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Enhancing Precision Irrigation with IoT-enabled Water Management Mobile App

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Abstract: The increasing demand for food supply and efficient water use requires intelligent methods that can ensure a consistent water supply for crop production, even during arid seasons. Precision irrigation can be valuable in ensuring efficient water management, subsequently leads to continuous water availability for crop production. This paper presents a model of an Internet of Things (IoT) device that uses precision technologies to improve water utilization. The developed system consists of hardware and software components integrated with a mobile app that allows remote monitoring of soil water levels to determine when irrigation is required. The key components of this system include the ESP8266 Arduino microcontroller board, soil moisture and temperature sensors, a DC mini water pump, and a relay module. The sensors continuously measure soil moisture and temperature, and the data is transmitted to the ESP8266 microcontroller for real-time processing, enabling precise and data-driven crop management. The ESP8266 microcontroller ensures seamless communication between the sensors and the user interface. Through a highly ergonomic mobile app, users can access real-time data on soil moisture and temperature, providing valuable insights into environmental conditions. The DC mini water pump adjusts based on soil conditions, optimizing water use to maintain ideal moisture levels for healthy plant growth. Ultimately, the data obtained is used to train a machine learning algorithm that enhances the decision process for the irrigation system, with an accuracy of 98.08%.

I Introduction

Agriculture plays a crucial role in sustaining the livelihoods of millions of individuals globally by providing essential resources such as food, fibre, fuel, and fodder. Moreover, it serves as a foundation for various non-agricultural sectors, contributing significantly to poverty alleviation and sustainable development (FAO, 2014). The world's escalating population necessitates a corresponding increase in food production, which intensifies pressure on water resources given that approximately 70% of global freshwater withdrawals are for irrigation purposes (Schilling et al., 2020). Projections indicate that by 2050, the demand for irrigation water will surge by 50%, underscoring the urgent need for investments in efficient irrigation systems and technologies for rainwater harvesting (Jaramillo, 2022). In Nigeria for instance with over 200 million inhabitants, there is an ongoing case of large-scale food scarcity as a result of limited food supply. Farmers majorly depend on the rainfall during the rainy season for crop cultivation as there is no established artificial irrigation systems compared to other countries. The study by Aiyedogbon et al., (2022) evaluated the correlation between population growth and food security in Nigeria, revealing that while population growth negatively affects agriculture output, increased investment in the agriculture sector and the implementation of family planning policies could mitigate food insecurity challenges. According to United Nation Children's Fund (UNICEF) in a study posited that over 23 million Nigerians are the risk of hunger (UNICEF, 2023).

Water stands as a precious asset in agricultural activities, thus essential for effective irrigation techniques in achieving sustainable crop production (Knox et al., 2012). Effective water management is crucial for irrigation, particularly due to the global concern over dwindling clean water resources, necessitating careful attention from agricultural and other industries. It entails managing soil moisture to ensure the timely and optimal application of water. Conventional irrigation practices often lead to excessive water consumption and environmental harm. Recently, there has been a rising interest in leveraging the capabilities of the Internet of Things (IoT) to enhance irrigation scheduling and mitigate water wastage (Obaideen et al., 2022). Previous studies have depicted that various factors, such as water demand from different sectors and the impact of temperature increases on hydrological resources, can have an influence on water management. Climate change and its consequences are often the subject of discussion in research papers on water resources and agriculture. The potential impacts of global warming have led to the consideration of implementing water adaptation measures to ensure the availability of water for food production, human consumption, and the preservation of ecosystems (Iglesias et al., 2018).

IoT consists of network of physical devices, vehicles, structures, and items furnished with sensors, software, and connectivity that facilitates the collection and exchange of data via the internet. Its primary objective is to establish a more interconnected and efficient environment where devices can interact, enhancing operations, automating functions, and offering valuable insights (Udo et al., 2021). An IoT-based irrigation system optimizes watering cycles by delivering water precisely when and where it is required, thereby eradicating wastage and enhancing operational efficiency (Rafiq, 2018). Furthermore, such a system holds the capacity to curtail water usage. Creating an IoT irrigation system with a mobile application necessitates a cumulations of both hardware and software elements. While software assumes a critical role in mobile applications, hardware components like sensors, controllers, and communication devices are equally indispensable (Thilakarathne et al., 2021).

Deployment of an IoT irrigation system integrated with a mobile app has the potential to improve the agriculture sector by offering an intelligent and efficient approach to irrigation management. However, the high costs associated with commercial sensors have traditionally hindered smaller farmers from adopting advanced irrigation monitoring systems (Rajak et al., 2023). Hence, there is a growing trend among manufacturers to offer affordable sensors that can integrate with nodes, enabling the development of cost-effective solutions for irrigation management and agricultural monitoring. This proposed system utilizes real-time data acquisition and machine learning algorithms to optimize watering schedules and water consumption, thereby enhancing agricultural yields and minimizing water wastage. Therefore, the paper proposes a method of enhancing water management through the use of IoT devices and reducing accessibility costs by providing a mobile app for monitoring responses from the IoT device. The utilization of a mobile app empowers farmers to remotely access and manage their farms, offering convenience and flexibility. This feature allows farmers to make necessary adjustments without the need for physical site visits, thereby saving time and boosting productivity.

In general, this paper leverages the available low-cost efficient sensors to develop a user-friendly precision irrigation system with easy accessibility to farmers for water management. The developed system uses temperature, soil moisture, humidity, and weather forecast data to take intelligent decisions to automate irrigation. The decision to activate the water pump is taken using a machine learning algorithm (ML) trained on the data obtained from the devices.

The solution integrates various components to optimize and automate the irrigation process. In order to increase water efficiency and crop yield, it integrates IoT sensors, data analysis procedures, remote control, and automation. To collect real-time data on environmental factors such as soil moisture, temperature, humidity, and rainfall, the system uses IoT sensors that are carefully positioned in the field or garden. These sensors wirelessly transfer the data they have gathered to a gateway device or central control unit while continuously monitoring the environment (Chew et al., 2020). Communication between the sensors and the mobile app is made possible by the control unit, which serves as the system's hub. Following the pressing need optimize and improve water usability, several researches have been executed in the past. Alomar & Alazzam, (2018) introduce a novel smart irrigation approach utilizing IoT and fuzzy logic control. Their system automates irrigation based on real-time environmental data, collected through sensors measuring soil moisture, temperature, humidity, and online weather sources. A fuzzy logic controller processes this data to optimize watering schedules for crops. The work by Karthikamani & Rajaguru (2021) utilizes Raspberry Pi and moisture sensors to optimize watering based on soil moisture levels. Raspberry Pi serves as the core controller, receiving real-time soil moisture data from sensors. Using Python software, Raspberry Pi determines the best irrigation schedule for crops. Hardware components include a Wi-Fi module, while a mobile app enables remote control and monitoring. Kanade & Prasad (2021) have devised an intelligently automated irrigation system that integrates Arduino-based hardware, machine learning, and IoT technology. The utilization of Arduino as the system's core enables effortless integration with diverse sensors and actuators. Through the application of machine learning algorithms, the system meticulously analyses sensor data, including soil moisture, temperature, and humidity, to optimize irrigation schedules and minimize water consumption. Additionally, the system leverages IoT capabilities for remote monitoring and control. This seamless integration of Arduino, machine learning, and IoT underscores the potential for developing intelligent irrigation systems that enhance crop yield, automate irrigation processes, and promote resource conservation.

While the forgoing methods advances research in this domain, our proposed method is enhanced with improved ML algorithms, sensors modules, water pumping device and highly user-friendly mobile app. The mobile app is built such that tech knowledge is not required for its operation.

II. Methodology

The method adopted in this paper involves the system conceptualization, system design, hardware construction, software integration and testing and deployment and evaluation. In the initial phase, a detailed analytical approach is taken to conceptualize the functionalities expected from the system such as improving the precise water usage in a farm by optimizing the irrigation procedure. The next phase includes the system design including, the definition of the system architecture using block diagram incorporating the hardware and software components and the communication protocols. This proposal used the Wireless Fidelity (WiFi) protocol to facilitate the communication between the mobile app and the control unit. The sensors to be utilized as well as their specification are evaluated. We use Proteus Software to design the circuit diagram and simulate the proposed model, then proceed to construct the physical device. Finally, we develop the software that controls the functionality of the hardware, mobile app and integrate the two systems. The data obtained is used to train a decision tree regression model to predict when irrigation would be required based on the input data as depicted on Figure 1. The brief description of the various components used to achieve the proposed IoT device is described.

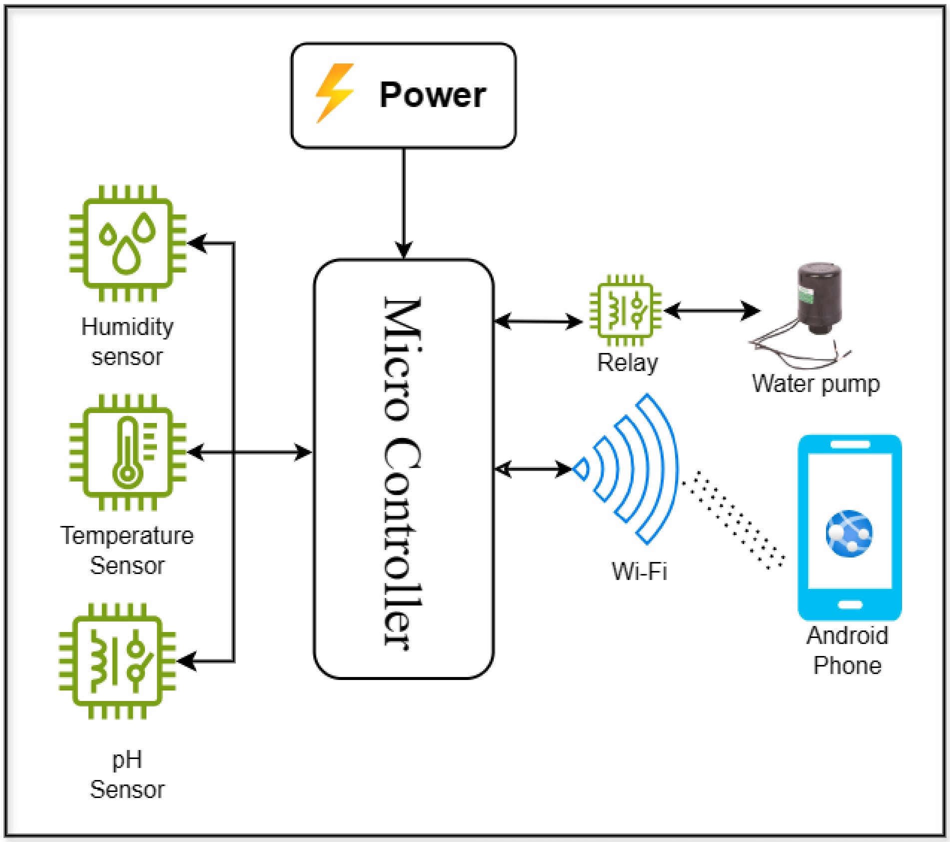

Figure 1: Block diagram for the proposed systems

Esp8266 Microcontroller board: The ESP8266 features a range of built-in peripherals, including GPIO (General Purpose Input/Output) pins, SPI (Serial Peripheral Interface), I2C (Inter-Integrated

Circuit), UART (Universal Asynchronous Receiver-Transmitter), and ADC (Analog-to-Digital Converter). These peripherals provide flexibility for interfacing with sensors, actuators, displays, and other external devices. It 32-bit LX106 RISC microprocessor with an adjustable clock frequency range of 80 MHz to 160 MHz and supports RTOS. To store data and programs, the NodeMCU hosting 4MB of Flash memory and 128 KB of RAM is used. Also, it provides built-in Wi-Fi connectivity, eliminating the need for third party WiFi module before the chip can connect and interact with other devices. The ESP8266 microcontroller chip stands out due to its affordability, compact size, low power consumption, extensive community support and documentation, and compatibility with the Arduino development environment, making it an ideal choice for budget-conscious projects, space-constrained devices, battery-powered applications, and IoT development with simplified prototyping capabilities.

Figure 3: Esp8266 Development Board

Soil Moisture Sensor: To measure the volumetric water content of the soil, we utilize a soil moisture sensor, a crucial tool for monitoring soil moisture levels in gardening systems. This sensor enables us to detect the moisture content within the irrigation field accurately, with a dedicated module for precise measurement analysis, allowing us to establish a reference standard for assessment.

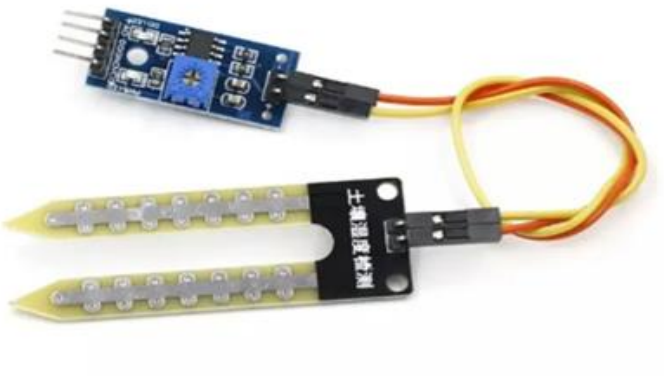

Figure 2: Soil Moisture Sensor

Temperature Sensor: This device is used to measure temperature in various environments by detecting changes in temperature and converting them into an electrical signal that can be interpreted by a microcontroller or other electronic device. In this paper, the sensor provides real-time temperature data, enabling monitoring and control of environment thereby optimizing irrigation practices, conserving water, protecting crops from environmental stressors, and maintaining the integrity of the irrigation system. The LM35 is a precision temperature sensor that provides accurate temperature measurements with a linear output voltage proportional to the temperature being measured. Key features include high accuracy, a wide temperature range, low power consumption, pre-calibrated output, and ease of use.

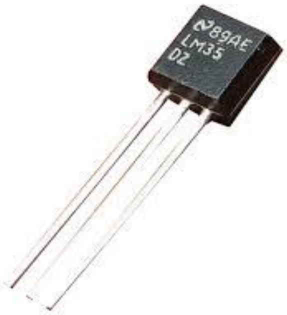

Figure 3: Temperature Sensor

DC Water Pump: A DC water pump is a device that moves or pressurizes fluids. The coil and commutator rotate when the water pump is operating, but the magnetic steel and carbon brushes are stationary. The commutator and brushes that revolve with the motor change the direction of the alternating current flowing through the coil. When the system detects that the soil is dry, the DC pump will be employed to pump water for irrigation of the soil.

Figure 4: DC Water Pump

Relay Module: Relay modules are circuit boards with one or more relays on them. They come in a range of sizes and shapes, but are most frequently rectangular and have 2, 4, or 8, or even up to

16 relays placed on them. Other parts are included in relay modules in addition to the relay unit. These consist of components such as safety diodes, transistors, resistors, and indicator LEDs. A 5V power supply is a device that provides a constant voltage of 5 volts to power electronic circuits, devices, and appliances that require 5 volts power to run effectively. The 5volts power module is often a design of a voltage regulator, capacitor resistor, indicator LED, and connection ports.

System Design and Integration

In this phase, we begin by conducting simulations using Proteus software to validate our design. Subsequently, we proceed to the hardware construction phase by following the flowchart depicted in Figure 3. The circuit diagram, simulated in Proteus software, is presented in Figure 2. Within the hardware setup, the sensors are interfaced with the ESP8266 Arduino Microcontroller, which functions as the central processing unit. This microcontroller is responsible for receiving, processing, and transmitting data collected from the sensors to the mobile application via Wi-Fi communication. This communication infrastructure ensures smooth data transfer and enables real-time monitoring and control of the irrigation system through the mobile app interface.

Furthermore, the integration of the ESP8266 microcontroller with the sensors and Wi-Fi module forms the foundation of the IoT-enabled irrigation system. This promotes intelligent decision-making and efficient management of water resources in agricultural environments.

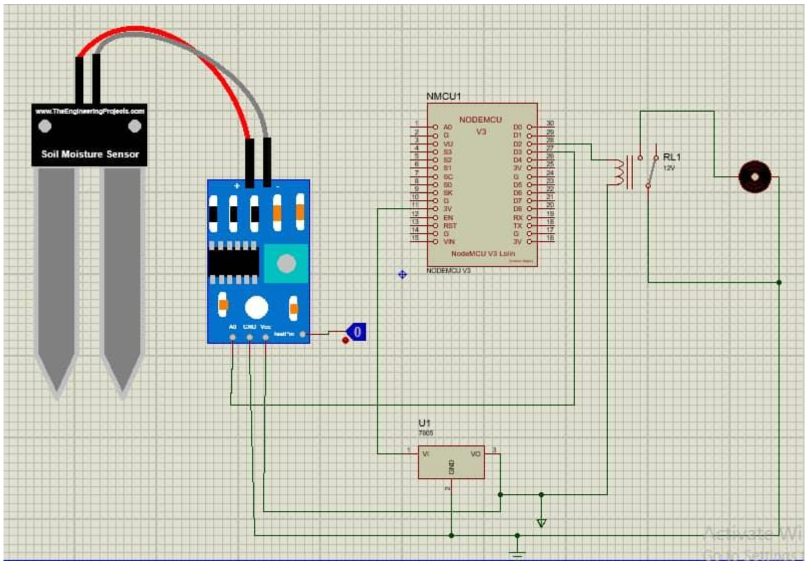

Figure 2: Circuit diagram of the proposed system showing the hardware interfacing with the Arduino board.

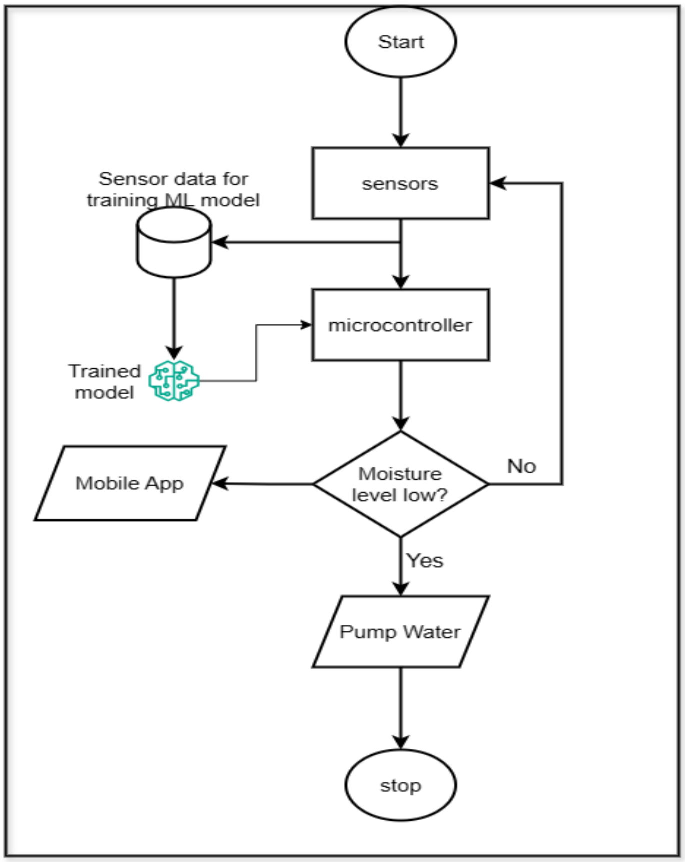

Figure 3: Flowchart representation of the system model process

Simultaneously, in the implementation phase, the Arduino ESP8266 microcontroller is programmed in C++ to define the rules behind the decision-making process. In other words, the high-level language designs the algorithm with the rules guiding how the microcontroller interprets sensor data, evaluates security measures, and performs actions based on the environmental information regarded, by quickly analysing the real-time data to execute an operating function of the irrigation system. Furthermore, a mobile application simultaneously communicates with the Arduino microcontroller through a Wi-Fi interface.

Machine Learning on the Collected Historical Data

To enhance the capabilities and adaptability of the proposed irrigation system, ML model is integrated. Specifically, a decision tree regressor (DTR) is adopted as the ML algorithm. The DTR algorithm is well-suited for handling non-linear relationships and complex decision-making processes. The ML is integrated to improve its ability to predict optimal irrigation scheduling and water management strategies. The historical sensor data collected from the irrigation system is processed by removing irrelevant inputs. This data includes various environmental parameters such as soil moisture levels, temperature and humidity. The DTR model learns to identify patterns and correlations that affect irrigation requirements and crop growth dynamics using the data. It works alongside the ESP8266 Arduino Microcontroller and the mobile application, receiving real-time sensor data inputs and generating predictive outputs for irrigation scheduling. The model's predictions are then transmitted to the mobile app, where users can visualize and act upon the recommended irrigation schedules.

III. Result and Discussion

The developed system is shown in Figure 4 consisting of the completed and coupled circuit, soil for monitoring the moisture and a water container for providing irrigation services. Initially, the soil moisture is obtained for a normal soil condition. Based on this, a threshold value is set for when the water pump should be activated to perform the irrigation. However, this threshold is used as a benchmark to define the target variable used for training the DTR model. Also, the readings obtained from the IoT system as shown on the mobile App is shown on Figure 4 consisting of the latest 20 readings from the device.

Last reading: 2023-11-05 07:15:05

View Latest 20 Readings

ID	Sensor	Location	Temperature	Moisture	Timestamp
1179	Tem/Moisture	Farm	28.06	4.00	2023-11-05 07:15:05
1178	Tem/Moisture	Farm	28.19	2.00	2023-11-05 07:15:02
1177	Tem/Moisture	Farm	28.13	1.00	2023-11-05 07:14:59
1176	Tem/Moisture	Farm	28.00	2.00	2023-11-05 07:14:57
1175	Tem/Moisture	Farm	27.88	1.00	2023-11-05 07:14:54
1174	Tem/Moisture	Farm	26.19	1.00	2023-11-05 07:14:50
1173	Tem/Moisture	Farm	26.00	1.00	2023-11-05 07:14:48
1172	Tem/Moisture	Farm	25.94	5.00	2023-11-05 07:14:45
1171	Tem/Moisture	Farm	25.81	1.00	2023-11-05 07:14:42
1170	Tem/Moisture	Farm	25.75	2.00	2023-11-05 07:14:40

Figure 4: Developed system and the data obtained as displayed on the Mobile App

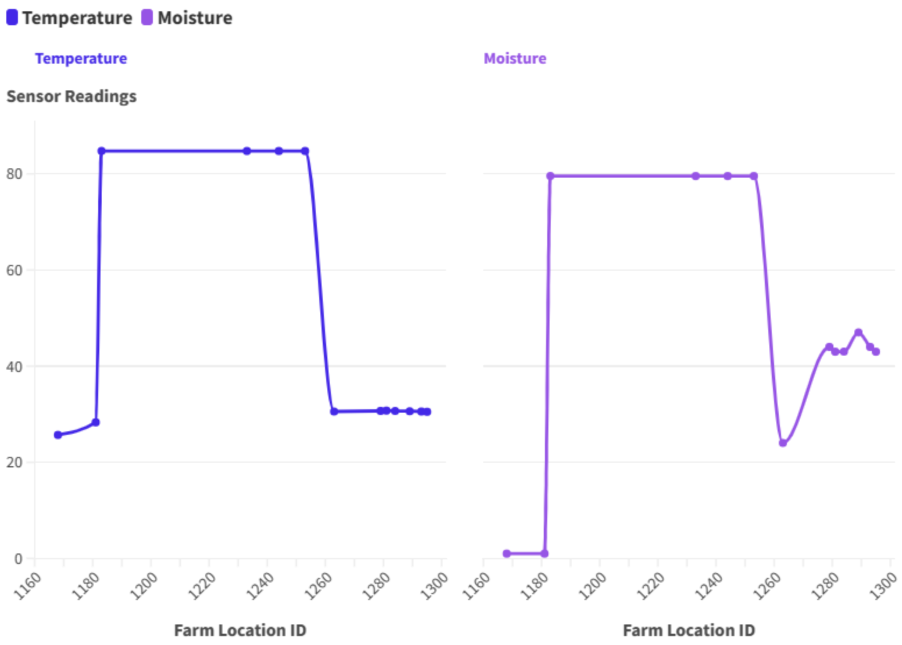

Figure 5: Distribution of the Temperature and Moisture measurements according to farm location

Figure 4 presents real-time data from the irrigation system, showcasing the latest sensor readings alongside their corresponding timestamps. Each row in the figure denotes a single sensor reading, with the ID serving as a unique identifier for the reading. The "Sensor" column indicates the type of sensor employed, which includes temperature and moisture, situated at a farm location. Temperature readings are recorded in degrees Celsius, while soil moisture levels are expressed as a percentage, representing the ratio of water volume to total soil volume. Timestamps denote the date and time of each reading acquisition. The fluctuation in temperature, as depicted in Figure 5, directly impacts the soil's moisture content, thereby influencing the necessity for irrigation.

IV. Conclusion

This paper outlines an efficient method that combines hardware, software, data, and user interaction for efficient irrigation management, thereby addressing water resource management challenges. Soil moisture and temperature sensors collect critical data about soil conditions, ESP8266 microcontroller analyzes sensor data and manages irrigation autonomously with aided intelligence from ML model, while continuous power is provided through 5-volt DC power module and 12-volt battery. The mobile app provides real-time monitoring of soil moisture and temperature data which optimizes water usage and ensures plants receive the precise amount of water. This data-driven approach enhanced the system's efficiency, user-friendliness, and resource management, potentially resulting in healthier plant growth and increased agricultural productivity. The integration of the DTR model adds an intelligent layer to the irrigation system, enabling it to dynamically adapt to changing environmental conditions and optimize water usage efficiency. Through the use of ML techniques, the system can anticipate irrigation needs more accurately, resulting in improved crop yields and resource conservation.

As a future work, exploring of advanced machine learning techniques and incorporating additional sensors for improved environmental monitoring can help to enhance the performance of the system.

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