Design and Construction of an ESP32-Based PPM Sensor in a Hydroponic System

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ABSTRACT

Hydroponics is a soil-less cultivation method that requires nutrient control. strict monitoring, especially the EC or PPM levels as indicators of solution quality. Manual use of TDS meters often results in inaccuracies, limited data historical, and does not allow for periodic monitoring. Literature review shows that implementation of the Internet of Things (IoT) through the ESP32 microcontroller equipped with Wi-Fi and Conductivity-based PPM sensor that has been calibrated using standard solution 1413 µS/cm and 2.76 mS/cm are able to improve measurement accuracy and monitoring stability. Through the Systematic Literature Review approach, it was found that the integration of PPM sensors, ESP32, and the MQTT protocol can provide real-time nutritional data, sending threshold notifications, as well as facilitating remote monitoring. The novelty of this study lies in the implementation of a low-cost monitoring system with real-time features. adapted for small-scale farming groups.

Keywords: Hydroponics, PPM, ESP32, IoT, Nutrient Monitoring

I. INTRODUCTION

Hydroponics is a soil-less cultivation technique that uses nutrient solutions as growing media for plants. This technique requires strict control of nutrients, especially the levels EC (Electrical Conductivity) or PPM is an indicator of the concentration of dissolved substances (Wulandari, 2022). The success of hydroponic cultivation is highly dependent on the stability of the soil. nutrients; excess nutrients can cause toxicity while nutrient deficiencies can causes stunted growth (Maharani, 2024). Problems such as the process of Nutrition monitoring is still manual using a TDS meter. This manual process causes several obstacles such as instability of accuracy due to human error factors. the existence of historical nutritional data, measurements are not carried out periodically and there is a lack of the ability to monitor conditions remotely.

The development of the Internet of Things (IoT) opens up opportunities for more automated monitoring. efficient. The ESP32 microcontroller is the main component that is widely used in IoT system development because it has a built-in Wi-Fi module and processing performance (Pristisia, 2025). PPM sensor based on electrical conductivity measurement (EC) works by reading the amount of electric current that can flow through the solution. This measurement is then converted to a PPM value using a conversion factor.sensor PPM yang berbasis pengukuran konduktivitas listrik (EC) bekerja dengan membaca besarnya arus listrik yang dapat mengalir melalui larutan. specific, depending on the type of nutrient solution. This sensor can be calibrated using a solution standards, such as 1413 µS/cm or 2.76 mS/cm. This two-point calibration can improve reading accuracy up to ±5%, making it suitable for small-scale hydroponic applications as well large (Tio et al., 2022).

Sensor reading data can be sent to the server via Wi-Fi using the protocol IoT communications. Among the various protocols, MQTT (Message Queuing Telemetry Transport) is the most efficient choice because it is light, fast, and stable in network conditions. which is not very strong. Gupta & Jana (2020) compare MQTT with HTTP and found that MQTT has lower latency and requires less bandwidth. much smaller, making it ideal for systems that transmit sensor data remotely continuous.

Based on the results of the literature review, the ESP32-based hydroponic nutrient monitoring system can designed by integrating PPM sensors, water level sensors, and Wi-Fi connections for send data to the IoT dashboard. The dashboard allows users to monitor real-time nutrient levels via mobile phone or computer. In addition, the system can be programmed to provide notification when PPM levels are below a certain threshold.

II. METHODOLOGHY

The methodology in this study was compiled using the Systematic Literature Review approach. (SLR), namely by tracing and analyzing various scientific sources related to PPM sensors, ESP32 microcontroller, as well as the application of IoT to hydroponic systems. The literature collected via Google Scholar, IEEE Xplore, and ScienceDirect with the keyword hydroponic monitoring, EC/ PPM sensors, ESP32, and IoT agriculture.

The sources selected should be relevant to the topic of hydroponic nutrient monitoring, as well as have academic credibility. Each literature is analyzed to obtain information regarding the principles sensor operation, measurement accuracy, calibration, ESP32 capabilities, and protocol performance Machine Translated by Google IoT communications. The analysis results are then synthesized into a conceptual design of the system. ESP32-based nutrient monitoring. This approach ensures that the system design based on the latest scientific findings and relevant to practical needs in the field.

III. RESULTS AND DISCUSSION

The results of the literature review show that monitoring nutrients in hydroponic systems is very important. influenced by the tool's ability to read PPM or EC values accurately and stably. Hydroponic plants require a nutrient solution with a certain concentration to support growth. growth, so that small changes in nutrient concentrations can have a direct impact on plant health (Pristisia, 2025). From the analysis of various studies, the PPM sensor Conductivity-based sensors have proven to be quite accurate when standard calibration is performed. EC sensors which was calibrated using standard solutions of 1413 µS/cm and 2.76 mS/cm was able to achieve reading accuracy with an error rate of less than ±5%. This finding supports that Even low-cost PPM sensors can be used in hydroponic applications, provided the process the calibration is done correctly (Yin et al., 2021).

In addition, the results of the study also show that the ESP32 is a very powerful device. Suitable for use as a control center for monitoring systems. ESP32 has the following advantages: Integrated Wi-Fi, fast processing, and low power consumption (Ardi et al., 2021). This capability makes it effective for transmitting sensor data in real-time without requires additional equipment. In terms of data delivery, literature proves that the MQTT protocol works faster. and stable compared to HTTP explains that MQTT is designed for IoT devices that send data periodically in small sizes, so as not to burden the network and able to maintain communication stability. This is very relevant to monitoring needs PPM that requires data updates every few seconds or minutes.

Based on all these findings, a system designed with a combination of sensors PPM, ESP32, and MQTT protocols can provide more accurate nutrient monitoring, stable, and can be accessed remotely.

The results of the study also show that this system has the potential to increase cultivation efficiency. hydroponics and reduce the risk of human error in measurements. Overall, This literature review supports that the design of an ESP32-based monitoring system is not not only technically feasible, but also appropriate for application on a farmer group scale.

IV. CONCLUSION AND NEWS

Based on the results of the literature review, the ESP32-based PPM sensor system was proven to be feasible and effective. Sensor PPM calibrated with standard solution is able to provide accurate readings, while the ESP32 provides stable Wi-Fi connectivity for data transmission. real-time. With the support of the lightweight and fast MQTT protocol, this system can displays nutrient levels and water conditions directly via the dashboard, so that makes it easier for farmers to maintain stable plant nutrition without manual measurements repeated.

The novelty of this design lies in the integration of a low-cost PPM sensor with the ESP32. which is focused on the needs of small-scale farming groups. This approach is not only increase the efficiency of hydroponic cultivation, but also provide practical and easy solutions operated for the local farming community.

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