# SIMPONI: Web-Integrated IoT Monitoring System for Indoor Hydroponics

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**Abstract.** Indoor hydroponics offers a promising solution for urban agriculture, enabling precise control over environmental conditions. However, without proper automation, growers still face challenges in monitoring key parameters that are crucial for plant health. To address these issues, this study presents SIMPONI, a web-integrated Internet of Things (IoT) platform designed for real-time monitoring in indoor hydroponic setups. The system uses an ESP32-S3 UNO microcontroller connected to various sensors to collect data on pH, TDS, water temperature, air temperature and humidity, light intensity, and water level. These sensor readings are transmitted to a Firebase cloud database and visualized through a web dashboard. The dashboard, built using Next.js and integrated with Firebase services, allows users to view historical trends, configure sensor thresholds, and manage device settings. The platform has been deployed in a controlled indoor hydroponic setup to validate its functionality. Results indicate consistent data transmission and responsive visualization. SIMPONI demonstrates a practical and extensible architecture for hydroponic monitoring and lays the groundwork for future enhancements such as automation and data-driven optimization.

## 1 Introduction

Urban agriculture is gaining traction as cities seek sustainable solutions for local food production. One of the most promising methods is hydroponics, a technique that grows plants without soil by using nutrient-rich water. Compared to conventional agriculture, hydroponics offers greater control over growing conditions, more efficient water usage, and the ability to produce crops in confined spaces. Among its various implementations, indoor hydroponic systems have shown particular advantages. By isolating the environment from external factors such as weather fluctuations or contamination from soil, indoor setups allow for a more stable and optimized growth environment [1, 2].

However, these advantages come with challenges. Maintaining optimal conditions requires continuous monitoring of environmental parameters such as water pH, temperature, and nutrient levels. Manual observation of these factors is often time-consuming and inconsistent, especially in systems operated by individuals with limited time or technical experience. Delays in detecting anomalies in pH levels, temperature shifts, or water shortages can quickly affect plant health and reduce yields [3, 4].

To address these limitations, Internet of Things (IoT)-based solutions have emerged as effective tools for automating data collection and remote monitoring. By deploying sensor-equipped microcontrollers and connecting them to cloud-based platforms, users can access real-time information about their hydroponic systems from anywhere. Nevertheless, many existing solutions focus primarily on sensor hardware, while lacking an integrated and intuitive user interface. This often limits accessibility for general users, particularly those without technical backgrounds [5, 6].

SIMPONI (System Monitoring Hydroponic Indoor) is developed as a comprehensive solution to these problems. It combines a microcontroller-based IoT device with a centralized cloud database and a web-based dashboard that presents sensor data visually and interactively. This approach not only simplifies real-time monitoring but also creates a foundation for future system expansion, such as automated controls or intelligent data analysis. The system is specifically designed for indoor hydroponic environments, where precision and stability are crucial for successful plant cultivation.

## 2 Related Work

The application of IoT in hydroponic systems has been widely studied to improve efficiency, automate data collection, and enable remote monitoring. Most existing works utilize microcontrollers such as Arduino, which are connected to environmental sensors that measure key parameters [7]. Another project focused on water quality monitoring for Bok Choy hydroponics using multiple sensors and a web interface. While this system successfully monitors parameters such

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as pH and TDS, it does not include other relevant environmental factors like ambient temperature, humidity, light intensity, or water level parameters [8]

In the study by A. Chatzopoulos et al. [9], an Arduino-based system was implemented for monitoring temperature, humidity, and light in a hydroponic setup. Data was sent via Wi-Fi to a mobile application, but system configuration and calibration still required manual code changes and re-uploading the program to the device. Similarly, H. L. Hasith Deshan et al. [10] introduced a hydroponic monitoring which integrates multiple microcontrollers like Arduino UNO and ESP32 but lacks remote calibration capabilities.

Some recent works have improved usability by incorporating dashboards, but most still rely on desktop applications or smartphone apps that require installation and may not be optimized across different device types [11]. Moreover, configuration changes such as sensor calibration thresholds or alert levels often require reprogramming the device, posing a technical barrier for non-technical users [12].

One of the other research projects is developing an IoT-based control and monitoring system using image processing and a mobile app to support plant growth [13]. However, this system was not tested in an indoor hydroponic environment like the SIMPONI indoor space.

Few systems explicitly address the challenges of outdoor hydroponic environments, where rainwater can dilute nutrient concentrations and drastically alter pH and temperature levels. These uncontrolled fluctuations can negatively impact plant health if not responded to quickly. In contrast, indoor hydroponic systems offer a more stable environment where lighting, temperature, and water quality can be controlled more precisely. However, existing research has rarely focused specifically on indoor contexts or tailored systems for this more predictable environment [5, 14].

Additionally, Adianggiali et al. [15] presented a system for classifying nutrient deficiencies in hydroponic lettuce using MobileNet, focusing on visual analysis of leaf images. While SIMPONI does not yet integrate image-based diagnostics, its structured sensor dataset and real-time data infrastructure can serve as a complementary foundation for future implementation of machine learning features, including classification models for plant health. The integration of environmental monitoring with data-driven models, as demonstrated in their work, aligns with SIMPONI's long-term vision to incorporate intelligent decision-making capabilities.

## 3 System Design

### 3.1 System Overview

SIMPONI is structured as an integrated system that combines Internet of Things (IoT) hardware, a cloud-based data infrastructure, and a web-based user interface to enable comprehensive environmental monitoring in indoor hydroponic setups. The design is modular, allowing each component to perform a distinct role while maintaining seamless communication between layers. Overall symphony system architecture is shown in Fig. 1.

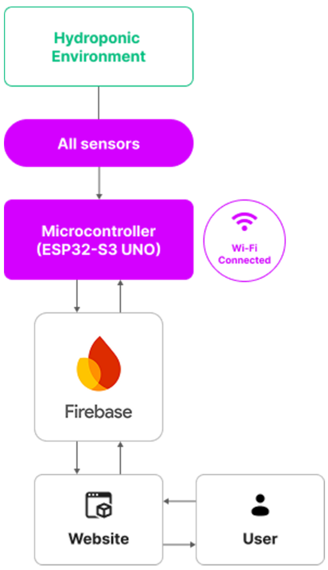


**Fig. 1.** SIMPONI System Architecture.

At the core of the system lies a network of environmental sensors managed by a microcontroller. These sensors collect key data points such as pH level, nutrient concentration (TDS), water and air temperatures, humidity, light intensity, and water level. The collected data is transmitted to a cloud database hosted on Firebase, where it is stored and organized for both real-time display and historical tracking.

On the user side, a web platform enables intuitive access to this information. Users can log in securely, monitor current conditions, analyze past trends, and update configuration settings such as calibration values or threshold alerts. This structure ensures that growers can maintain oversight of their hydroponic systems at all times, even when not physically present at the location. With this architecture, SIMPONI bridges the gap between traditional hydroponic monitoring and modern digital agriculture, making it more practical for indoor and small-scale urban farming contexts.

### 3.2 IoT Device

The IoT device in SIMPONI is responsible for acquiring environmental data from the hydroponic system. It is built around the ESP32-S3 UNO, a microcontroller chosen for its Wi-Fi capabilities, GPIO flexibility, and compatibility with sensor libraries. The device supports multiple analog and digital sensors, which are wired and configured to operate simultaneously. The connection center still uses a breadboard because the product is still in the prototype stage for ease of installation and removal of pins. However, in the future this breadboard is better replaced with a PCB. The following Fig. 2 shows the connection schematic of the IoT device.

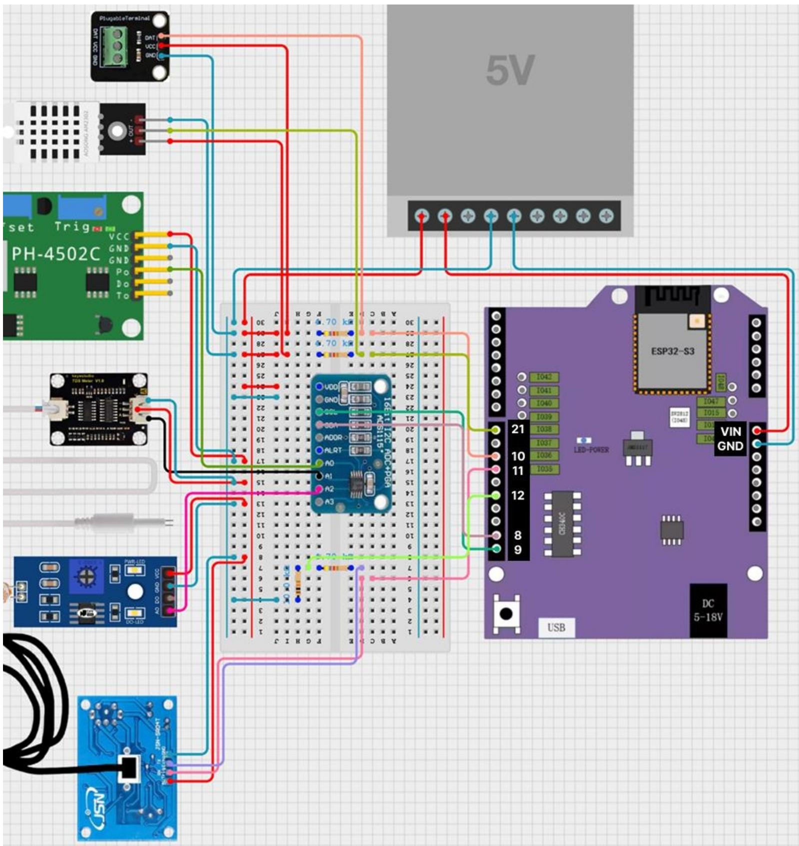


**Fig. 2**. SIMPONI IoT Schematic.

The sensors are interfaced via analog or digital pins and, where necessary (e.g., for pH and TDS sensors), passed through an ADS1115 16-bit ADC module to enhance reading accuracy. Sensor readings are collected every few seconds using a timer-based loop and prepared for transmission in JSON format. The IoT device is powered by a dedicated 5V power supply and can operate once connected to Wi-Fi.

### 3.3 Cloud Database Integration

SIMPONI utilizes Google Cloud Firestore as its core backend database, managing sensor data, device configurations, and calibration settings in a unified and scalable environment. Unlike systems that rely on Firebase Realtime Database, SIMPONI leverages Firestore's document-based NoSQL structure to simplify architecture while supporting both real-time and historical data needs. Sensor readings are transmitted using the Firebase ESP Client library, with the system adopting a dual-storage scheme within Firestore. The most recent sensor values are written to a latestReading field, updated approximately every 10 seconds, which serves as the data source for real-time visualization. In parallel, a permanent log of readings is created every two minutes within a dedicated readings subcollection. This setup separates ephemeral real-time data from long-term records, improving database performance and supporting trend analysis without incurring excessive write operations.

Another notable feature of SIMPONI's database integration is the cloud-based calibration mechanism. Traditional systems often require manual reprogramming to apply updated calibration constants, but SIMPONI enables remote adjustments by storing calibration parameters such as pH offset and slope, TDS correction coefficients, and water level adjustments in each device's document on Firestore. These values are retrieved by the ESP32-S3 UNO microcontroller during startup and applied dynamically before sensor data is transmitted. Through the web interface, users can revise these values on the Settings Page without physical access to the device, thereby improving flexibility, reducing maintenance, and ensuring more reliable long-term monitoring accuracy. Even though Firestore is not MySQL based, the following Fig. 3 is an illustration of the database design used.

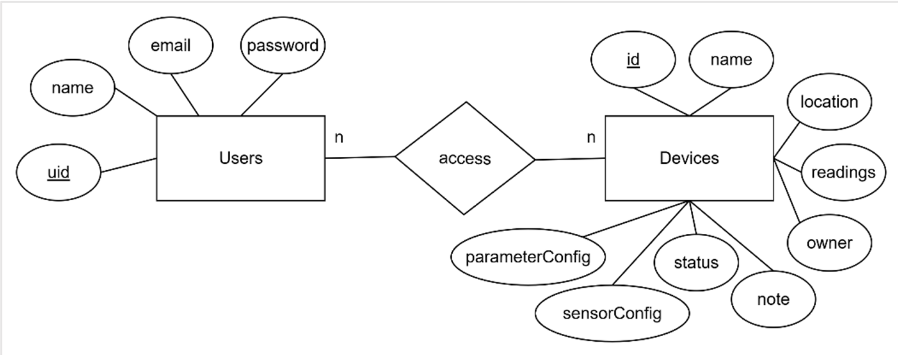


**Fig. 3.** Database Diagram.

### 3.4 Web Platform

The SIMPONI web platform serves as the main point of interaction for users, providing a responsive and accessible interface for monitoring sensor data and managing system configurations. It is developed using Next.js, a React-based framework that supports both server-side and static generation, allowing fast page loads and dynamic content rendering. The design follows a clean and minimal aesthetic using Tailwind CSS, ensuring usability across devices ranging from desktops to smartphones. Fig. 4 shows a preview of the website

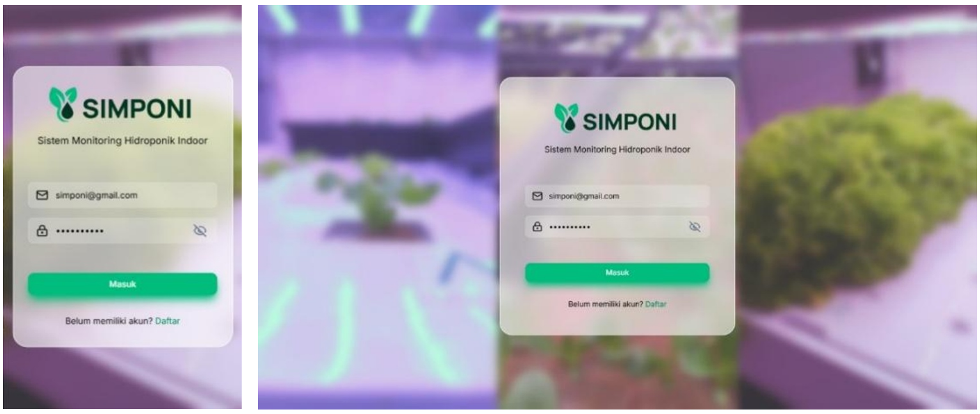


**Fig. 4.** Web Authentication Page in Mobile and Desktop Screen.

#### *3.4.1 Authentication Page*

The authentication page is the entry point of the platform, where users can log in using email and password credentials. Firebase Authentication manages user sessions securely and provides built-in support for password recovery and session persistence. Upon successful login, users are redirected to their personalized dashboard, which is scoped to the devices associated with their account.

#### *3.4.2 Dashboard Page*

This page displays the most recent sensor readings from the selected hydroponic device. Data shown includes water pH, TDS, air and water temperature, humidity, light intensity, and water level. Each value is accompanied by indicators that signal whether the current reading falls within the optimal range, which is determined based on threshold values retrieved from the cloud. The dashboard refreshes automatically as new data arrives via the Firebase Realtime Database, ensuring minimal latency between device and display.

#### *3.4.3 History Page*

Historical data is visualized on this page using interactive charts. Users can observe environmental trends over time, select date ranges, and analyze fluctuations in key parameters. The data is sourced from Cloud Firestore and plotted using charting libraries such as Chart.js or Recharts. This feature supports decision-making by helping users identify patterns or diagnose issues based on past conditions.

#### *3.4.4 Settings Page*

The Settings page in the SIMPONI web platform allows users to manage their devices remotely and efficiently. Users can rename devices and assign locations to easily distinguish between multiple hydroponic setups. Calibration values for pH, TDS, and water level can be adjusted directly from the web interface. These values are stored in Firestore and automatically applied by the IoT device during startup, removing the need for physical reprogramming.

Users may also configure sensor thresholds, which currently serve as visual references but can support future features like alerts or automation. Additionally, devices can be unlinked from a user's account through the interface, useful for reassigning or decommissioning hardware. All changes are applied in real-time without requiring a system restart, enhancing flexibility and ease of use.

### 3.5 Indoor Hydroponics Context and Deployment

SIMPONI is deployed within an indoor hydroponic farming environment as shown in Fig. 5, besides preventing the core of the IoT device from being exposed to rainwater, indoor hydroponic farming environments also provide their own advantages over outdoor setups. In outdoor hydroponics, variables such as rain, wind, and fluctuating temperatures can negatively affect water quality and disrupt system stability. For instance, rainwater can unexpectedly dilute nutrient concentrations, leading to unbalanced pH or TDS levels. Moreover, temperature swings due to sun exposure or cold nights can stress plant physiology.

**Fig. 5.** Hydroponic Room.

In contrast, indoor hydroponic systems provide greater environmental stability and isolation, allowing better control over critical parameters. Temperature and humidity can be regulated using fans, air conditioning, or dehumidifiers, while lighting is controlled through grow lights with adjustable intensity and duration. These conditions create a more predictable environment for plant growth, and as a result, monitoring systems like SIMPONI can operate with higher precision and less noise in the data.

The system was tested in a compact indoor installation using the Nutrient Film Technique (NFT). This arrangement allows a thin film of nutrient solution to flow over the roots of plants placed in horizontal PVC channels. The physical environment includes controlled lighting and room temperature, ensuring that sensor readings reflect meaningful variations rather than random environmental interference.

## 4 Result and Discussion

SIMPONI was deployed in a small-scale indoor hydroponic setup utilizing the Nutrient Film Technique (NFT), supported by artificial lighting and air conditioning for controlled environmental conditions. Sensors were strategically installed to ensure accurate data acquisition, with pH, TDS, and DS18B20 probes immersed in the nutrient tank and other sensors positioned accordingly. The ESP32-S3 UNO microcontroller, housed in a protective enclosure, was powered by a dedicated 5V source, with all sensor connections stabilized to ensure continuous operation. The following Fig. 6 shows the overall IoT installation scheme.

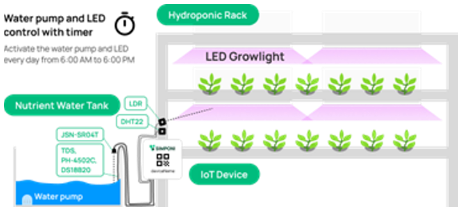


**Fig. 6.** IoT Device Installation Schematic.

To support this deployment, Fig. 7 shows the IoT device that has been installed in the hydroponic room. The IoT Components was housed in a protective enclosure and connected to multiple sensors positioned throughout the hydroponic unit.

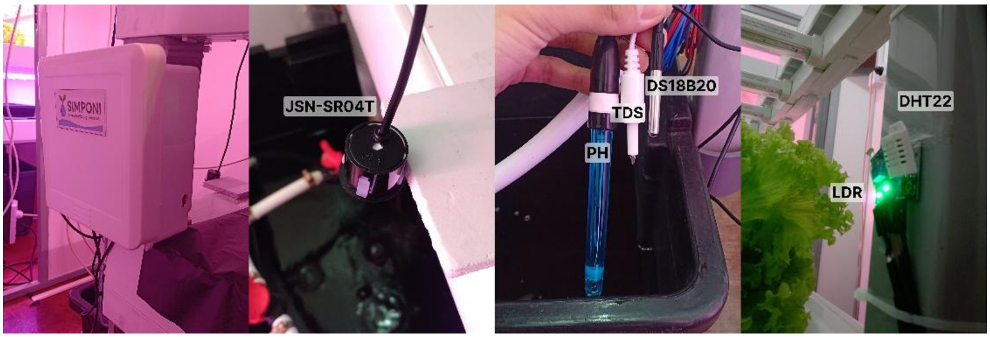


**Fig. 7.** IoT Device Real Implementation.

Sensor data was collected every 5–10 seconds and transmitted to Firestore reliably, updating the latestReading field in near real-time for dashboard display as shown in Fig. 8. Simultaneously, data was logged every one minute into a readings subcollection to support historical analysis. This dual-layered storage enabled users to monitor both live conditions and long-term trends through intuitive visualizations, helping to identify anomalies such as temperature spikes or sudden drops in TDS due to water dilution.


**Fig. 8.** Web Dashboard Realtime Monitoring.

The website is hosted through Vercel and can be accessed through the link https://simponi-sgl.vercel.app, built with responsive design principles, functioned on both desktop and mobile devices. It provided features such as real-time monitoring, interactive historical graphs, device metadata editing, calibration adjustment, and device removal. All configuration changes made via the web interface were reflected in the Firestore database and synchronized by the IoT device in subsequent cycles, confirming the system's capability for remote management. The concept or flow of this feature is shown as in Fig. 9.

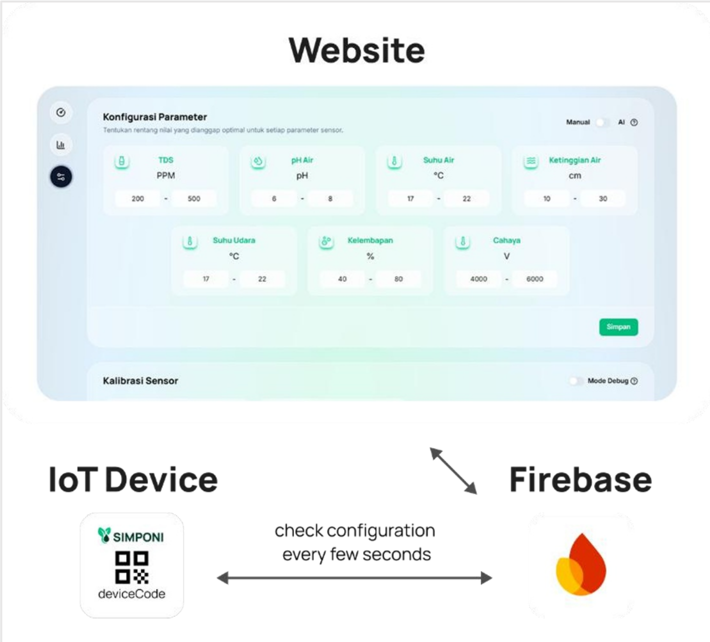


**Fig. 9.** Remote Configuration Concept.

Despite these functional successes, several limitations were observed. The system has not yet undergone formal user testing, and sensor accuracy particularly for pH and water level may degrade over time, requiring occasional user validation. While the dashboard supports parameter thresholds, no automated control logic has been implemented in the deployed version. However, preliminary experiments using relay modules, peristaltic pumps, and a solenoid valve confirmed the ESP32's ability to control actuators based on sensor input, indicating readiness for future automation integration.

Quantitative performance metrics such as power consumption, latency, or system uptime have yet to be evaluated. Additionally, while the architecture supports AI integration, no machine learning features have been developed at this stage. The structured dataset stored in Firestore lays the foundation for future capabilities, such as plant classification or decision support systems using labeled data.

## 5 Conclusion

Indoor hydroponic systems require precise and continuous monitoring of environmental parameters to maintain optimal plant health. SIMPONI has been developed as a web-integrated IoT-based platform designed specifically for such indoor hydroponic environments. By combining a microcontroller-based sensor node with cloud-based data storage and a responsive web dashboard, SIMPONI enables real-time observation of parameters such as pH, TDS, water temperature, air temperature and humidity, light intensity, and water level. Users are able to monitor trends over time, set custom threshold values, and remotely adjust calibration data all through a single integrated platform accessible from any device.

The system has been successfully deployed and tested in a controlled indoor environment using the Nutrient Film Technique (NFT) hydroponic method. Results show that SIMPONI provides reliable sensor readings and stable performance over time. Furthermore, the cloud-based calibration system offers a unique advantage, allowing remote adjustment without the need to reprogram the device an improvement over previous systems that required manual firmware updates for such tasks.

Although SIMPONI currently focuses on monitoring, its architecture is designed to accommodate future expansion. Preliminary hardware tests for control functions such as automated nutrient dosing using peristaltic pumps and solenoid valves have shown promising results, paving the way for automated response systems. As part of future work, the platform will be extended with control logic and machine learning models to enable predictive recommendations, anomaly detection, and autonomous decision-making. Additionally, user studies will be conducted to evaluate the usability and effectiveness of the platform in real-world scenarios, along with dataset enrichment to support AI model training.

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