A Low-Cost IoT-Driven Reuse of Condensate Water for Automated Plant Irrigation

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***Abstract*— In this undergraduate paper, we present the implementation of an automated irrigation system for low-cost household plants. The system leverages water collected from air conditioner condensation as its primary irrigation source, promoting sustainable water reuse. We used a moisture sensor inserted 5 cm into the soil, connected to an ESP32, which collects moisture data and sends it to a broker via the MQTT protocol. The aim of this article is to demonstrate the system's operation and its applications, benefits, and limitations. The analysis provides a clearer understanding of how emerging technologies can be used to optimize plant care, promoting efficiency in water resource usage, particularly through the repurposing of otherwise wasted condensate water.**

***Keywords*— ESP32, Moisture Sensor, Remote Monitoring, irrigation.**

I. Introduction

IoT has played an important role in domestic agriculture, enabling efficient monitoring of plant conditions [1]. In recent years, interest in low-cost solutions for home plant cultivation has grown exponentially [2]. With this increase, the need arises to adopt technologies that allow for remote monitoring of soil conditions. Efficient water management in irrigation is a relevant field within the IoT context, as optimizing this resource is essential for sustainable cultivation [3]. One innovative approach to improving sustainability involves utilizing condensate water from air conditioning systems as an irrigation source, which would otherwise go to waste. Recent research shows that the use of moisture sensors can reduce water waste and improve plant health [4].

Moisture sensors are widely used to monitor soil conditions in domestic environments [5]. However, integrating these sensors with microcontrollers such as the ESP32 has emerged as a promising alternative, enabling automated and affordable irrigation. The system uses water from air conditioner condensation as the irrigation source, promoting water conservation by reusing water that would otherwise be wasted.

The contribution of this work is the proposal of a system to automatically use the condensated water of air conditioners. In addition, the system sends messages about the proper irrigation to the user, the lack of messages can issue a warning to the owner of the plants preventing problems to the monitored plants.

In Section II, we discuss the importance of automated irrigation, the role of moisture sensors in monitoring soil conditions, and how using air conditioner condensation water can provide an eco-friendly solution. In Section III, we detail the implementation of the automated irrigation system prototype, including the configuration of the moisture sensor, integration with the ESP32, and adjustments made to allow the use of condensation water for irrigation. In Section IV, we present the test results and analyze the system's performance in collecting soil moisture data and utilizing the condensation water, in addition to discussing the challenges faced. In Section V, we conclude the work.

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II. Soil Moisture Detection Systems

A. Core Components and Technologies

The automated irrigation system utilizes a combination of efficient technologies for optimal performance. Soil moisture sensors, such as capacitive and resistive models, provide real-time data on the water content in soil, ensuring proper irrigation. These sensors require accurate calibration and consideration of factors like soil type and temperature for reliable readings.

The system employs the MQTT protocol, a lightweight messaging protocol, to facilitate real-time communication between devices with minimal bandwidth consumption. Despite requiring additional security measures such as authentication, MQTT is widely adopted due to its efficiency and flexibility in IoT applications.

The ESP32 microcontroller [6], known for its low cost and powerful features, integrates seamlessly with the sensors and facilitates IoT connectivity. Its Wi-Fi and Bluetooth capabilities make it a versatile choice for remote monitoring and automation. With dual-core processing and energy efficiency, the ESP32 is an ideal option for both beginner and professional developers.

To pump water, the system uses a submersible mini pump, operating within a 3-6V range, powered by two batteries. This compact pump is ideal for low-power applications and integrates well into IoT projects, ensuring efficient and reliable operation while conserving energy. Its small size and low power consumption make it an excellent match for portable and autonomous irrigation systems.

Fig. 1. Prototype of the automated irrigation system with a soil moisture sensor, ESP32, and condensation water for irrigation.

B. Eco-Friendly Solution: Using Air Conditioner Condensation Water

Using air conditioner condensation water for irrigation offers a sustainable solution to water waste. This water, which would typically be discarded, can be repurposed to irrigate plants, reducing the demand for freshwater. By capturing and filtering the condensation water, the system helps minimize environmental impact while providing a steady, eco-friendly source of water for irrigation.

III. The Implemented Methods

Figure 1 presents the implemented prototypes, namely the automated irrigation system that uses a soil moisture sensor, an ESP32 microcontroller for data collection, and software for remote monitoring. The sensor, positioned 5 cm into the soil, measures the moisture and sends this information to a broker via the MQTT protocol, allowing real-time monitoring of soil conditions. The irrigation system utilizes water directly sourced from the air conditioner drain pipe, providing a sustainable and eco-friendly water source for the plants.

For the irrigation system, a prototype was created using a soil moisture sensor that collects real-time moisture data. The sensor measures the soil's resistivity to determine the amount of water present, allowing for accurate analysis of plants' water needs. The MQTT protocol [7] was chosen to send information about soil moisture, ensuring efficient communication with low energy consumption. The irrigation water is sourced directly from the air conditioner drain pipe, allowing for a continuous and eco-friendly solution.

Each sensor, positioned in different pots, sends messages to the broker whenever moisture reaches a critical level, enabling the automatic activation of irrigation systems. The Python-developed software captures MQTT messages and provides a graphical interface for real-time visualization of moisture levels, helping users monitor and manage the irrigation system effectively.

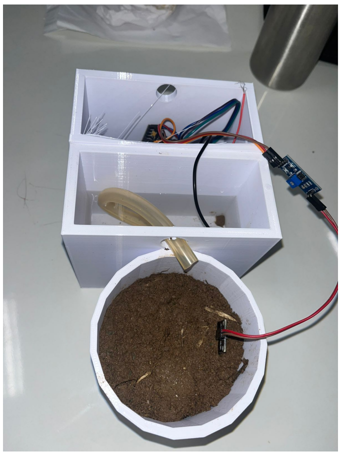

Fig. 2. Water reuse system prototype.

IV. Analysis of Results

The prototype using the soil moisture sensor demonstrated effectiveness in monitoring water conditions in both indoor and outdoor environments [8]. Accurate readings were ensured by installing the sensor at a 5 cm depth, chosen to avoid surface moisture interference and optimize sensor performance.

The integration of a 3D-printed plant pot with a water storage compartment, filled directly by air conditioner condensation, and an automatic watering system proved functional [9]. The motor efficiently pumped water based on real-time data from the sensor, enabling autonomous irrigation.

MQTT communication allowed remote monitoring of soil conditions and system status, promoting better water use. The ESP32 microcontroller connected all components, ensuring fast response and adaptability. A Python software interface displayed moisture data and allowed system control, improving usability.

Sensor calibration remained essential, as factors like soil compaction and composition influenced readings. Regular recalibration improved reliability. The system's modularity and IoT integration enable future expansion for broader plant care applications, supporting sustainability in various settings.

V. Conclusion

In summary, the implementation of a low-cost automated irrigation system for domestic plants offers several advantages, such as water use efficiency and ease of remote monitoring. Integrating a 3D-printed plant pot with a dedicated water storage compartment allows for sustainable water use. The automatic watering system, powered by a motor, ensures efficiency and simplicity. Choosing the moisture sensor and ESP32 microcontroller is key to seamless integration and control.

Real-time data transmission via MQTT enables practical management of soil conditions, allowing users to monitor and optimize irrigation remotely. This also provides insights into plant health, helping to prevent improper watering.

Proper calibration, installation, and motor control are crucial for accurate operation. The motor's specifications meet system needs while ensuring reliability and efficiency over time.

Looking ahead, adding more IoT features could enhance the system further. Automated watering schedules based on plant needs would increase efficiency and support the development of a fully autonomous irrigation solution. The system could also monitor the level of water in the storage compartment.

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