Autonomous System for the Health Care of Plants

Óscar A. Abaunza M.[a], Juan D. Ospino R.[a]

[a] *Aerospace Engineering, Universidad de Antioquia, Medellín, Colombia, 050010*

Abstract

Agriculture is increasingly adopting advanced technologies like robotics, sensors, and data analysis to enhance productivity, efficiency, and environmental sustainability. This project proposes the development of an autonomous system for plant health monitoring, integrating measurement, instrumentation, and control systems using the ESP32 microcontroller. The system will monitor key agricultural parameters such as soil moisture, ambient temperature, humidity, water levels, solar radiation, and soil nutrients through a variety of sensors. Data will be transmitted using MQTT protocol to a graphical user interface (GUI) for real-time monitoring and control. Actuators, including servomotors and water pumps, will automate tasks like irrigation, fertilizer deployment and solar panel positioning. The system is designed to provide alerts when critical conditions are detected. Structural components will be designed using CAD tools, and the framework will be evaluated for performance and durability. This project serves as a preliminary step towards fully automated farming systems, addressing the challenges of cost-effectiveness, scalability, and efficient resource management. Further exploration into artificial vision and alternative nutrient monitoring solutions is proposed to enhance system capabilities.

Keywords: Autonomous plant monitoring, precision agriculture, ESP32, MQTT, soil moisture sensors, IoT in agriculture, robotic farming, smart farming, environmental monitoring, sensor networks, agricultural automation, digital farming, plant health care, remote sensing.

1. Introduction

Today's agriculture increasingly incorporates sophisticated technologies such as robots, temperature and moisture sensors, aerial imaging, and GPS. These advanced tools, combined with precision agriculture (PA) and robotic systems, enable businesses to operate more profitably, efficiently, and safely, while also being more environmentally sustainable [1]. As a result, there is growing attention on the methods and devices used to operate these high-tech systems, which rely heavily on measurement, instrumentation, and control systems.

The impact of automation on industry is now a key focus in efforts to boost productivity. A greater reliance on industrial robots has been shown to significantly improve total factor productivity (TFP). Moreover, these advanced technologies are often associated with higher wages and either stable or increased employment levels [2].

Agriculture is traditionally a labor-intensive industry, requiring workers to constantly monitor and maintain the health of crops. This includes tasks such as irrigation, planting, monitoring soil moisture, detecting and preventing plant diseases, weed control, field scouting, and harvesting. However, with the advent of *digital farming*, many of these tasks can now be automated, making the process far more efficient. Digital farming refers to the use of modern technologies such as sensors, robotics, and data analytics to automate and optimize farming operations. Some of the key challenges in this field include object identification, task planning algorithms, and the digitalization and optimization of sensors. Additionally, using autonomous systems with simpler axis manipulators could be faster and more cost-effective than the expensive professional systems currently in use. Robots, in fact, are becoming indispensable in modern farms [3].

The goal of this project is to develop an autonomous system for plant health monitoring, serving as a preliminary step toward the application of high-tech industry processes in agriculture. The research will focus on measurement, instrumentation, and control theories to ensure a robust project development.

The primary objective is to use the ESP32 microcontroller, taking advantage of its capabilities as a development platform with WiFi communication. In the project, the MQTT protocol will be used to link sensor data with a graphical user interface (GUI) embedded in an interactive web application for analytics and visualization.

We aim to measure several key variables critical to precision agriculture [4, 5], including: temperature and humidity (for both soil and ambient conditions), water level (to monitor the water reservoir), solar light intensity (to optimize solar panel positioning), ambient air pollution (to monitor environmental conditions), soil nutrients (to capture specific soil data), and visual plant monitoring. Additionally, electromechanical devices such as servomotors and DC motors will act as actuators. The structure will be designed using CAD software to explore different materials and select the most suitable one.

This autonomous plant care system will include a mechanism for alerting the user when the plant's health reaches critical limits, ensuring timely intervention and optimal plant care.

2. Method's and Materials

2.1. Methods

In general terms, the methodology involves obtaining readings of soil, ambient, and water reservoir conditions. This data is transmitted to the microprocessor through sensors, which then sends the information to a GUI. Additionally, the microprocessor controls actuators to manage the desired variables or generate alerts when necessary. This framework enables efficient monitoring and control of the plant's health. In the following paragraphs, we explore different proposed methodologies:

Kumar et al. [6], in their work *"Smart Garden Monitoring and Control System with Sensor Technology"*, proposed a schematic, shown in Figure 1, which illustrates the logical process behind their proposal. This schematic effectively outlines the workflow and interactions between various system components, demonstrating how it facilitates the monitoring and control of essential parameters for optimal plant growth. This approach provides a clear framework for implementing smart gardening solutions.

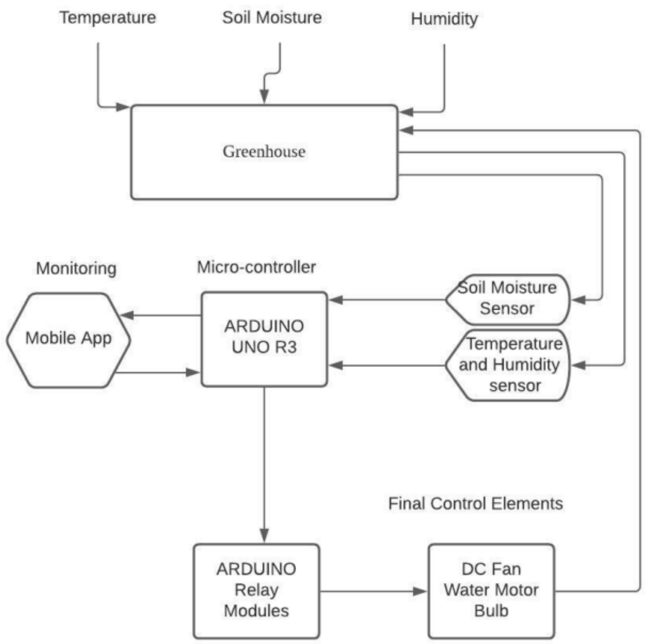

Figure 1: Block diagram of automated gardening control and monitoring using Arduino [6].

Shafi et al. [7], in their work *"Precision Agriculture Techniques and Practices: From Considerations to Applications"*, outlined various practices and techniques in the field of Internet of Things (IoT)-based automation of agricultural activities and Precision Agriculture (PA) using Wireless Sensor Networks (WSNs). They listed 23 different sensors to capture soil, plant, and ambient conditions, as well as 7 common wireless nodes used in the agricultural domain. They also provided 7 wireless communication protocols used in PA and delved into the application of spectral image-based remote sensing, which includes airborne, satellite, and Unmanned Aerial Vehicle (UAV)-based sensing. The techniques cover vegetation indices such as the Normalized Difference Vegetation Index (NDVI), Difference Vegetation Index (DVI), and Soil Adjusted

Vegetation Index (SAVI), among others.

Finally, they developed a complete solution for crop health monitoring based on IoT and remote sensing, designed according to two main modules. The first module consisted of a WSN-based system, in which multiple wireless nodes were developed and deployed across the field in a star topology. The master node collected readings from all slave nodes and transmitted the captured data to the back-end server for further processing. After initial processing, the master node transmitted the data to the cloud using Global System for Mobile (GSM) communication technology. The second module was used for monitoring crop health using multi-spectral imagery collected by a multi-spectral camera mounted on a drone. All data was sent to the cloud for further analysis. Multiple web services were provided on the web portal, including historical and real-time data visualization through graphs, weather monitoring, NDVI mapping, and correlation analysis among measured parameters. Figure 2 shows the architecture of this methodology.

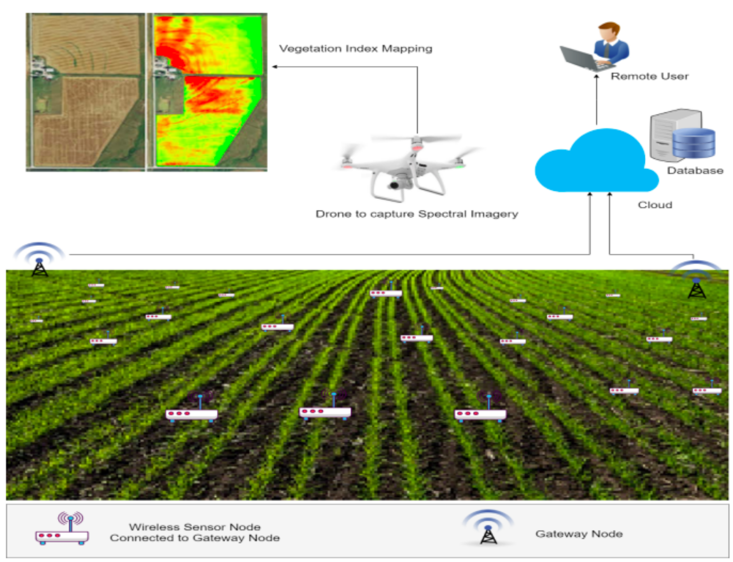

Figure 2: System architecture [7].

Narayana and Deepthi [8], in their work *"Real Time Automatization of Agri-*

culture Environment for Social Modernization Using ESP32 and Cloud Computing", introduced improvements to the agricultural system by incorporating IoT sensors capable of providing real-time information about agricultural fields. They utilized the ESP32 microcontroller with 5 measured variables: water level, humidity, temperature, soil moisture, and rain conditions. Communication was deployed via WiFi, and the data was transmitted to the cloud through Google Cloud Platforms using Firebase. The output was logged into a Google Sheets file in a data-logger format. Figure 3 presents a representation of this procedure.

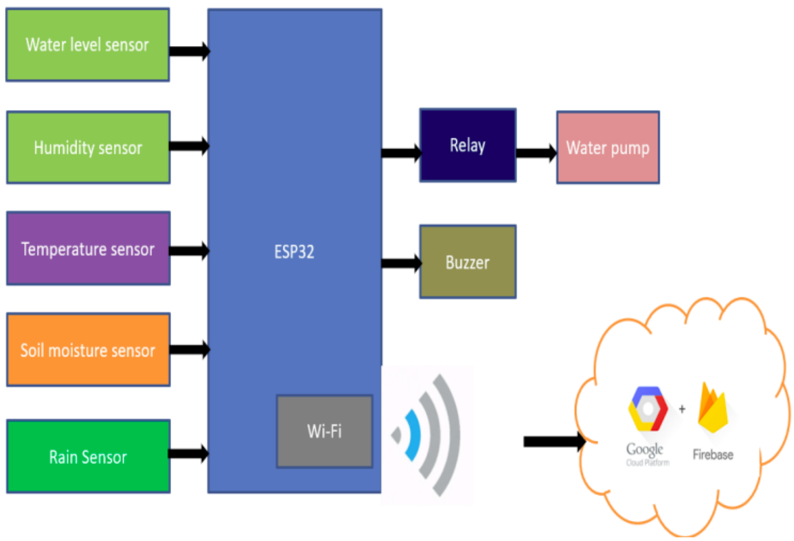

Figure 3: System architecture [8].

2.2. Materials

To develop this project, we identified the key components necessary for the control systems to function. These elements include the control unit, sensors, actuators, passive elements, energy reservoir, and auxiliary electronic devices.

1. **Microprocessor (ESP32):** Serves as the main component of the system, enabling data processing, sensor management, component control, and communication with external devices.

2. **Humidity sensor:** Measures the soil moisture levels to determine irrigation needs.
3. **Solar radiation sensor:** Detects sunlight intensity to optimize the positioning of the solar panel for efficient energy capture.
4. **Level sensor:** Measures the water level in the reservoir to monitor the availability of water for irrigation.
5. **Water pump:** Pumps water from the reservoir to the ground for irrigation when needed.
6. **Servomotor:** Acts as an actuator to adjust the solar panel's position based on solar radiation readings.
7. **LEDs:** Illuminate to signal specific alerts or notifications, providing visual feedback.
8. **Battery:** Powers the autonomous system, ensuring continuous operation.
9. **Solar panel:** Recharges the battery using solar energy.
10. **Water tank:** Stores water for the irrigation system, supplying the water pump.
11. **Motor driver:** An auxiliary device used to control the DC motor that powers the water pump.

3. Discussion

In this project, the selection of appropriate tools and technologies for both hardware and software plays a critical role in achieving effective monitoring and control. Initially, tools such as Grafana, Node-RED, mobile applications, and MATLAB were identified as essential components for the user interface (GUI), and these are currently under evaluation to select the most suitable platform. These tools provide flexibility and enable seamless data visualization, analysis, and control, which are crucial for user interaction with the autonomous system.

The choice of sensors is also a key factor in the system design. Proper sensor selection and configuration are essential for ensuring the accuracy of the system's feedback and responses. Future work will focus on determining which sensors best meet the requirements of the autonomous system.

Additionally, the placement of sensors, solar panels, batteries, and structural materials will be carefully defined. Strategic positioning is critical for optimal system performance, especially in terms of energy harvesting and sensor accuracy. The materials selected for the structure will need to provide durability and protection against environmental factors, while remaining cost-effective.

Given the high cost of NPK sensors for soil nutrient detection, alternative approaches will be explored. Identifying a more cost-effective solution could significantly reduce overall project costs without sacrificing the ability to monitor nutrient levels in the soil. This remains an area for future research and development. We are currently investigating the potential correlation between soil nutrient content and soil pH levels, suggesting that a pH sensor could be a viable alternative for this purpose.

Finally, the potential implementation of artificial vision was explored as an enhancement to the system. Incorporating a vision-based solution could allow for the detection of plant diseases and the assessment of vegetation health, providing a more comprehensive monitoring system. Further investigation is needed to assess the feasibility and effectiveness of integrating this technology into the current design.

4. Conclusions

This work represents the first of three phases in the final project submitted for the Measurement and Instrumentation course, in combination with the Flight Control course. We have outlined the fundamental concepts relevant to the research area. By implementing various methodologies and applying theories discussed in the course lectures, we have established a strong foundation for this project, justifying it as a robust and well-considered initiative for future research.

With the provided general context, highlighting the importance of the topic and the research objectives, along with the careful selection of sensors, devices, and materials, and an understanding of different methodologies, the team is now well-prepared for the next stages of development. The ultimate goal is to deliver a functional prototype of this technology by the third and final phase of the project.

References

[1] N. I. of Food, A. (NIFA), Agricultural technology, accessed: 2024-10-12 (2024).
URL https://www.nifa.usda.gov/topics/agriculture-technology

[2] L. Kromann, N. Malchow-Møller, J. R. Skaksen, A. Sørensen, Automation and productivity: a cross-country, cross-industry comparison, Industrial and Corporate Change 29 (2) (2020) 265–287. doi:10.1093/icc/dtz039.
URL https://doi.org/10.1093/icc/dtz039

[3] R. R. Shamshiri, C. Weltzien, I. A. Hameed, I. J. Yule, T. E. Grift, S. K. Balasundram, et al., Research and development in agricultural robotics: A perspective of digital farming, International Journal of Agricultural and Biological Engineering 11 (4) (2018) 1–14.

[4] L. Mancipe-Castro, R. Gutiérrez-Carvajal, Prediction of environment variables in precision agriculture using a sparse model as data fusion strategy, Information Processing in Agriculture 9 (2) (2022) 171–183. doi:https://doi.org/10.1016/j.inpa.2021.06.007.
URL https://www.sciencedirect.com/science/article/pii/S2214317321000561

[5] P. Singh, P. C. Pandey, G. P. Petropoulos, A. Pavlides, P. K. Srivastava, N. Koutsias, K. A. K. Deng, Y. Bao, 8 - hyperspectral remote sensing in precision agriculture: present status, challenges, and future trends, in: P. C. Pandey, P. K. Srivastava,

H. Balzter, B. Bhattacharya, G. P. Petropoulos (Eds.), Hyperspectral Remote Sensing, Earth Observation, Elsevier, 2020, pp. 121–146. doi:https://doi.org/10.1016/B978-0-08-102894-0.00009-7. URL https://www.sciencedirect.com/science/article/pii/B9780081028940000097

[6] V. Kumar, K. Ramya, J. Abishek, T. Arundhathy, B. Bhavvya, V. Gayathri, Smart garden monitoring and control system with sensor technology, department of Electrical and Electronic Engineering (2024). URL https://ieeexplore.ieee.org/abstract/document/9451788/figures#figures

[7] U. Shafi, R. Mumtaz, J. García-Nieto, S. A. Hassan, S. A. R. Zaidi, N. Iqbal, Precision agriculture techniques and practices: From considerations to applications, Sensors 19 (17) (2019). doi:10.3390/s19173796. URL https://www.mdpi.com/1424-8220/19/17/3796

[8] L. Narayana, B. Deepthi, Real time automatization of agriculture environment for social modernization using esp32 and cloud computing, International Research Journal of Engineering and Technology (IRJEdT) 4 (11), professor, Department of Electronics and Communication Engineering, KLM College of Engineering for Women & M.Tech Scholar, Department of Electronics and Communication Engineering, KLM College of Engineering for Women (November 2022).