development includes fabrication of the aeroponic tower, nutrient delivery system, and automated water-refill mechanism. Experimental results demonstrate effective luminance-based irrigation control, humidity–temperature notifications, autonomous water-level regulation, and successful plant growth over a 7-day trial using green beans. The system achieved reliable environmental sensing, responsive actuation, and stable communication with the IoT server. The findings highlight the potential of low-cost IoT-enabled aeroponics as a sustainable agricultural approach for urban environments. Recommendations for system enhancement and scalability are also discussed.

Keywords: Aeroponics, Internet of Things (IoT), Vertical Farming, Smart Irrigation, Environmental Monitoring

INTRODUCTION

Aeroponics has emerged as a leading controlled-environment agriculture (CEA) technique that enables rapid crop production with minimal water and nutrient usage. Unlike soil-based systems, aeroponics suspends plant roots in air and delivers nutrients through periodic misting, resulting in enhanced oxygenation, faster metabolic activity, and accelerated growth rates (Jones, 2014; Resh, 2013). As global urbanization intensifies and arable land becomes increasingly limited, vertical farming and aeroponics offer scalable solutions capable of producing high crop yields within constrained spaces (Alvarez & Gomez, 2020; Vertical-Farming.net, n.d.). Compared with traditional agriculture, aeroponics can reduce water consumption by up to 98% and support more frequent harvest cycles, demonstrating substantial gains in sustainability and efficiency (Rani & Singh, 2021; Sharma et al., 2018).

Recent advancements in Internet of Things (IoT) technology have further revolutionized precision agriculture by enabling remote monitoring, automation, and real-time decision making (Debasis & Jaydip, 2011; Porter & Wescott, 2018). IoT-based smart farming integrates environmental sensors, microcontrollers, cloud communication, and mobile dashboards to achieve consistent environmental regulation and reduce manual intervention (Han & Li, 2020; Kim et al., 2019). Studies show that IoT-enhanced systems significantly improve irrigation precision, nutrient delivery, and environmental stability, thereby enhancing plant growth and resource management (Sharma et al., 2018; Kim et al., 2019).

In aeroponics, maintaining optimal environmental conditions is essential for healthy root development, photosynthesis, and nutrient absorption. Critically important parameters include temperature, humidity, water level, and light intensity—variables identified as central constraints affecting aeroponic performance (NASA, n.d.; Emily, 2010). Real-world issues such as pump clogging, nutrient film inconsistency, and root desiccation highlight the need for continuous monitoring and automation (Instructables, n.d.; Coconauts, n.d.). Integrating IoT-based sensing into aeroponics systems provides growers with real-time visibility and automated corrections to environmental deviations, thereby reducing the risk of crop failure from equipment malfunction or sudden environmental changes.

Vertical farming provides an additional advantage by maximizing spatial efficiency through multi-layered plant arrangements, enabling higher density cultivation in constrained indoor environments (Alvarez & Gomez, 2020). In this context, IoT-enabled aeroponics systems represent a promising advancement for urban agriculture, combining vertical design with intelligent sensor-driven control. The present research contributes to this field by developing an IoT-based aeroponics vertical farming prototype using Arduino Uno, DHT11 temperature–humidity sensors, LDR luminance sensors, ultrasonic water-level detection, and a Blynk IoT interface. The system aims to optimize plant growth while reducing water consumption, improving automation reliability, and enabling real-time environmental monitoring.

The integration of IoT within aeroponics aligns with global agricultural digitalization trends, providing a low-cost, scalable framework suitable for modern production. By leveraging automation, environmental sensing, and remote access, this study demonstrates how IoT-driven aeroponics systems can enhance agricultural sustainability and contribute to future smart-farming ecosystems (Kim et al., 2019; Porter & Wescott, 2018; Han & Li, 2020).

METHODOLOGY

The methodology for the IoT-based aeroponics vertical farming system involved four stages: system planning, hardware–software development, prototype fabrication, and performance evaluation. The methodological framework was informed by best practices in aeroponics, IoT architecture, and smart irrigation design (Jones, 2014; Resh, 2013; Kim et al., 2019).

1. System Planning

The planning stage focused on selecting appropriate sensors, microcontrollers, structural materials, and communication modules. Consistent with prior aeroponics system designs, essential environmental variables—light intensity, temperature, humidity, and water level—were identified as primary indicators required for optimized plant growth (NASA, n.d.; Emily, 2010). IoT-based agricultural systems frequently integrate multiple sensing sources for improved accuracy and automation reliability (Porter & Wescott, 2018; Han & Li, 2020), guiding the choice of an LDR sensor, DHT11 module, and ultrasonic sensor for environmental monitoring.

2. Hardware and Software Integration

Following established smart-farming architectures (Kim et al., 2019; Rani & Singh, 2021), the Arduino Uno acted as the primary controller responsible for data acquisition, actuator control, and communication. The ESP8266 Wi-Fi module enabled cloud-based data transmission to the Blynk platform, which offered real-time visualization and remote access. The irrigation subsystem consisted of an electric water pump linked to a drip line within the tower, while a solenoid valve facilitated automatic reservoir refilling based on ultrasonic water-level readings.

Automation logic was developed using the Arduino IDE, integrating sensor thresholds and conditional control strategies. For instance, light intensity thresholds influenced irrigation activation, consistent with daytime photosynthetic requirements (Bottoms et al., 2015). Temperature and humidity thresholds were configured to trigger notifications, supporting responsive environmental control (Instructables, n.d.; Coconauts, n.d.).

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3. Aeroponics Tower Fabrication

The tower was constructed using a 110 mm PVC pipe, consistent with vertical farming applications recommended in prior studies (Alvarez & Gomez, 2020). Openings were created using heat molding to accommodate planting pods. A closed-loop nutrient system recirculated water from the reservoir through a vertical perforated hose, reducing water consumption while maintaining root aeration (Sharma et al., 2018; Resh, 2013).

4. System Evaluation and Plant Testing

System performance was evaluated through functional testing of sensors, pump operation, IoT connectivity, and irrigation timing. Water-level regulation was tested by simulating low reservoir conditions, validating solenoid valve responsiveness. Similarly, temperature and humidity tests confirmed accurate readings and timely notifications. IoT dashboards on the Blynk app displayed real-time values for each sensor, enabling remote monitoring, consistent with modern IoT agricultural frameworks (Kim et al., 2019; Porter & Wescott, 2018).

A 7-day green bean growth trial was performed to validate biological feasibility. Metrics observed included sprouting, hydration, and leaf emergence. Results indicated that the aeroponics environment supported healthy early-stage growth, aligning with findings from prior aeroponics research (Rani & Singh, 2021; Jones, 2014).

RESULTS AND DISCUSSION

Hardware Testing Results

Figure 1 provides luminance measurements corresponding to LDR resistance and voltage. Indoor lighting produced readings between 100–1000 lux, while daylight exceeded 10,000 lux. These values were used to calibrate the watering logic, enabling the pump only under sufficient luminance to promote photosynthesis. Temperature and humidity measurements using the DHT11 senso in Figure 2 and 3 showed stable voltage-to-parameter mapping, enabling accurate environmental readings.

Figure 1. LDR Luminance Data

Condition	Luminance (Lux)	LDR resistance (kilo ohm)	Voltage across LDR (V)
Moonlight night	1	70	0.1
Dark room	10	10	0.5
Bright room	100	1.5	2.0
Overcast room	1000	0.3	3.8
Full daylight	10000>	0.1	4.5

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Figure 2. Humidity Data

Percentage range of humidity	Voltage range to Arduino
20 - 30	1.5 – 2.00
30 - 40	2.00 – 2.5
40 - 50	2.5 – 3.00
50 - 60	3.5 – 4.00
60 – 70	4.00 – 4.5
70 – 80	4.5 – 5.00

Figure 3. Temperature Data

Temperature range in degree Celsius	Temperature output to Arduino reading (Vout)
20 - 25	1.00 – 1.25
25-30	1.25 – 1.5
30-35	1.5 – 1.75
35-40	1.75 – 2.00
40 - 45	2.00 – 2.25
45 - 50	2.25 – 2.5
50 – 55	2.5 – 2.75
55 - 60	2.75 – 3.00
60 – 65	3.00 – 3.25
65 - 70	3.25 – 3.5
70 75	3.5 – 3.75
75 – 80	3.75 – 4.00
80 - 85	4.00 – 4.25

System Response Performance

The automated system exhibited reliable response to sensor thresholds:

- LDR ≥ 500 lux → Pump ON

- Temperature ≥ 38°C or Humidity ≥ 80% → Notification Triggered
- Water Level ≤ 25 cm → Solenoid Valve Activated

Plant Growth Results

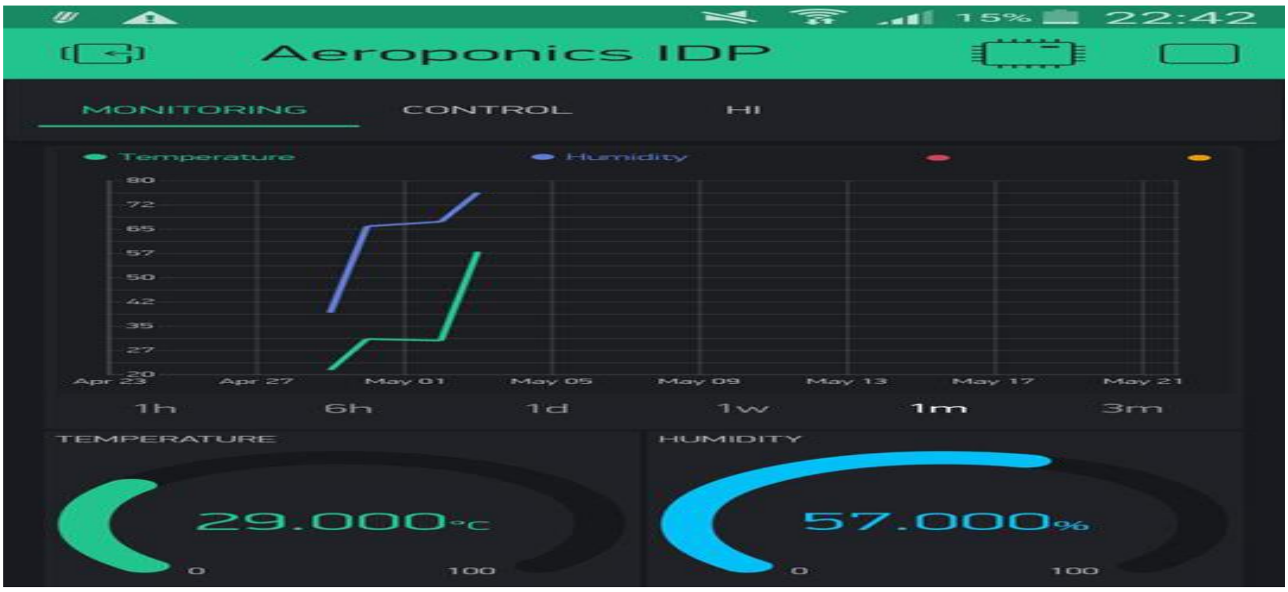
The 7-day green bean trial shown in Figure 4 demonstrated successful plant development. Day-1(Left) seeds showed initial hydration and swelling; Day-2 (Middle) sprouts emerged; and by Day-7(Right), plants exhibited elongated stems and healthy leaf development. The system maintained adequate hydration and nutrient supply through periodic misting.

Figure 4. 7 Day Green Bean Trial

IoT Monitoring and Automation

Figure 5 shows active Blynk dashboards displaying live sensor data. Real-time feedback allowed users to monitor environmental conditions and override automation via manual mode. Smart notifications provided immediate warnings, enhancing system reliability.

Figure 5. Blynk Dashboard



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Smart Refilling Mechanism

The ultrasonic-based auto-refill feature effectively prevented pump dry-run conditions. When water dropped below the threshold, the solenoid valve activated until the reservoir was refilled to optimal level.

CONCLUSION

The IoT-Based Smart Aeroponics Vertical Farming System successfully integrates environmental sensing, automated irrigation, vertical hydroponic structure, and IoT connectivity into a compact and efficient agricultural prototype. Through Arduino-based control and multi-sensor inputs, the system autonomously maintained optimal plant-growing conditions while reducing water usage, energy consumption, and manual labor. Real-time monitoring via the Blynk platform offered enhanced visibility and remote control, enabling users to receive alerts and make timely decisions. The automated water-level refill mechanism further improved system reliability by preventing pump malfunction. Results from the 7-day plant growth experiment confirmed the system's capability to support healthy and consistent growth. Overall, the project demonstrates that IoT-enabled aeroponics systems are a viable and sustainable solution for modern urban agriculture. Future enhancements may include higher-precision sensors, improved nutrient control, integration of AI-based predictive analytics, and scalable modular tower designs.

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