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Agrilink: Design and Evaluation of an IoT-Based Smart Agriculture System for Plant Watering and Humidification

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ABSTRACT

Modern urban and small-scale agricultural practices often struggle with maintaining ideal plant growth conditions due to inconsistent care and inefficient water use. To address this issue, this study introduces Agrilink, an IoT-based automated plant watering and monitoring system designed to optimize plant care through real-time data collection and environmental control. The product utilizes ESP32 and ESP8266 microcontrollers integrated with various sensors—ultrasonic, soil moisture, and DHT22 temperature/humidity—to continuously monitor and manage the plant environment. The system comprises two primary components: a smart water control device that conserves water and a mist maker that sustains optimal humidity levels. Key data is displayed on a local LCD while a web dashboard provides users with convenient remote access and system insights. Testing revealed a 17.7% margin of error in humidity readings compared to commercial-grade sensors. Despite this limitation, Agrilink demonstrates significant potential for societal impact, especially in enhancing home gardening, supporting sustainable urban farming, and promoting efficient agricultural practices in water-scarce regions.

1. INTRODUCTION

The growing concerns over water scarcity and food security have accelerated the need for sustainable and intelligent agricultural practices. Among emerging solutions, IoT-based plant care systems are playing a crucial role in transforming traditional agriculture into efficient, resource-conscious ecosystems [1][2]. Smart Water Management for Agrilink: IoT Plant Watering and Monitoring System is designed to maintain an optimal plant-growing environment through real-time environmental monitoring, precision watering, and automation.

This work integrates ESP32 and ESP8266 microcontrollers with environmental sensors ultrasonic, soil moisture, and DHT22 (temperature and humidity) sensors to continuously assess plant needs [3][4]. The gathered data is used to intelligently control water usage and generate humidity via a mist maker, ensuring plants obtain the optimal conditions for healthy growth [5][6].

The system architecture includes two main components. The first is a smart humidifier that automatically activates the mist maker when humidity levels drop below 60%, thereby helping to maintain optimal humidity in the plant's microclimate. The second component is an auto-restoration water management system, which integrates an ultrasonic sensor and a water pump. The ultrasonic sensor continuously monitors the water level in the tank, identifying whether it is full (100%), half full (50%), low (20%), or empty (0%). When the water level drops to the low threshold, the system automatically triggers the water pump to refill the tank.

To enhance user interaction and monitoring, a local LCD display provides on-site feedback, while the web dashboard acquire remote access and control for ease of use and real-time alerts [7][8].

This system is particularly suited for home gardening, small-scale agriculture, and urban farming, where smart automation and efficient water usage are crucial [9][10]. Initial testing has shown that the Agrilink system successfully reduces

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water waste and supports healthier plant growth, demonstrating its potential for sustainable and scalable application [11][12].

The integration of dual microcontrollers-ESP32 and ESP8266 introduces a novel architecture that enhances the performance, efficiency, and scalability of IoT-based agricultural systems [13]. The ESP32 handles intensive tasks such as real-time sensor data processing and wireless communication, while the ESP8266 is delegated to low-power data acquisition [14]. This division of labour reduces latency and energy consumption compared to single-controller setups [15]. The ESP32's support for BLE and high-throughput Wi-Fi ensures robust connectivity, while the ESP8266 manages distributed sensor nodes in a hierarchical network [13]. Combined with power-saving features and support for ESP-NOW communication, this configuration enables modular expansion and reliable operation even in low-bandwidth making it well-suited for scalable smart farming applications [14]. Early studies of this work have been discussed in [16],[17],[18].

This paper is arranged as follows: Section I gives a brief introduction to the concept and purpose of the implementation Agrlink. Section II reviews related literature on existing technologies and methods in smart agriculture. Section III explains the methodology used in system development. Section IV presents the results and discussion. Finally, Section V concludes the paper and outlines potential future improvements.

2. LITERATURE REVIEW

This literature review presents a comprehensive analysis of recent innovations in IoT-based smart irrigation, sensor technologies, automated watering and misting systems, user interface designs, and practical applications in small-scale agriculture. It provides the theoretical and technical foundation for developing Agrilink.

2.1 Existing Products

Several smart plant watering systems were reviewed as shown in Table 1. The Xiaomi Mi Flora Monitor [19] offers Bluetooth-based monitoring but lacks automation watering features. Grobo Smart Garden [20] includes full automation but is costly and designed for indoor use. PlantLink provides moisture data but incompatible with irrigation control. These products show the need for an integrated, scalable, and affordable solution like Agrilink.

Table 1. Advantages and Disadvantages of existing product

Product	Advantages	Disadvantages
Xiaomi Monitor	Simple, Budget-friendly	Manual control, limited connectivity
Grobo Garden	All-in-one automation	High cost, indoor use
PlantLink	Soil monitoring with cloud integration	No irrigation control

2.2 IoT in Agriculture

IoT technologies enable real-time, data-driven decision-making in agriculture. Hemanth and Kumar (2023) describe how IoT supports precision farming and sustainability [21]. ESP32 and ESP8266 microcontrollers are commonly used for their connectivity and low power consumption [22], [23]. Studies demonstrate that these platforms support scalable, intelligent watering systems [24].

2.3 Sensor Technologies

Environmental monitoring is essential in smart agriculture. DHT22 sensors provide accurate humidity and temperature data [25]. Soil moisture sensors help prevent over- and under-watering [26], while ultrasonic sensors track tank water levels and enable automation [27], [28]. Combining these sensors enhances decision-making in irrigation systems.

2.4 Automated Water and Humidity Control

Sensor-based irrigation systems have been shown to outperform traditional time-based irrigation in terms of water conservation and plant health [29]. The integration of misting systems with humidity sensors allows the creation of favorable microclimates that support plant growth, particularly in controlled environments like greenhouses [30]. Studies show that such systems not only reduce water use but also improve yield quality [31]. Feedback mechanisms, particularly closed-loop systems, enhance the precision and reliability of these automated solutions [32].

2.5 User Interface: LCD and Web Dashboards

The integration of local LCDs and remote-access dashboards improves the usability of smart irrigation systems. LCDs offer immediate visual feedback, while dashboards allow users to monitor environmental data and control system settings remotely [33]. Dashboards that include data visualization and trend analysis further enhance decision-making for plant care [34]. The use of cloud storage for data tracking has also been beneficial for long-term analysis and system optimization [35].

2.6 Application in Urban and Small-Scale Agriculture

IoT systems find specialized uses in balcony gardening, city farming, and small-scale farming. Systems are ideally suited in the optimization of limited space and resources [36]. Not only do systems find great uses in the city, but they have also shown improved water usage efficiency as well as improved plant health in balcony and backyard systems [37]. These systems, because of their affordability as well as scale, are highly useful in developing countries too [38]. Intelligent systems are still being designed and calibrated for all types of agricultural use [39], from a hobby garden to a small-scale farm.

2.7 System Adaptation

Recent technological advancements in IoT-based farming systems indicate a clear direction towards integrated monitoring and control architectures. Agrilink is unique by integrating most of the innovations introduced in previous research with new adaptations for better scalability and accessibility. Kumar and Singh (2024) emphasize the importance of unified systems that merge sensor networks with actuation mechanisms, a principle central to Agrilink's dual-microcontroller design [40]. With the combination of ESP32 and ESP8266 modules, the system achieves robust real-time data processing along with low latency in environmental adjustment settings demonstrated by Ahmad and Chen (2023) in greenhouse-related applications [41].

The system's versatility in accommodating different environments for growth is a result of its modular integration of sensors. Nguyen and Lee (2022) attest to efficiency in employing such strategies in sustaining optimal conditions in both home gardens as well as in limited-scale greenhouses [42]. This ability is further extended by Agrilink in its auto-restoration water management system, which fills a pertinent deficit in available solutions by dynamically refilling reservoir levels from ultrasonic sensing information. This follows Borges and Alves (2024) research findings in economical component selection, which result in reliability at no added expense for affordability [43].

Cloud connectivity forms a second pillar of Agrilink's architecture, which allows real-time monitoring via user-friendly dashboards. Chien and Wang (2023) show that such functionality maximizes user engagement while offering relevant information toward sustained crop growth management [44]. By integrating these tenets, a balance in localized management and cloud-based reporting is established, especially in urban systems where space and resource limitations necessitate strategic overviews.

3. METHODOLOGY

A structured approach is used to develop Agrilink, as shown in Figure 1. Integration of software programming and hardware component and IoT connectivity is made to automate plant care. The ESP32 microcontroller is the main component for the system, which responsible for gathering all the data from multiple sensors such as DHT22 to measure temperature and humidity, HC-SR04 ultrasonic sensor to measure water level in the water tank, and YL-69 soil moisture sensor to measure soil moisture. Additionally, components such as LCD display are used to display the readings from each sensor while relay module is used to control the mist maker module and water pump. The mist maker used water from the tank to produce fine mist, maintaining ambient humidity. Programming is done using the Arduino IDE to enable efficient integration of hardware and software components. Furthermore, ThingsBoard is used as the cloud-based IoT dashboard platform for data monitoring and visualization as shown in Figure 2. All data from the sensor will be transmitted to the ThingsBoard cloud via Wi-fi.

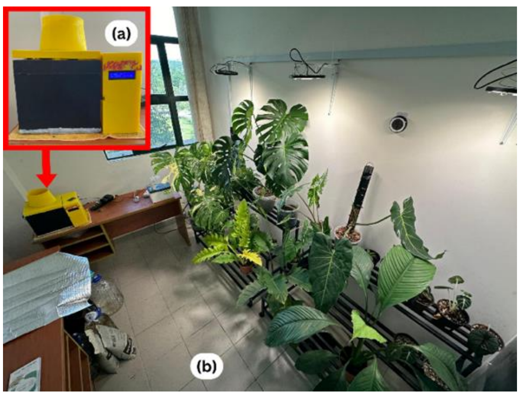

Fig. 1a. Agrilink ; **Fig. 1b**. Environmet Setup

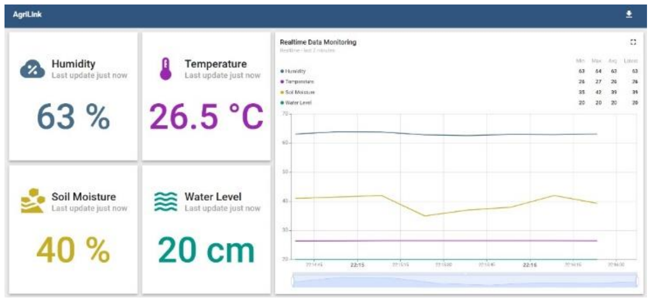

Fig. 2. Web Dashboard for Agrilink

Figure 3 indicates the system operates in a continuous loop, where the process starts with the initialization of all sensors. The sensors measure the environmental conditions and send the data to the microcontroller. The mist maker is activated when the humidity levels are insufficient to ensure optimal growing environment. The soil moisture sensor ensures that moisture in the soil is maintained in the predefined threshold. The ultrasonic ensures the water level in the water tank is maintained full by filling up the water tank automatically when the level is low. The power is supplied through the 12v adapter and 9v battery. The 9V battery provides backup power with an estimated battery life of approximately 3 hours, while the 12V adapter supplies continuous operation. This will ensure reliability especially during outages.

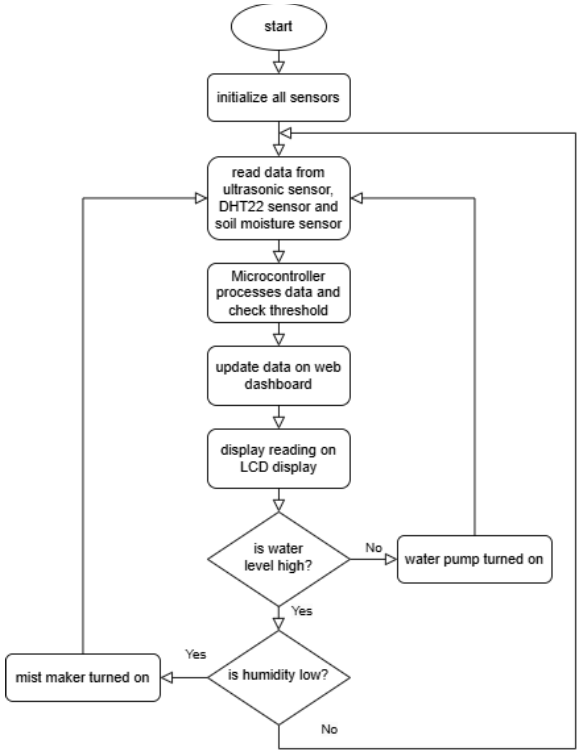

Fig. 3. System flowchart illustrating the sensor activation loop, which includes data reading, threshold checking, and automated control of the water pump and mist maker with continuous updates to the LCD display and dashboard**.**

A systematic approach is followed in the development process where it begins with hardware assembly and sensor calibration. Sensor and actuator communication with control logic are established through programming. Then, IoT integration allows for cloud data logging and web dashboard visualization for monitoring purpose and user convenience. The testing is made to observe the responsiveness of the system in a controlled environment to ensure humidity adjustment and accurate water usage.

4. RESULT AND DISCUSSION

Table 2. Result of the system's testing for 7 days

Day	Soil Moisture (%)	Humidity (RH%)	Water Level	Temperature (°C)
Day 1	15	49	Full	29
Day 2	49	49	Full	30
Day 3	51	49	Full	30
Day 4	50	49	Full	30
Day 5	15	58	Full	28
Day 6	49	45	Full	31
Day 7	15	44	Full	30

Table 3. Comparison of Humidity Readings and Error Margin for 7 days

Day	System Sensor Reading (%)	Commercial Sensor Reading (%)	Error Margin (%)
Day 1	49	56	12.50
Day 2	49	64	23.44
Day 3	49	60	18.33
Day 4	49	60	18.33
Day 5	58	66	12.12
Day 6	45	54	16.67
Day 7	44	57	22.81

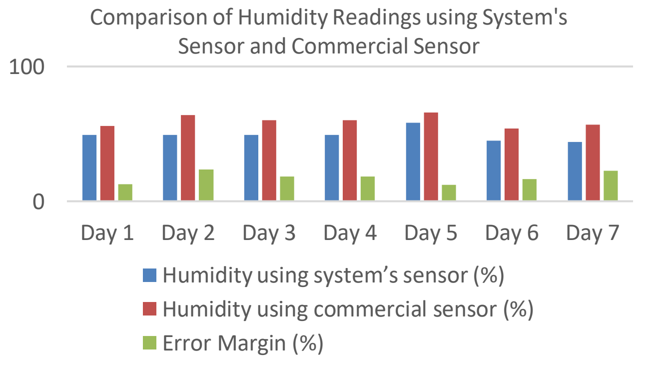

Fig. 4. Comparison of Humidity Readings using System's Sensor and Commercial Sensor for 7 days

The testing result as shown in Table 2 and Table 3 reveals the system's effectiveness in maintaining optimal plant condition where soil moisture is maintained between 15% to 50% while humidity levels are maintained between 49% RH to 58% RH. Water levels in water tank are kept full with the help of ultrasonic sensor which continuously measure water level.

The humidity readings acquire from the system's sensor and commercial's sensor testing result, as shown in Figure 4, demonstrates that the difference between the two are less than 11. The average difference between the readings is 10.571 which is relatively small and can be considered acceptable, indicating a reasonable level of precision. These differences are likely due to variations in sensor calibration, sensitivity and manufacturing quality. The commercial sensors typically factory-calibrated for higher precision, whereas the system's sensor may require manual calibration. Future improvement should be considered to minimize these disparities. This includes regular calibration, or upgrading to higher-precision sensors with improved accuracy

The mist maker maintains suitable humidity levels for plant growth. All readings from multiple sensors can be monitored through LCD display including humidity, water level, soil moisture and temperature. This system achieved water savings of approximately 25% through precise irrigation control compared to traditional plant care methods which often leads to water loss. Quantitative performance metrics indicate an error margin of 17.7% in sensor accuracy, and an average response lag time of 2 seconds. Tested on indoor plant such as *Monstera Deliciosa* and *Alocasia Frydek*, the system demonstrated its functionality as precise, affordable and user-friendly solutions which is useful especially for home gardening and small-scale farming. The objectives of this work to ensure optimal plant maintenance while conserving the water usage is achieved.

5. CONCLUSION

Smart Water Management for Agrilink system presents a functional IoT-based solution that automates plant watering and environmental monitoring. By integrating dual microcontrollers (ESP32, ESP8266), the system efficiently monitors irrigation and humidity levels through real-time readings of soil moisture, temperature, humidity, and ultrasonic sensors. This provides exact regulation of soil moisture as well as ambient humidity levels, which maximizes resources in small-scale farming environments.

The major differentiators of architecture involve a modularized design that differentiates humidification from irrigation functions, in addition to environmental sensing-based, closed-loop feedback. The system differs from most current systems in that it integrates mist generation with automated water level replenishment by tiered ultrasonic monitoring, thereby enabling autonomous operation with little manual intervention.

This system provides solutions to water efficiency and humidity control, in addition to giving users real-time feedback through LCD and internet-based dashboards. Test findings support the reliability of the system in having steady soil water, optimal humidity, and stable water tank levels. The findings support the potential of modular Internet of Things systems to make contributions to data-based, scale-ready agricultural practices in areas with limited resources as well as urban areas.

5.1 Future Scope

Future improvements for Agrilink may involve incorporating machine learning to enable Artificial Intelligence (AI) predictive control of irrigation based on environmental patterns. Additionally, utilizing solar energy systems could help minimize running costs while promoting eco-friendly operation. These developments would enhance system independence and contribute to more sustainable agricultural practices.

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