Low-cost IoT-based monitoring system for precision agriculture

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Abstract. The increasing impact of climate change on agriculture necessitates advanced monitoring and management of environmental conditions to ensure sustainable agricultural productivity. This paper introduces a cost-effective, Internet of Things (IoT)-based smart monitoring system designed to provide real-time insights into soil moisture levels and weather conditions across various segments of a single agricultural plot. The system comprises autonomous wireless sensor nodes, a comprehensive weather station, and a centralized base station that collectively capture, process, and relay environmental data to a user-friendly mobile application. Our empirical results demonstrate that this system not only facilitates efficient environmental data monitoring and analysis but also empowers farmers with actionable intelligence for timely decision-making. The proposed model showcases a promising avenue for enhancing agricultural resilience and productivity through technology-driven precision farming.

Key word: internet of things; wireless sensor network; automation; low-cost sensors; data analysis; monitoring system; Cloud.

1 Introduction

Agriculture is one of the most important economic sectors in many countries, providing an essential source of food and income for millions of people. However, agriculture is also one of the sectors most affected by climate change [1], making food production more difficult and uncertain. Climate change directly impacts the availability of resources such as water, temperature, precipitation, and soil moisture [2], as well as crop diseases and pests. These impacts affect food production, food quality, food prices, and food security. To address these challenges, monitoring weather and plant parameters is essential to enable farmers to make informed decisions about managing their crops [3].

Technologies have an important role to play in improving the monitoring of weather and plant parameters [4].

The Internet of Things (IoT), as a nascent technological marvel, holds immense promise for the continuous observation of agricultural environments. Through the deployment of IoT sensors across farmlands, it becomes feasible to track an array of essential agricultural metrics such as atmospheric conditions, soil moisture content, aquatic levels, ambient temperatures, the health of crops, and the concentration of nutrients [5,6]. This technological intervention offers numerous advantages for various agricultural operations and methodologies in a real-time context, encompassing irrigation management, crop protection strategies, the elevation of produce quality, optimization of fertilization processes, and the anticipation of plant diseases [7]. Furthermore, technological progress in agricultural machinery has markedly expanded the scope, velocity, and efficiency of farming tools, facilitating the cultivation of larger expanses of land with heightened efficiency. Innovations in seeds, irrigation systems, and fertilizers have significantly contributed to augmenting crop yields [8]. The application of IoT for intelligent fertilization and irrigation practices is critically important for agriculture, given that soil moisture and nutrient availability are fundamental for the growth of plants and crops [9]. Despite these advantages, the integration of IoT-driven precision agriculture technologies, including the use of variable-rate fertilizers, pesticides, irrigation systems, cloud-based analytical tools, and telematics, remains relatively unadopted among row crop farmers in the Midwest [10].

The main contribution of this paper is a low-cost Internet of Things (IoT)-based monitoring system for tracking environmental variations. Section 2 summarizes the methodology for developing the monitoring system, while Section 3 presents the experimental results. Finally, Section 4 concludes the paper.

2 Methodology

2.1 System design

Measuring soil moisture at multiple points in a plot is a critical practice for farmers, as it allows them to monitor soil moisture content at different locations in the plot. This avoids uniform application of irrigation, which can lead to water waste and yield losses, and can help farmers adjust their irrigation and optimize their yield. To measure soil moisture, moisture sensors are installed in the planting rows, which measure soil moisture in the direct vicinity of the plant roots at four different levels. The data measured by the sensors is collected by a base station every 15 minutes. In addition to the sensor data, a weather station also measures wind speed, solar radiation, temperature and air humidity. This station then sends all the environmental condition data to the base station every 15 minutes and, through an API, also sends it to a mobile app via the cloud. This allows farmers to track environmental conditions in their plots in real time and make informed decisions about managing their irrigation based on the data collected.

2.2 Materials

2.2.1 Wireless sensor nodes

For the design of a low-cost, low-power autonomous wireless sensor node, we selected cost-effective electronic components that meet the requirements of environmental monitoring. To maximize the battery life of the wireless sensor node's circuitry, we used efficient methods to minimize electrical power consumption. The wireless sensor network is organized to be dispersed in the plot to detect, measure, and collect environmental information, such as soil moisture, air temperature, brightness, and rainfall, and wirelessly transmit it to the base station. The data is then processed to obtain valuable information about the environment and to decide on necessary irrigation actions.

The block diagram of the sensor node shown in Fig.1 shows that each sensor node is composed of four basic units, namely the acquisition unit, the processing unit, the transmission unit and the power supply unit as shown.

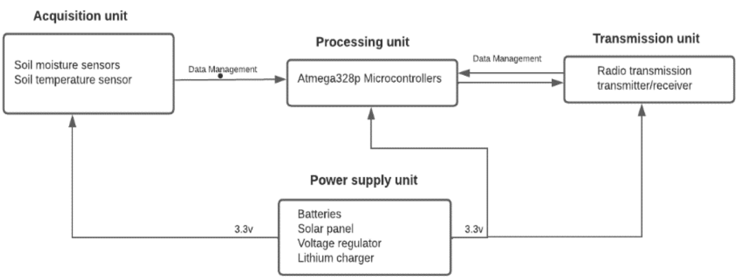

Fig. 1. Block diagram of the sensor node.

The acquisition block contains four soil moisture sensors and a DS18B20 temperature sensor. The soil moisture sensor type YL-69 consists of two electrodes to detect the moisture content around it through a current that is passed through the electrodes into the soil and the resistance to the current in the soil determines the soil moisture. The four YL-69 are placed in a PVC plastic pipe with a distance between them of 10 cm to monitor the water content in four levels of soil.

The processing unit is based on the ATmega328P microcontroller which is an 8-bit megaAVR circuit based on the AVR enhanced RISC architecture. It incorporates pico Power technology which offers ultra-low power consumption and low power standby modes, ideal for battery powered applications. It runs communications protocols that allow a node to collaborate with other nodes in the network. It can also analyze captured data to ease the burden on the data collector.

The transmission unit is the unit responsible for all data transmission and reception. It consists of an NRF24L01 with a power amplifier and an LNA, which is a transceiver. It can transmit information within its transmission range of up to 1 km in the range of 2.4 GHz to 2.525 GHz, in steps of 1 MHz, and communicate with up to 6 similar units. It has a memory of 32 bytes and can manage up to 6 communication channels simultaneously. It is powered by a voltage between 1.9 and 3.7 V and, at the microcontroller connection, it has a serial peripheral interface and an interrupt pin called IRQ to notify the master microcontroller that a new data packet has been received. This feature allowed us to reduce the power consumption of the microcontroller by putting it in sleep mode and switching it to normal mode when the transmission unit has just received data.

The power supply unit is composed of a 5v solar panel, a lithium battery charger TP4056 and a 26800 mAh 3.7v rechargeable battery. It distributes the available energy to the different modules in an optimal way.

2.2.2 Base station

The base station is the unit responsible for collecting data from wireless sensor nodes and storing the data in the cloud. It also receives data from the weather station from the weather station platform via the API. It consists of the following components:

- The Raspberry Pi 4: is a single-board nano-computer with an ARM processor and Wi-Fi, Ethernet and Bluetooth interfaces, as well as USB and BUS SPI, I2C and serial ports. It contains a quad-core 1.5 GHz ARM Cortex-A72 processor and 4G of RAM.

- A wireless data transmission module NRF24L01 with PA and LNA.

2.3 Software

At the programming level, the wireless sensor nodes are programmed by Arduino IDE and the base station by Thonny Python IDE. And at the level of the design of the WSN PCB. The design of the WSN PCB was done by the free web tool EasyEDA. The proposed system requires a smartphone capable of installing the system's Android application. ia this platform, users gain access to immediate sensor-generated data from their fields, alongside a historical record of soil moisture levels. The development of the Android app was facilitated by leveraging the open-source mobile app framework, React Native, and the Visual Studio Code development environment. For cloud services, Thinkspeak, a dedicated IoT application development platform, was utilized. Thinkspeak specializes in offering functionalities such as the real-time gathering of data, visualization of this data in tables, and the creation of plugins and applications that integrate with web services, social media platforms, and various other APIs.

2.4 Proposed Algorithm

The proposed system uses a network of sensors to monitor soil moisture in a given plot. These sensors are installed on the planting lines to cover a large area and are capable of measuring soil moisture at different locations. In addition, a weather station is installed near the plot to monitor the surrounding weather conditions, such as ambient temperature, air humidity, solar radiation and precipitation. The data collected by the sensors and weather station is sent to a central base station where it is stored in the cloud. A mobile app is used to access this data and allow users to track soil moisture and weather conditions in real time. The system works by collecting data from the sensors and the weather station at regular intervals. This data is stored in the cloud and is then analyzed using algorithms. If the data shows that the soil moisture is below a certain threshold, the app generates an alert to warn the user. Similarly, if the weather conditions are unfavorable, the app also sends an alert to the user.

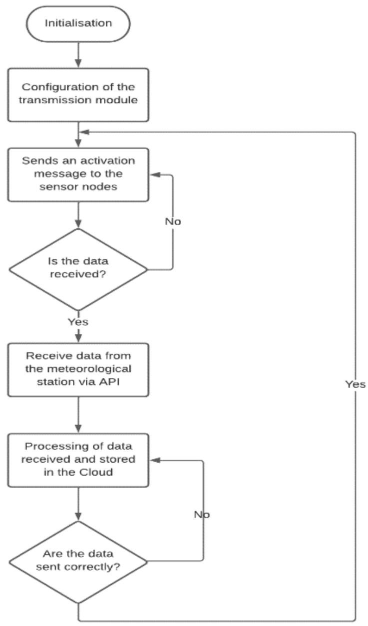

Fig. 2. Base station flow chart.

The algorithm shown in Fig.2 describes the operation of the base station in the agricultural monitoring system using IoT-connected sensors. Once installed in the field, the base station is configured to communicate wirelessly with the sensor nodes installed in the field. The sensor nodes are in sleep mode to conserve electrical power and wait for an external interruption to wake up and transmit the collected data to the base station. Every 15 minutes, the base station sends a message to the sensor nodes to activate them and measure soil moisture and temperature. Once the measurements are taken, the data is sent directly to the base station. In addition to the data from the sensor nodes, the base station also uses data from the weather station to monitor the weather conditions of the environment in which the plot is located. The base station retrieves this data via an API that provides all the information about the weather station sensors and the measured data. The base station also calculates the daily evapotranspiration by the Penman-Monteith equation [11] using the data provided by the sensor nodes and the weather station. All data collected by the base station is stored in the cloud, allowing the user to access real-time information and monitor crop health. If a critical threshold is exceeded for a specific variable, such as soil moisture, ambient temperature or air humidity, the mobile app generates an alert to inform the user of the situation and take action to remedy the problem.

3 Result

The system was tested in a plot where the data transmission distance between the nodes and the base station did not exceed 600 meters. This distance limitation was crucial to ensure efficient and reliable communication between the various system components. By limiting the range to 600 meters, we were able to accurately assess the system's ability to collect and transmit data in a close environment. This test under these transmission conditions provides a better understanding of the system's performance in real-life situations and shows that it was able to collect and record meteorological data such as temperature, air humidity, wind speed, precipitation and solar radiation from the weather station via an API executed by the base station every 15 minutes, periodically and without any missing data, as illustrated in Table 1. In addition, it can also monitor humidity trends at the four ground levels of the installed nodes, as shown in Tables 2 and 3.

Date Time	**Temp °C**	**Wind Km/h**	**Hygro %**	**Pluv mm**	**Radia W/m²**
28/04/2023 09:10	30,44	0,4	26,95	0	311,73
28/04/2023 09:25	30,94	2,01	28,03	0	318,75
28/04/2023 09:40	31,48	1,56	26,6	0	374,48
28/04/2023 09:55	33,16	0,28	23,19	0	400,37
28/04/2023 10:10	33,68	1,31	25,77	0	420,56
28/04/2023 10:25	32,6	8,61	25,38	0	415,29
28/04/2023 10:40	33,2	6,47	24,05	0	412,66
28/04/2023 10:55	32,99	9,89	24,4	0	468,39

Table 1. Part of the meteorological data of the weather station collected by the base station via API.

Table 2 shows the results of soil moisture measurements before irrigation. Data were collected by a sensor node installed in the field and recorded every 15 minutes. Measurements were taken at different depths, ranging from 10 to 40 cm. The data revealed relatively low moisture levels in the first 20 cm of depth, with a maximum moisture of 43.97% recorded at 40 cm depth.

Date Time	**Depth 10cm**	**Depth 20cm**	**Depth 30cm**	**Depth 40cm**
2023-04-28 08:45	38,95	38,80	42,10	43,97
2023-04-28 09:00	38,91	38,75	42,08	43,94
2023-04-28 09:15	38,80	38,65	42,05	43,93
2023-04-28 09:30	38,74	38,58	42,03	43,92
2023-04-28 09:45	38,63	38,50	42,00	43,89
2023-04-28 10:00	38,58	38,45	41,98	43,88
2023-04-28 10:15	38,52	38,37	41,93	43,87

Table 2. Soil moisture data before irrigation.

Date Time	**Depth 10cm**	**Depth 20cm**	**Depth 30cm**	**Depth 40cm**
2023-04-28 12:00:09	51,90	49,51	48,18	51,23
2023-04-28 12:15:04	53,73	50,68	56,31	54,66

2023-04-28 12:30:04	55,09	52,28	58,83	53,30
2023-04-28 12:45:12	55,32	56,49	59,05	53,50
2023-04-28 13:00:02	53,59	60,09	59,15	53,57
2023-04-28 13:15:02	54,23	52,34	57,16	52,54
2023-04-28 13:30:02	54,69	55,28	57,64	52,83

Table 3. Soil moisture data after irrigation.

Table 3, on the other hand, presents the soil moisture and temperature data after irrigation. The data show a significant increase in soil moisture at all depth levels, reaching moisture levels of 55.32%, 60.09%, 59.15% and 54.66.1% at 10 cm, 20 cm, 30 cm and 40 cm depths respectively.

The increase in soil moisture after irrigation is an expected result and indicates good water uptake by the soil. These results are important for farmers and water managers to better understand the effects of irrigation on the soil and to determine the optimal amount of water needed for efficient irrigation. The data collected by the sensor nodes can help with irrigation decisions and contribute to more efficient use of water resources.

Fig. 3. (A) Screenshot of the mobile application displaying real-time weather station data, (B) Screenshot of the mobile application displaying sensor node data.

In Figure 3, screenshots of the mobile app show the data collected by the sensor nodes and the weather station in real time. The app displays the data, allowing farmers to better understand the environmental conditions and water requirements of their crops. In addition, the app generates alerts if certain variables, such as soil moisture, ambient temperature and air humidity, exceed a certain threshold, allowing farmers to react quickly and adjust their irrigation system accordingly.

4 Conclusion

This paper proposes the design and implementation of an agricultural monitoring system based on sensor nodes and a weather station to accurately monitor soil moisture, temperature and other environmental parameters. The system was designed to be easy to use, economical in terms of energy and cost, and to provide real-time data to help farmers make informed irrigation and crop management decisions. The results showed that the monitoring system is able to reliably collect and transmit data. The data collected by the sensor nodes showed that irrigation significantly increased soil moisture at different depths, which is crucial for maintaining optimal conditions for plant growth. In addition, the results showed that the weather station provided important data on environmental conditions, such as temperature, air humidity, wind speed and radiation, which are also important for crop management. Screenshots of the mobile app also showed how farmers can easily access and view the collected data in real time, allowing them to make more informed decisions and better manage their farms. Ultimately, this agricultural monitoring system provides a cost-effective solution for farmers looking to improve productivity and profitability while minimizing their water consumption and environmental impact. This work can be expanded and enhanced in the future to include more sensors and other environmental parameters to provide comprehensive and customized agricultural monitoring.

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