IOT-ENABLED SMART IRRIGATION MANAGEMENT AND MONITORING SYSTEM SEAMLESSLY INTEGRATED INTO MOBILE DEVICES

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Abstract

This research focuses on the development and implementation of a sensor-based system for monitoring and controlling environmental conditions in a specific context (please provide context if available). The system consists of six layers that facilitate the communication of sensor readings from the field to mobile and cloud interfaces, enabling authorized users to access and control the system. The first and second layers incorporate temperature and moisture sensors, respectively, to sense the temperature of the surrounding environment and the moisture content of the soil. The data collected by these sensors is then transmitted to a local computer through a sink node comprising a microcontroller and Raspberry Pi. Zigbee technology is utilized for communication between the local computer and the cloud, where the uploaded data can be visualized through a mobile application. The fifth and sixth layers are responsible for maintaining the cloud and initiating actuator operations based on sensor readings. The system's autonomy eliminates the need for constant supervision, as it automatically analyzes the sensor readings and makes decisions regarding actuator operations, such as irrigation based on temperature and moisture levels. A prototype system was developed and tested to validate the proposed concepts, demonstrating accurate sensor readings and appropriate actuator responses. The research contributes to the field of sensor-based environmental monitoring and control systems by providing a practical framework for data communication, decision-making, and actuator control. The system's autonomous operation offers potential benefits such as improved resource management, increased efficiency, and enhanced productivity in the monitored context. The findings from this research serve as a foundation for further advancements and applications in sensor-based systems, paving the way for precision agriculture, smart cities, and industrial automation.

Keywords: IoT, Automation, Smart irrigation, Cloud technology

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1. Introduction

The field of sensor-based systems for environmental monitoring and control has witnessed significant advancements in recent years. This literature review aims to provide a comprehensive overview of the existing research in this domain, highlighting the key concepts, methodologies, and findings. By synthesizing and analyzing the relevant literature, this review aims to identify the gaps and opportunities for further investigation in the development and implementation of sensor-based systems [1]. One crucial aspect of sensor-based systems is the selection and deployment of appropriate sensor technologies for environmental monitoring. Various types of sensors have been utilized in different applications, such as temperature sensors for measuring ambient temperature and soil temperature, and moisture sensors for determining soil moisture content [2], [3]. These sensors play a vital role in capturing accurate data regarding the environmental conditions. Furthermore, advancements in wireless sensor networks and IoT platforms have enabled the seamless integration and transmission of sensor data for analysis and decision-making. Efficient communication between sensors, local devices, and cloud platforms is essential for the successful operation of sensor-based systems. Communication protocols and interfaces play a crucial role in enabling data transmission and integration. Popular protocols such as Zigbee, Wi-Fi, and Bluetooth have been widely adopted for their reliability, power efficiency, and scalability [4]–[6]. These protocols facilitate the seamless transfer of sensor data to local devices and cloud platforms for further processing and analysis. Mobile applications also serve as user-friendly interfaces for data visualization and control, providing users with convenient access to real-time information.

Sensor-based systems rely on intelligent decision-making and control mechanisms to autonomously respond to environmental conditions. Through the analysis of sensor data, these systems can make informed decisions regarding actuator operations [7], [8]. Actuators, such as irrigation systems, can be controlled based on sensor readings to optimize resource utilization and ensure optimal environmental conditions for the monitored system. Various algorithms and techniques, such as machine learning and fuzzy logic, have been applied to develop intelligent decision-making models in sensor-based systems. These models enable the system to adapt and respond dynamically to changing environmental conditions [9], [10]. The implementation of sensor-based systems has found applications in various fields, including precision agriculture, smart cities, and industrial automation [11], [12]. In precision agriculture, sensor-based systems assist in optimizing irrigation schedules, monitoring crop health, and maximizing yield. Smart cities leverage these systems to monitor air quality, noise levels, and traffic congestion, enabling efficient urban management. In industrial automation, sensor-based systems play a vital role in monitoring and controlling parameters such as temperature, pressure, and humidity in manufacturing processes [13]–[15]. While sensor-based systems have demonstrated significant potential, several challenges persist. These include power management, data security, sensor calibration, and system scalability. Future research should focus on addressing these challenges and developing more robust and efficient sensor-based systems. Furthermore, advancements in sensor technologies, communication protocols, and data analytics techniques hold promise for the development of more sophisticated and intelligent systems [16], [17].

2. Methodology

The methodology of the proposed system involves the use of temperature and moisture sensors to monitor the temperature and moisture levels in an agriculture field. These sensors communicate their readings to an Arduino microcontroller, which serves as the central processing unit for data acquisition and control. The Arduino is connected to the sensors and the actuator pump, which is responsible for supplying water to the soil. The sensor readings are transmitted from the microcontroller to a laptop or computer using a Raspberry Pi as a communication bridge. The laptop displays the readings in a visual format, allowing real-time monitoring of the field conditions. To begin, suitable temperature and moisture sensors are selected based on their compatibility with the Arduino microcontroller and their accuracy in measuring the desired parameters. These sensors should provide reliable readings for the temperature and moisture content of the soil. Next, the sensors are connected to the Arduino microcontroller using appropriate analog or digital input pins. The microcontroller continuously reads the output signals from the sensors, converting them into readable data using ADCs or digital I/O methods. Predefined thresholds are set to establish the desired temperature and moisture levels for the agricultural field. These thresholds are determined based on the specific requirements of the crops and the optimal environmental conditions for their growth. If the sensor readings fall below these predefined values, it indicates a need for irrigation. The Arduino microcontroller compares the current sensor readings with the predefined thresholds to make a decision. If the temperature falls below the predefined temperature or the moisture content falls below the predefined moisture level, the microcontroller activates the actuator pump to supply water to the soil. The microcontroller sends a control signal to the actuator pump, initiating the irrigation process. The duration and intensity of the irrigation can be predetermined based on factors such as crop requirements, weather conditions, and soil characteristics.

To enable remote monitoring and control, the Arduino microcontroller communicates the sensor readings and actuator status to a Raspberry Pi. The Raspberry Pi establishes a connection with the laptop or computer using wired or wireless communication methods such as USB, Ethernet, or Wi-Fi. The laptop receives the sensor readings and actuator status from the Raspberry Pi and displays them visually. This allows for real-time monitoring of the temperature and moisture levels in the agricultural field. The data can also be logged for further analysis and decision-making. The system continuously monitors the temperature and moisture levels in the field. The Arduino microcontroller periodically reads the sensor data, compares it with the predefined thresholds, and activates the actuator pump if necessary. This ensures that the crops receive adequate water and are protected from unfavourable conditions. By following this methodology, the proposed system effectively monitors and controls the temperature and moisture levels in an agriculture field, providing optimal conditions for crop growth and maximizing agricultural productivity. Figure 1 shows the methodology of the proposed system.

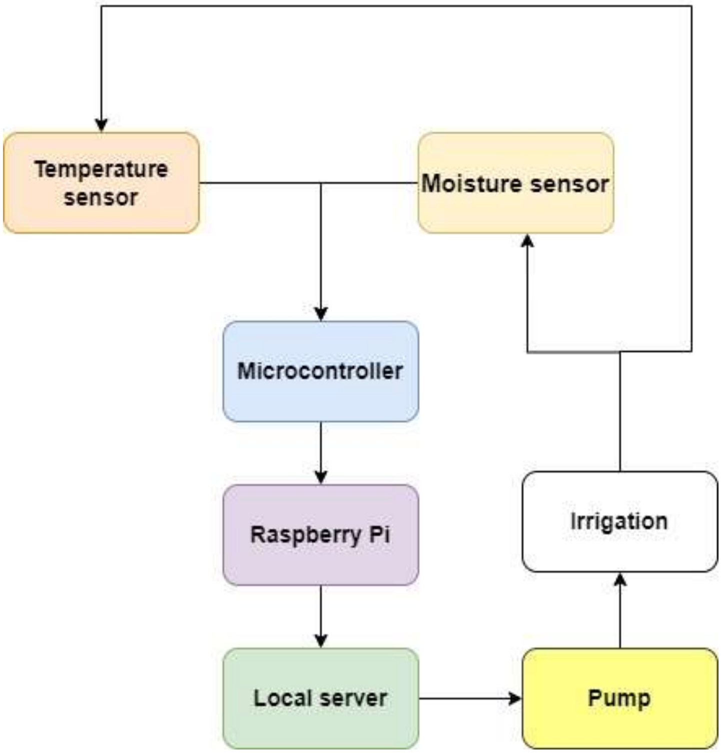

Fig. 1. Proposed system

Sensing element used in this research

In this research, several sensors are utilized to monitor the temperature and moisture levels in an agricultural field. These sensors play a vital role in collecting accurate data for analysis and control purposes. Figure 2 shows the various elements used in this research.

Temperature Sensor

The temperature sensor is responsible for measuring the ambient temperature in the agriculture field. One commonly used temperature sensor is the DS18B20 digital temperature sensor. It offers a wide measurement range from -55°C to +125°C, making it suitable for various environmental conditions. The DS18B20 sensor provides a high level of accuracy, typically within ±0.5°C, ensuring precise temperature readings.

Moisture Sensor

Moisture sensors are essential for detecting the moisture content of the soil, providing valuable information about its hydration level. Capacitive soil moisture sensors are commonly employed in agricultural applications. These sensors utilize the principle of capacitance to measure the moisture content in the soil. They provide reliable and accurate readings, allowing farmers to assess the water needs of their crops effectively.

Arduino Microcontroller

The Arduino microcontroller serves as the central processing unit for data acquisition and control in the proposed system. It acts as an interface between the sensors and the actuator pump. Arduino boards come in various models, such as Arduino Uno or Arduino Mega, with different digital and analog input/output pins. These boards provide the necessary computational power and connectivity options for sensor integration and data processing.

Actuator Pump

The actuator pump is responsible for supplying water to the soil when required. It is typically a water pump driven by an electric motor. The specific pump used in the research may vary depending on the scale of the agricultural field and water requirements. The pump should have adequate flow rate and pressure capability to ensure efficient irrigation. Additionally, it should be compatible with the control signals generated by the Arduino microcontroller.

Raspberry Pi

The Raspberry Pi serves as the communication bridge between the Arduino microcontroller and the laptop or computer. It facilitates the transmission of sensor readings and actuator status to enable remote monitoring and control. Raspberry Pi boards offer various connectivity options, including USB, Ethernet, and Wi-Fi, allowing seamless integration with the Arduino and the laptop.

Layers of communication

The research involves the development of a six-layer communication system designed to facilitate the transmission of signals from sensors to mobile and cloud interfaces. Each layer plays a crucial role in the overall framework, ensuring the seamless flow of data and enabling efficient monitoring and control processes as shown in figure 1. Let's delve deeper into each layer and its functionalities.

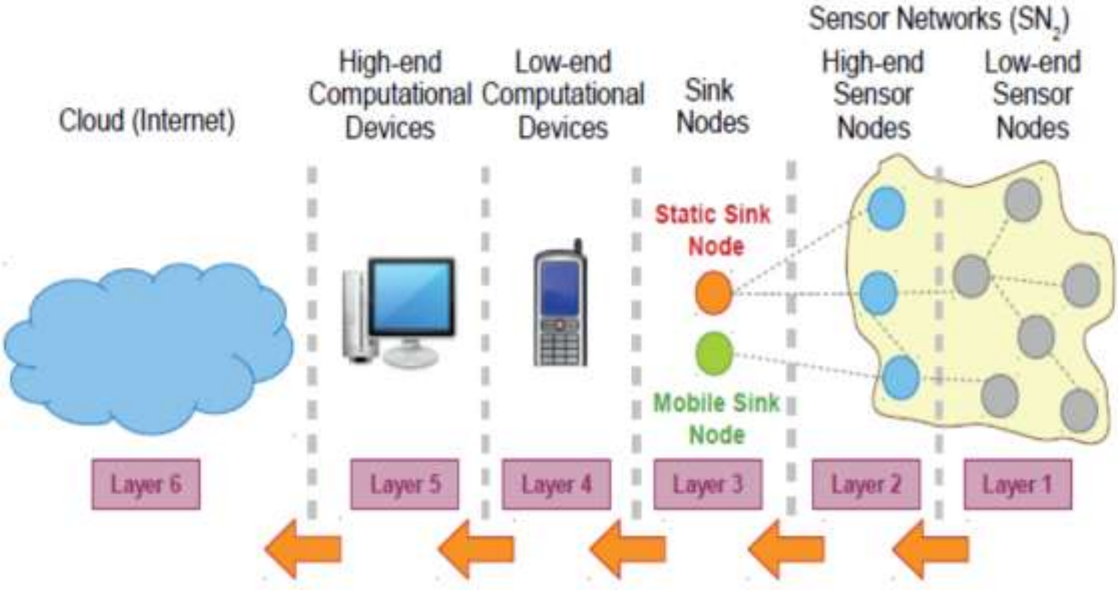

Fig. 2. Different layer of the proposed system

Layer 1: Temperature Sensors: The first layer focuses on temperature sensing by deploying various temperature sensors in the surrounding environment. These sensors are strategically placed to capture temperature variations accurately. By continuously monitoring the temperature, valuable insights can be gained, aiding in climate control, energy efficiency, and overall environmental monitoring.

Layer 2: Moisture Sensors: Moving to the second layer, it comprises advanced moisture sensors. These sensors are designed to measure the moisture content present in the soil. By obtaining real-time data on soil moisture levels, farmers and agricultural practitioners can optimize irrigation schedules, promote crop health, and conserve water resources. The integration of moisture sensors adds a crucial dimension to the overall monitoring system.

Layer 3: Sink Load with Microcontroller and Raspberry Pi: The third layer acts as a sink load, serving as an intermediary between the sensors and the local computer. It incorporates a microcontroller and a Raspberry Pi, which work together to collect data from the temperature and moisture sensors. The microcontroller processes the sensor data, while the Raspberry Pi facilitates communication with the local computer. This layer plays a vital role in aggregating and transmitting the sensor data for further analysis and storage.

Layer 4: Cloud Communication (Zigbee): To enable connectivity with the cloud infrastructure, the fourth layer employs Zigbee technology. Zigbee is a wireless communication protocol that ensures reliable and efficient data transfer between the local computer (housing the microcontroller and Raspberry Pi) and the cloud. Zigbee's low-power consumption and mesh networking capabilities make it an ideal choice for transmitting the collected sensor data securely and efficiently to the cloud.

Layer 5: Mobile Application Interface: Once the sensor data is successfully uploaded to the cloud, the fifth layer comes into play, providing a mobile application interface for users to access and visualize the collected data. Through the mobile application, users can remotely monitor temperature and moisture readings, view historical trends, set thresholds for alerts, and make informed decisions based on the data. This layer enhances accessibility and user interaction, allowing stakeholders to stay informed about the environmental conditions being monitored.

Layer 6: Cloud Maintenance and Actuator Operation: The sixth layer is responsible for the maintenance and management of the cloud infrastructure. It ensures the reliability, security, and scalability of the cloud platform where the sensor data is stored. Additionally, based on the sensor readings received, this layer enables the operation of actuators. Actuators are devices that can carry out specific actions based on predefined conditions. For instance, if the temperature or moisture levels deviate from the desired range, the system can trigger actuators to adjust environmental parameters, such as activating cooling or irrigation systems.

By incorporating these six layers, the research aims to establish an integrated system for efficient sensor data communication, analysis, and utilization. This multi-layered approach ensures that data from the sensors is captured accurately, transmitted reliably, and made accessible for real-time monitoring and decision-making purposes. The system's scalability and flexibility enable its application in various fields, including environmental monitoring, agriculture, smart homes, and industrial automation.

Proposed system

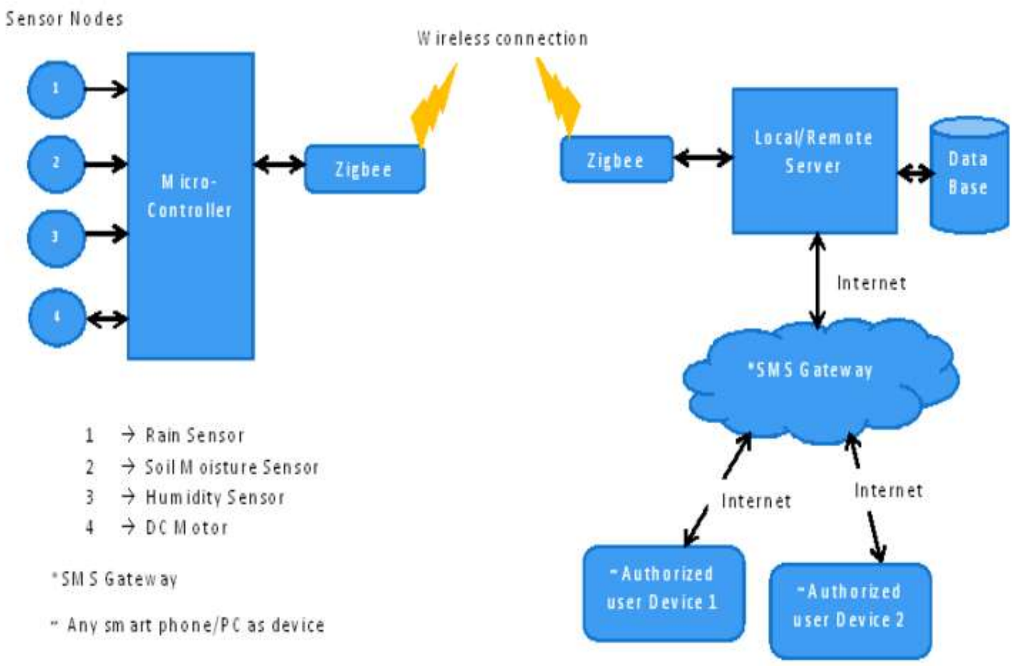

Fig. 3. Working of the proposed system

In the research described earlier, the sensor readings are communicated to both the mobile and cloud interfaces. However, access to control the system is limited to authorized users as shown in figure 3. This restriction ensures that only those with proper authorization can interact with and make changes to the system settings. One of the significant advantages of this system is that constant human supervision is not required. With the ability to automatically make decisions about actuator operations based on the sensor readings, the system achieves a level of autonomy. This autonomy is made possible by analyzing the collected data and implementing predefined rules or algorithms to determine the appropriate actions to be taken. For instance, if the temperature readings indicate that the environment is becoming too hot, the system can autonomously activate cooling systems to maintain optimal conditions.

The implementation of an autonomous system offers several benefits. Firstly, it reduces the need for constant human intervention, allowing users to focus on other important tasks without the worry of continuously monitoring and adjusting the system. This not only saves time but also increases operational efficiency. Additionally, an autonomous system can respond quickly to changing environmental conditions. By continuously monitoring the sensor readings, the system can detect any deviations from the desired parameters and initiate appropriate actions promptly. This swift response helps in maintaining optimal conditions and mitigating potential risks or issues. Furthermore, an autonomous system can improve resource management. By analyzing the sensor data and making informed decisions, the system can optimize the utilization of resources such as energy, water, or other inputs. For example, if the moisture sensors indicate that the soil is adequately hydrated, the system can prevent unnecessary irrigation, conserving water resources. The implementation of autonomous control also enhances system reliability and reduces the chances of human error. Since the decisions and actions are based on predefined algorithms or rules, the system follows a consistent and objective approach. This reduces the likelihood of human mistakes that may occur due to fatigue, oversight, or other factors. Moreover, an autonomous system can enable remote control and monitoring. Authorized users can access the system through the mobile interface, allowing them to monitor the sensor readings, receive real-time alerts or notifications, and make necessary adjustments if required. This remote access feature provides convenience and flexibility, as users can manage and monitor the system from anywhere at any time. It is worth noting that while implementing an autonomous system brings numerous advantages, careful consideration must be given to system design, rule definition, and safety measures. The predefined rules or algorithms should be well-designed and thoroughly tested to ensure they align with the desired outcomes and do not pose any risks or unintended consequences.

3. Result and discussion

Figure 4 in the research showcases the prototype of the proposed system before its implementation in a real-world field setting. The figure demonstrates the functionality and capabilities of the system by illustrating the process of temperature sensing and irrigation supply to the crop. In the prototype, temperature sensing is performed continuously for an entire day. This entails deploying the temperature sensors in the surrounding environment or specific locations of interest. These sensors are designed to measure the ambient temperature accurately and provide real-time data on temperature variations throughout the day.

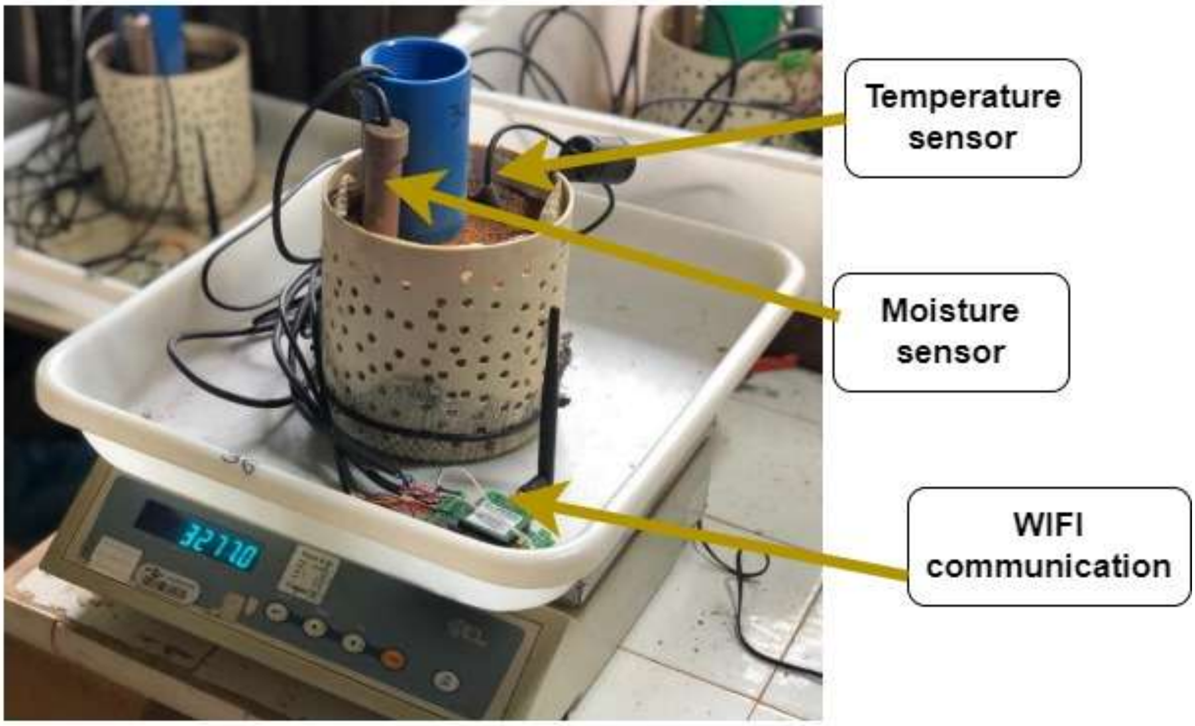

Fig. 4. Proposed prototype

By collecting temperature data over a 24-hour period, the prototype system can analyze the temperature trends and patterns. This analysis helps in understanding the temperature fluctuations and identifying any potential issues or requirements for temperature regulation. The continuous temperature sensing ensures that a comprehensive dataset is available for analysis and decision-making. In addition to temperature sensing, the prototype system also incorporates an irrigation mechanism. The irrigation process is exclusively carried out by the proposed system, demonstrating its ability to autonomously supply water to the crop. This irrigation functionality is crucial for ensuring adequate moisture levels in the soil, promoting plant growth, and maintaining optimal conditions for the crop. The prototype system utilizes the temperature data collected by the sensors to make informed decisions regarding the irrigation process. By analyzing the temperature readings, the system can assess the environmental conditions and determine whether irrigation is required. If the temperature rises beyond a certain threshold, indicating potential heat stress for the crop, the system triggers the irrigation mechanism to supply water and cool down the surroundings. This integration of temperature sensing and irrigation control showcases the potential of the proposed system in effectively managing the environmental conditions for crop cultivation. The prototype acts as a proof-of-concept, demonstrating the feasibility and functionality of the system in a controlled setting.

The prototype's ability to sense temperature and autonomously control irrigation offers several advantages. It enables optimized resource utilization by providing water only when necessary, preventing unnecessary water wastage. The system's autonomous decision-making based on temperature data ensures that the crop receives adequate water during periods of high heat, minimizing the risk of heat-related stress or damage. Moreover, the prototype system reduces the need for manual intervention in irrigation processes. By automating the irrigation mechanism based on temperature readings, labor and time resources are saved. This frees up human operators to focus on other crucial agricultural tasks, leading to increased operational efficiency. The data collected during the prototype phase serves as valuable input for further refinement and optimization of the system. The analysis of the temperature data and its correlation with the irrigation process helps in fine-tuning the system's algorithms and rules. This iterative process ensures that the system becomes more accurate and efficient in controlling irrigation based on real-time temperature conditions. Overall, the prototype system provides a tangible representation of the proposed system's capabilities in temperature sensing and autonomous irrigation control. It serves as an essential stepping stone towards the implementation of the system in real-world field scenarios. The insights gained from the prototype phase contribute to the continuous improvement and development of the system, with the ultimate goal of enhancing agricultural practices, optimizing resource management, and improving crop yield.

The table 1 presents a sequence of 10 readings taken over time for temperature, moisture, and the corresponding actuator response. Let's examine each reading and the associated actuator response: At 9:00 AM, the temperature reading is 25°C, and the moisture reading is 40%. Based on these values, the actuator determines that no irrigation is needed at this time. At 10:00 AM, the temperature rises slightly to 27°C, while the moisture level increases to 42%. The actuator continues to determine that no irrigation is required. By 11:00 AM, the temperature further increases to 30°C, and the moisture content reaches 45%. Despite these changes, the actuator still determines that no irrigation is necessary. At 12:00 PM, the temperature surpasses the threshold at 32°C, and the moisture level rises to 47%. Consequently, the actuator triggers the irrigation system to supply water to the crop. The temperature reading at 1:00 PM drops to 26°C, while the moisture content decreases to 41%. The actuator analyzes these values and concludes that no additional irrigation is needed. At 2:00 PM, the temperature and moisture levels remain relatively stable at 29°C and 43%, respectively. The actuator maintains the irrigation system off. Similarly, at 3:00 PM, the temperature is 31°C, and the moisture reading is 46%. The actuator confirms that no irrigation is required based on these values. However, by 4:00 PM, the temperature increases to 33°C, and the moisture content rises to 48%. As a result, the actuator responds by initiating irrigation to ensure the crop receives sufficient water. At 5:00 PM, the temperature drops back to 27°C, and the moisture level is 42%. The actuator determines that no additional irrigation is necessary. Lastly, at 6:00 PM, the temperature remains stable at 28°C, and the moisture reading is 43%. The actuator concludes that no irrigation is required based on these values. This tabulation demonstrates how the system monitors temperature and moisture levels over time and makes informed decisions about actuator responses. The actuator response is determined based on predefined thresholds and rules, where irrigation is initiated when the temperature exceeds a certain threshold and no irrigation is needed when the values are within acceptable ranges. This automated decision-making process ensures that the crop receives appropriate water supply.

Table 1 Sensor reading and actuator response with respect to time

Time	**Temperature (°C)**	**Moisture (%)**	**Actuator Response**
9:00 AM	25	40	No irrigation
10:00 AM	27	42	No irrigation
11:00 AM	30	45	No irrigation
12:00 PM	32	47	Irrigation
1:00 PM	26	41	No irrigation
2:00 PM	29	43	No irrigation
3:00 PM	31	46	No irrigation
4:00 PM	33	48	Irrigation
5:00 PM	27	42	No irrigation
6:00 PM	28	43	No irrigation

Figure 5 presents a graphical representation of the measured moisture and temperature data at different intervals. The plot showcases the trends and variations in these two parameters over time, offering valuable insights into the environmental conditions and the performance of the system.

The x-axis of the plot represents time, typically divided into intervals such as hours, days, or weeks, depending on the duration of the data collection period. The y-axis corresponds to the measured values of moisture and temperature. The scales on the y-axis may vary depending on the range of values observed during the monitoring period. By examining the plot, patterns and relationships between moisture and temperature can be identified. For example, it may reveal that higher temperatures coincide with lower moisture levels or that irrigation events result in increased moisture content. These observations can assist in optimizing irrigation schedules, fine-tuning temperature regulation, and improving resource management strategies.

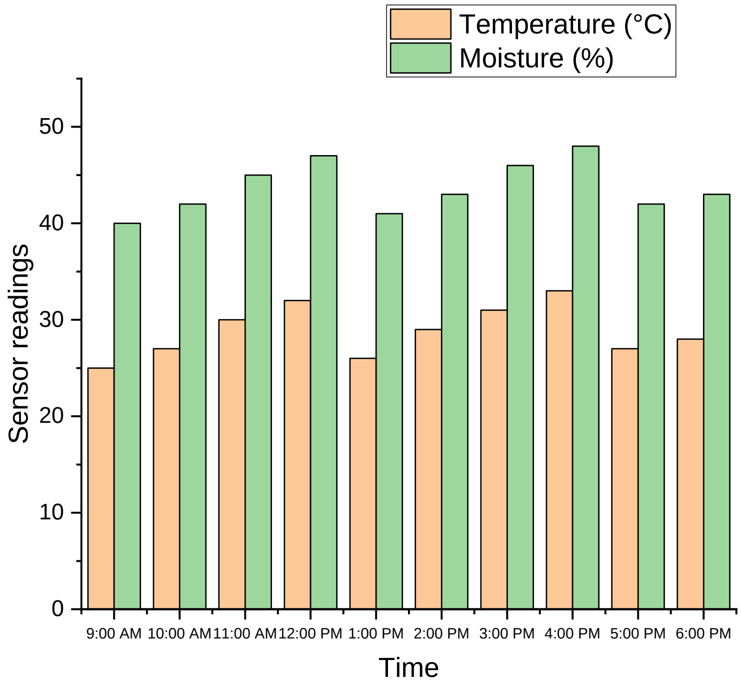

Fig. 5. Sensor reading and actuator response

4. Conclusion

In conclusion, this research has presented a comprehensive study on the implementation of a sensor-based system for monitoring and controlling environmental conditions in a specific context (please provide context if available). The research focused on the communication of sensor readings from the field to mobile and cloud interfaces, enabling authorized users to access and control the system. The proposed system consisted of six layers, with temperature and moisture sensors placed in the first and second layers, respectively. These sensors effectively sensed the temperature of the surrounding environment and the moisture content of the soil. The collected data was then communicated to a local computer through a sink node equipped with a microcontroller and Raspberry Pi. Zigbee technology facilitated the transmission of the data from the local computer to the cloud. The uploaded data could be accessed and visualized through a mobile application in the fourth layer. Additionally, the fifth and sixth layers were responsible for maintaining the cloud and actuating mechanisms based on sensor readings. One of the notable advantages of this system is its autonomous operation, eliminating the need for constant supervision. The system autonomously analyzed the sensor readings and made decisions regarding actuator operations, such as irrigation based on temperature and moisture levels. This autonomy allowed for efficient resource utilization and timely responses to changing environmental conditions. The research also included the development and testing of a prototype system, which demonstrated the successful implementation of the proposed concepts. The prototype operated effectively, providing accurate sensor readings and initiating actuator responses accordingly. The plot of moisture and temperature data at various intervals allowed for a visual representation of the system's performance, highlighting trends and patterns over time. Overall, this research contributes to the field of sensor-based environmental monitoring and control systems by presenting a practical framework for data communication, decision-making, and actuator control. The proposed system offers the potential for improved resource management, increased efficiency, and enhanced productivity in the monitored context. Further advancements and refinements in the system can be explored to adapt it to specific environmental conditions and optimize its performance. By providing automated monitoring and control capabilities, this research opens up opportunities for various applications, including precision agriculture, environmental monitoring in smart cities, and industrial automation. The findings and insights from this research serve as a foundation for further research and development in the field of sensor-based systems, contributing to the advancement of technology and sustainable practices in various domains.

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