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Smart Irrigation Infrastructure Using Automated Canal Gate Control and Integrated NPK Soil Analysis Based on Microcontroller

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Abstract: Efficient water management and soil nutrient monitoring are major challenges in modern agriculture due to increasing water scarcity and the demand for higher agricultural productivity. Traditional irrigation systems often rely on manual control and fixed irrigation schedules, which can lead to inefficient water use and reduced crop yields. This paper presents a smart irrigation infrastructure that integrates automated canal gate control with real-time soil nutrient monitoring using Nitrogen (N), Phosphorus (P) and Potassium (K) (NPK) sensors. The proposed system utilizes a microcontroller-based platform to collect environmental data from soil moisture sensors, ultrasonic water level sensors, and NPK soil nutrient sensors. Based on the sensed parameters, the system automatically regulates canal gates through a solenoid valve mechanism to ensure optimized water distribution. The system also provides real-time monitoring through a Liquid Crystal Display (LCD) interface, allowing farmers to observe irrigation conditions and soil nutrient levels. Experimental implementation demonstrates improved irrigation efficiency, reduced water wastage, and enhanced soil fertility management. The proposed system provides a cost-effective and sustainable approach for smart farming, particularly in canal-based irrigation regions.

Keywords: Smart Irrigation, Precision Agriculture, Soil Nutrient Monitoring, Canal Gate Automation, NPK Sensor, Microcontroller.

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1. Introduction

Agriculture plays a vital role in ensuring global food security [1] and supporting economic development in many countries, particularly in developing regions where a large portion of the population depends on farming as a primary source of livelihood. However, the agricultural sector is currently facing numerous challenges due to rapid population growth, climate change [2], and the increasing scarcity of water resources. These challenges have created significant pressure on existing agricultural systems to produce higher yields while utilizing limited natural resources more efficiently. Among these challenges, efficient irrigation management has emerged as a critical factor in sustaining agricultural productivity and ensuring long-term environmental sustainability.

Traditional irrigation [3] methods, such as flood irrigation and manually operated canal systems, are widely used in many parts of the world. While these methods are simple and cost-effective, they often suffer from major limitations, including excessive water consumption, uneven distribution of water, and lack of real-time control. These inefficiencies can lead to water wastage, soil erosion [4], nutrient leaching, and ultimately reduced crop yield. Furthermore, manual irrigation systems are highly dependent on human intervention, making them prone to delays, errors, and inconsistent operation.

To address these issues, recent advancements in agricultural technology have introduced the concept of smart irrigation systems. These systems utilize modern technologies such as sensors, microcontrollers, and automation techniques to improve irrigation efficiency and optimize resource utilization. Smart irrigation [5] systems enable continuous monitoring of environmental parameters, including soil moisture, water level, temperature, and soil nutrient content. By collecting real-time data [6], these systems can dynamically adjust irrigation schedules and water supply according to the specific needs of crops, thereby reducing water wastage and enhancing crop productivity.

One of the key advantages of smart irrigation systems is their ability to integrate sensor data [7] with automated control mechanisms. Soil moisture [8] sensors play a crucial role in determining the water requirements of crops, while water level sensors ensure the availability of sufficient water for irrigation. Additionally, the incorporation of soil nutrient monitoring technologies, such as NPK sensors [9], provides valuable insights into soil fertility conditions. Nitrogen (N), phosphorus (P), and potassium (K) are essential macronutrients required for plant growth, and maintaining their optimal levels is critical for achieving high crop yields. Real-time monitoring of these nutrients [10] allows farmers to apply fertilizers more efficiently and avoid excessive or insufficient nutrient application.

Despite the significant advancements in smart irrigation [11] technologies, many existing systems primarily focus on water management and do not fully address the integration of nutrient monitoring with irrigation control. Moreover, in regions where canal-based irrigation systems are prevalent, manual operation of canal gates remains a major challenge. Automated canal gate [12] control can significantly improve water distribution efficiency by regulating the flow of water based on real-time environmental conditions.

In the present research proposes a smart irrigation infrastructure that integrates automated canal gate control with real-time NPK soil analysis using a microcontroller-based system. The proposed system utilizes multiple sensors to monitor soil moisture, water level, and nutrient content, and processes this data through an Arduino-based control unit. Based on the analyzed data, the system automatically controls irrigation by operating a solenoid valve that functions as an automated canal gate. This integrated approach ensures precise water distribution while also supporting effective nutrient management [13].

The primary objective of this research is to develop an efficient, cost-effective, and sustainable irrigation system that can optimize both water usage and soil fertility. By combining real-time monitoring, automated control, and feedback-based decision-making, the proposed system aims to enhance crop productivity, reduce resource wastage, and promote sustainable agricultural practices. Furthermore, the system can be extended in the future with IoT-based remote monitoring and advanced data analytics to support large-scale smart farming applications.

2. Literature Review

Efficient irrigation management has become a critical component of modern agriculture due to the increasing demand for food production and the limited availability of freshwater resources. Traditional irrigation systems rely heavily on manual operation and fixed irrigation schedules, which often lead to inefficient water use and uneven water distribution across agricultural fields. To address these issues, researchers have developed smart irrigation systems that integrate sensor networks, microcontrollers, and Internet of Things (IoT) technologies.

Several studies have explored the use of sensor-based irrigation systems to improve water management. Vallejo-Gomez et al. [14] conducted a comprehensive systematic review on smart irrigation systems, highlighting the integration of sensors, automation, and data-driven decision-making in modern agriculture. The study emphasized that smart irrigation technologies enable real-time monitoring of key environmental parameters such as soil moisture, temperature, and weather conditions, allowing irrigation systems to dynamically adjust water supply based on crop requirements. The authors also discussed the role of IoT platforms in enhancing system connectivity and enabling remote monitoring and control of irrigation infrastructure. Recent developments in smart irrigation systems have been significantly influenced by the integration of IoT technologies and advanced sensor networks.

García et al. [15] presented a comprehensive overview of IoT-based smart irrigation systems, focusing on the role of sensors and communication technologies in precision agriculture. The study highlighted that IoT-enabled irrigation systems allow real-time monitoring of environmental parameters such as soil moisture, temperature, humidity, and water availability, thereby enabling automated and data-driven irrigation decisions. The authors emphasized that wireless sensor networks play a crucial role in collecting field data and transmitting it to centralized control units or cloud platforms for further analysis.

Efficient water management remains a fundamental challenge in modern agriculture, particularly in regions facing water scarcity and climate variability. Ray and Majumder [16] discussed recent innovations in irrigation practices aimed at improving water use efficiency and sustainability in agricultural systems. Their study highlighted the transition from conventional irrigation methods to advanced techniques such as precision irrigation, sensor-based monitoring, and automated control systems. The authors emphasized that modern irrigation solutions integrate real-time data collection and intelligent decision-making to optimize water distribution according to crop requirements.

Ndunagu et al.[17] developed a wireless sensor network and IoT-based smart irrigation system aimed at improving irrigation efficiency through real-time monitoring and automation. The study demonstrated that integrating soil moisture sensors with IoT platforms enables continuous data collection and remote control of irrigation processes. The system effectively reduced water wastage and improved crop management by providing timely irrigation based on actual field conditions

Saraf et al. [18] proposed an IoT-based smart irrigation monitoring and control system that utilizes sensor data and wireless communication to automate irrigation processes. The system enables real-time monitoring of environmental parameters such as soil moisture and temperature, allowing efficient water management and reduced manual intervention. Their approach demonstrated improved irrigation efficiency and resource utilization through automated decision-making. Kim et al. [19] developed a distributed wireless sensor network for remote sensing and control of irrigation systems. Their study demonstrated that real-time data acquisition and remote-control capabilities can significantly improve irrigation efficiency and reduce water wastage. The system utilized wireless communication to transmit sensor data to a central control unit, enabling automated irrigation decisions without direct human intervention.

Navarro-Hellín et al. [20] proposed a decision support system for managing irrigation in agriculture by integrating sensor data and intelligent decision-making algorithms. The system enables efficient irrigation scheduling by analyzing environmental parameters and optimizing water usage based on crop requirements. The study demonstrated that decision support systems can significantly enhance irrigation efficiency and reduce water consumption. Adhikary et al. [21] presented a real-time soil nutrient monitoring system using NPK sensors to support precision agriculture practices. The study demonstrated that continuous monitoring of nitrogen, phosphorus, and potassium levels enables better decision-making for fertilization and crop management. The system improves soil health assessment by providing accurate and timely nutrient data.

Sanjeevi et al. [22] explored the application of IoT and wireless sensor networks in precision agriculture to enhance farming efficiency and resource management. The study demonstrated that real-time data collection from multiple sensors enables automated monitoring of environmental conditions and supports intelligent decision-making for irrigation and crop management.

Shingote et al. [23] proposed a microcontroller-based flow control system for automated canal gate operation in irrigation systems. Their work demonstrated that using embedded systems for canal gate automation can significantly improve water distribution efficiency and reduce manual intervention. The system enables precise control of water flow based on predefined parameters, making irrigation management more reliable and efficient.

Kumar et al. [24] evaluated the performance of ultrasonic sensors for flow measurement in open channel irrigation systems. The study demonstrated that ultrasonic sensing technology provides accurate and non-contact measurement of water flow, making it suitable for real-time monitoring in irrigation applications. Their findings highlighted the effectiveness of ultrasonic sensors in improving water management and ensuring reliable flow control in canal-based systems.

Wolfert et al. [25] presented a comprehensive review on the role of big data in smart farming, highlighting how data-driven technologies can transform agricultural practices. The study emphasized that the integration of large-scale data analytics, sensor networks, and digital platforms enables more informed decision-making in areas such as irrigation, crop monitoring, and resource management. Their work demonstrated that big data technologies can significantly improve efficiency, productivity, and sustainability in agriculture

3. Proposed System Architecture

The proposed smart irrigation infrastructure integrates automated canal gate control with real-time soil nutrient monitoring to improve irrigation efficiency and crop productivity. The system is designed using a microcontroller-based architecture that collects environmental data from multiple sensors, processes the data, and automatically controls irrigation mechanisms based on predefined thresholds.

The overall architecture of the system consists of three major subsystems: sensing unit, processing unit, and control unit. These subsystems work together to monitor environmental conditions and regulate irrigation operations in real time.

3.1. System Overview

The block diagram represents the closed-loop control architecture of the proposed smart irrigation system, designed to automatically regulate soil conditions using sensor feedback and actuator control. The system consists of several key components including the reference input, error detector, controller, actuators, controlled system, and feedback sensors. These components work together to maintain optimal soil moisture and nutrient conditions in agricultural fields.

Here, the process begins with the reference input, which represents the desired soil conditions required for proper crop growth. These conditions include target soil moisture levels and nutrient concentrations such as NPK. The reference values are predefined in the system and act as the set point for the irrigation control process.

Reference input is compared with the actual measured conditions through an error detector, represented by the summation (Σ) block. This unit calculates the difference between the desired soil conditions and the current conditions measured by the sensors. The resulting value, known as the error signal, indicates whether the system needs to increase or decrease irrigation activity.

The controller, implemented using an Arduino Uno microcontroller, receives the error signal and processes it using a control algorithm programmed into the system. The controller determines the appropriate control action required to minimize the error. Based on the computed decision, the controller generates control signals that activate the system actuators responsible for irrigation and environmental management.

The system includes two types of actuators. The primary actuators consist of the water pump and solenoid valve, which regulate the flow of water from the irrigation canal to the agricultural field. The solenoid valve functions as an automated canal gate that opens or closes depending on the controller's signal. The secondary actuator, represented by the light trap, is used for pest management and operates based on environmental conditions such as light intensity detected by the Light Dependent Resistor (LDR) sensor.

The controlled system, also referred to as the plant or process, represents the actual agricultural field where irrigation takes place. This block includes the soil and crops whose moisture and nutrient levels are affected by the actions of the actuators. When irrigation is applied, the soil moisture content increases, gradually bringing the system closer to the desired reference conditions.

To maintain system stability and ensure accurate control, the system incorporates feedback sensors that continuously monitor environmental conditions. These sensors include soil moisture sensors for measuring soil water content, NPK sensors for detecting nutrient levels, ultrasonic sensors for measuring water levels in irrigation channels or reservoirs, and LDR sensors for monitoring ambient light conditions. The measured data from these sensors is transmitted back to the controller, forming a feedback loop.

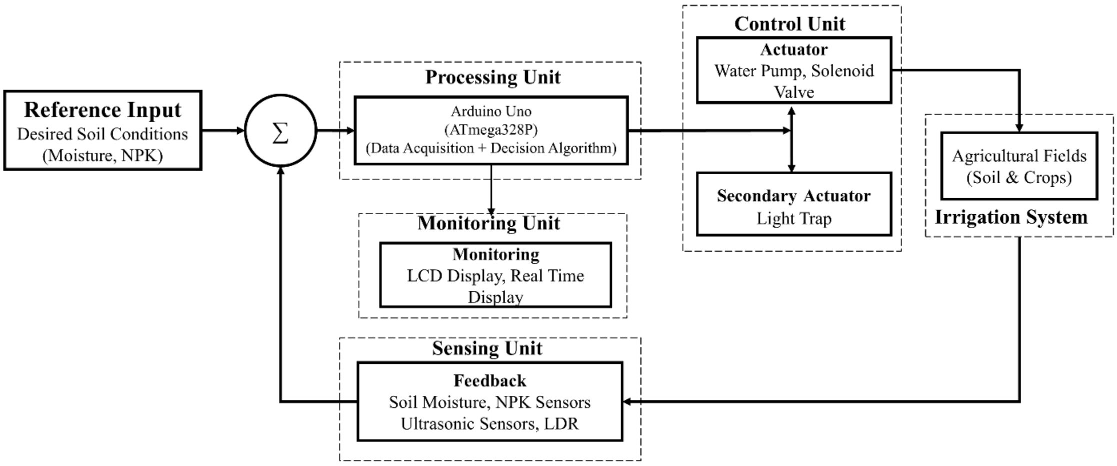

Figure 1. *Block representation of the proposed smart irrigation system*

Through this closed-loop feedback mechanism, the controller continuously compares the measured conditions with the desired reference values and adjusts the actuator operations accordingly. This feedback-based control ensures efficient irrigation management, reduces water wastage, and maintains optimal soil conditions for sustainable agricultural production.

3.2. Sensing Unit

The sensing unit [26] is responsible for collecting environmental data related to irrigation and soil conditions. Multiple sensors are used to monitor different parameters essential for efficient irrigation management.

3.2.1. Soil Moisture Sensor

The soil moisture sensor [27] measures the water content present in the soil. It works by detecting changes in electrical conductivity between two probes inserted into the soil. When soil moisture decreases, the sensor output changes accordingly, allowing the microcontroller to detect the need for irrigation.

The soil moisture sensor plays a critical role in preventing both under-irrigation and over-irrigation by ensuring that crops receive the required amount of water

3.2.2. Ultrasonic Water Level Sensor

The ultrasonic sensor [28] is used to measure the water level in irrigation canals. It operates by transmitting ultrasonic sound waves toward the water surface and measuring the time required for the echo signal to return.

By calculating the distance between the sensor and the water surface, the system determines the water level available in the canal. This information helps regulate canal gate operations and ensures proper water distribution.

3.2.3. NPK Soil Nutrient Sensor

The NPK [9] sensor measures the concentration of nitrogen (N), phosphorus (P), and potassium (K) in the soil. These nutrients are essential for plant growth and soil fertility.

Real-time monitoring of soil nutrients allows farmers to make informed decisions regarding fertilizer application. Integrating nutrient monitoring with irrigation management enables precision agriculture by ensuring that both water and nutrients are delivered efficiently.

3.2.4. Light Dependent Resistor (LDR)

LDR sensor measures ambient light intensity [29]. Although not directly related to irrigation, it can provide additional environmental information for advanced agricultural applications such as greenhouse automation and crop monitoring.

3.3. Processing Unit

The processing unit of the system is the Arduino Uno microcontroller, which performs the core data processing and decision-making functions. The microcontroller receives analog and digital signals from the sensing unit and processes them using a programmed algorithm.

Arduino Uno is based on the ATmega328P microcontroller and provides sufficient processing capability for sensor data acquisition and control operations. The microcontroller continuously reads sensor data and compares the values with predefined threshold levels stored in the system program.

The decision-making process follows a simple logic:

1. Read soil moisture sensor value
2. Read NPK nutrient sensor data
3. Measure canal water level using ultrasonic sensor
4. Compare soil moisture value with predefined threshold
5. If soil moisture is below threshold, activate irrigation system
6. If soil moisture is sufficient, stop irrigation

This automated control mechanism ensures efficient water distribution and reduces the need for manual irrigation management.

3.4. Control Unit

Control unit is responsible for regulating irrigation operations based on the decisions made by the processing unit.

3.4.1. Solenoid Valve

A solenoid valve is used to control the flow of water through canal gates. The valve operates as an electromechanical [30] device that opens or closes when an electrical signal is received from the microcontroller.

When the soil moisture level drops below the predefined threshold, the microcontroller sends a signal to activate the solenoid valve, allowing water to flow into the irrigation channel. Once the soil moisture reaches the desired level, the valve automatically closes to stop water flow.

3.4.2. Canal Gate Mechanism

The canal gate mechanism regulates the flow of irrigation water from the main canal to agricultural fields. The gate is connected to the solenoid valve and controlled automatically through the microcontroller.

Automating canal gate control reduces manual labor and ensures that water distribution occurs efficiently and consistently.

3.5. Monitoring and Display Unit

The monitoring unit consists of an LCD display module connected through an I2C communication interface. The LCD module displays real-time system parameters such as:

- Soil moisture level
- NPK nutrient values
- Canal water level
- Irrigation status

This real-time feedback allows farmers to monitor the system performance and verify that irrigation operations are functioning correctly.

3.6. System Model

The flowchart illustrates the operational sequence of the proposed smart irrigation system, which is based on a closed-loop feedback control mechanism. The system begins with the initialization stage, where the microcontroller and all associated sensors are activated and configured for operation. This ensures accurate and reliable data acquisition from the sensing unit. Following initialization, the system enters the data acquisition phase, where real-time measurements of soil moisture, soil nutrient levels and canal water level are collected. These sensor readings are then processed by the microcontroller, which compares the measured values with predefined threshold levels stored in the system. The first decision stage evaluates whether the soil moisture level is below the specified threshold. If the soil moisture is above the threshold, indicating sufficient water content, the system keeps the solenoid valve closed and no irrigation is performed. Conversely, if the soil moisture level falls below the threshold, the system proceeds to evaluate water availability in the canal. In the subsequent decision stage, the canal water level is assessed using the ultrasonic sensor. If the water level is below the required threshold, the system prevents irrigation by keeping the solenoid valve closed, thereby avoiding inefficient water usage. If the water level is adequate, the system activates the irrigation process by opening the solenoid valve, allowing water to flow through the canal gate. During irrigation, the system continuously monitors soil moisture levels in a feedback loop. Once the soil moisture reaches the desired threshold, the microcontroller terminates the irrigation process by closing the solenoid valve. The system then returns to the monitoring phase, ensuring continuous and adaptive irrigation control. This automated workflow enables efficient water management by integrating real-time sensing, decision-making, and control actions. The closed-loop operation minimizes water wastage, prevents over-irrigation, and maintains optimal soil conditions for sustainable agricultural productivity.

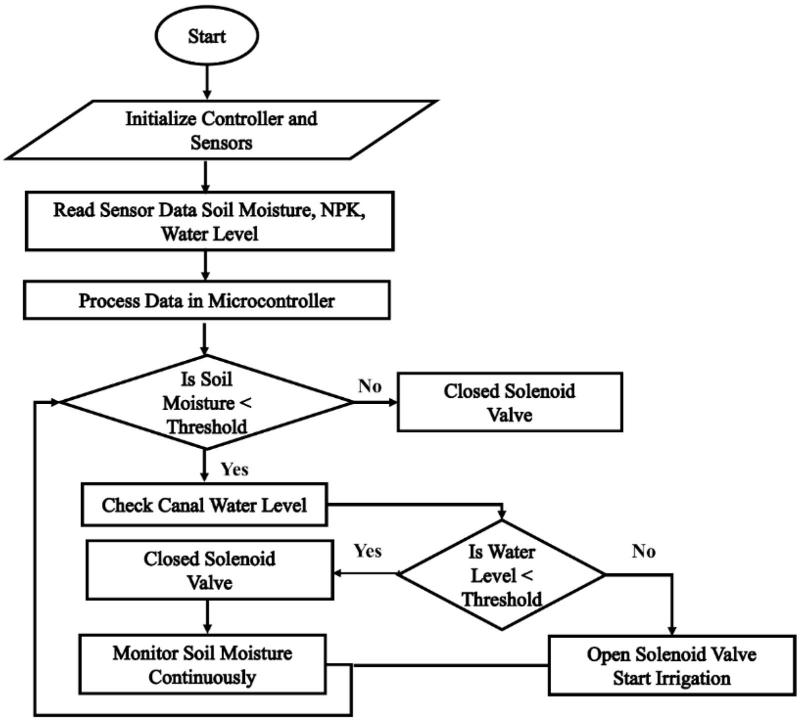

Figure 2. *Flowchart of the proposed system*

4. System Implementation

The implementation of the proposed smart irrigation infrastructure involves the integration of multiple sensors, a microcontroller-based processing unit, and automated irrigation control mechanisms. The system is designed to monitor environmental parameters in real time and regulate irrigation processes accordingly. Both hardware and software components are integrated to ensure efficient operation of the irrigation system.

The core component of the system is the Arduino Uno microcontroller, which serves as the central control unit responsible for collecting sensor data, processing environmental information, and controlling irrigation operations. The Arduino Uno is based on the ATmega328P microcontroller and provides multiple digital and analog input/output pins that allow seamless integration with various sensors and actuators used in the system. The microcontroller is programmed using the Arduino Integrated Development Environment (IDE) with embedded C/C++ programming language.

The system incorporates several sensors to monitor environmental conditions relevant to irrigation management. A soil moisture sensor is used to measure the water content present in the soil. The sensor produces an analog output that varies according to the soil moisture level. This signal is connected to the analog input pin of the Arduino microcontroller, where it is converted into digital data using the built-in analog-to-digital converter (ADC). By continuously monitoring soil moisture levels, the system can determine whether irrigation is required.

An ultrasonic sensor is employed to measure the water level in the irrigation canal. The sensor operates by transmitting ultrasonic waves and measuring the time required for the reflected signal to return from the water surface. Using this time measurement, the system calculates the distance between the sensor and the water surface to determine the available water level. This information ensures that the irrigation system only operates when sufficient water is present in the canal.

To enhance precision agriculture capabilities, the system integrates an NPK soil nutrient sensor. These nutrients play a crucial role in plant growth and soil fertility. The sensor communicates with the microcontroller through serial communication interfaces such as UART or I2C. The real-time nutrient data allows farmers to assess soil fertility conditions and make informed fertilization decisions.

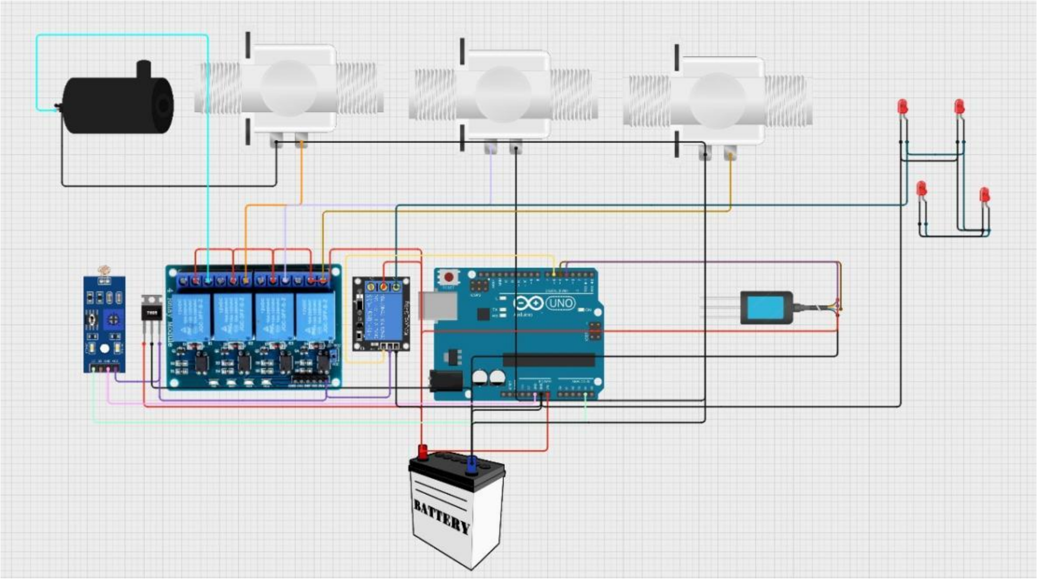

Figure 3. *Circuit diagram of the proposed system*

The irrigation control mechanism is implemented using a solenoid valve connected to the canal gate system. The solenoid valve acts as an electromechanical switch that controls the flow of water. When the microcontroller detects that the soil moisture level is below a predefined threshold, it sends an electrical signal to activate the solenoid valve. This activation opens the canal gate, allowing water to flow into the irrigation channel. Once the soil moisture level reaches the desired value, the microcontroller deactivates the solenoid valve, closing the canal gate and stopping the water flow. This automated control mechanism ensures efficient water usage and prevents over-irrigation.

To provide real-time monitoring and user interaction, the system includes an LCD module connected through an I2C communication interface. The LCD shows important system parameters such as soil moisture level, NPK nutrient values, canal water level, and irrigation status. This visual feedback allows farmers and operators to monitor system performance and verify irrigation operations without needing complex equipment.

The entire system is powered by a regulated power supply that ensures stable voltage for the microcontroller and sensors. Voltage regulation is achieved using a buck converter, which steps down the input voltage to the required operating level of the electronic components. This ensures reliable operation of the system even under fluctuating power conditions.

From the software perspective, the system operates using a continuous monitoring algorithm programmed into the microcontroller. The algorithm repeatedly reads sensor data, processes the environmental information, and determines whether irrigation should be activated. The software logic compares sensor readings with predefined threshold values and controls the solenoid valve accordingly. This automated decision-making process ensures that irrigation is performed only when necessary.

Through the integration of sensor technologies, microcontroller-based control, and automated irrigation mechanisms, the implemented system provides an efficient and intelligent irrigation solution. The system reduces water wastage, improves soil fertility management, and supports sustainable agricultural practices. The modular design of the system also allows future enhancements such as IoT-based remote monitoring and cloud data analysis for large-scale smart farming applications.

5. Results and Discussion

The proposed smart irrigation system was experimentally tested to evaluate its performance in monitoring soil conditions and controlling irrigation automatically. The prototype system was deployed in a controlled agricultural environment where the sensors measured soil moisture, soil nutrient levels, and canal water level in real time. The collected data was processed by the Arduino microcontroller to determine irrigation requirements and regulate the canal gate mechanism accordingly.

During the experiment, soil moisture levels were recorded at different times of the day to observe natural variations in soil water content and to evaluate the system's responsiveness to changing conditions. A soil moisture threshold of 40% was set in the control algorithm. Whenever the soil moisture level dropped below this threshold, the system automatically activated the solenoid valve to initiate irrigation. As shown in Figure 4, the soil moisture level increased progressively during irrigation and stabilized once the optimal moisture level was reached. At this point, the system automatically stopped the water flow, demonstrating effective closed-loop control and prevention of over-irrigation.

To moisture monitoring, the system continuously measured soil nutrient levels using the NPK sensor. The readings obtained during the experiment are presented in Figure 5. These measurements indicated that nitrogen, phosphorus, and potassium levels remained within acceptable ranges for healthy crop growth. The real-time nutrient monitoring capability provides valuable information for planning fertilizer application and enhancing soil fertility management.

The measured nitrogen, phosphorus, and potassium levels remained within acceptable ranges for crop growth during the experiment. These measurements can assist farmers in determining appropriate fertilization schedules for improved crop productivity.

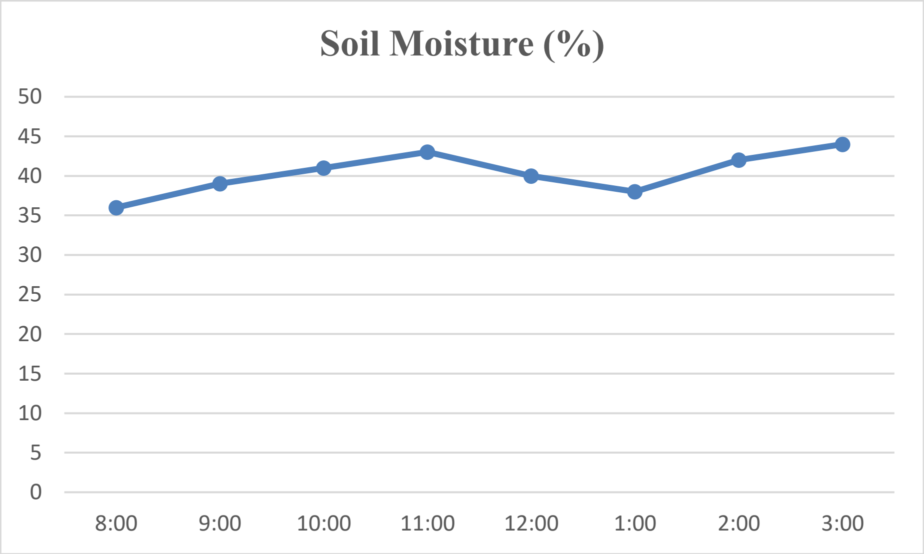

Figure 4. *Soil moisture variation*

The system also monitored the water level in the canal using the ultrasonic sensor to ensure that irrigation operations were performed only when sufficient water was available. This additional safety mechanism prevents the system from operating under low water conditions, thereby protecting irrigation infrastructure and ensuring reliable system operation.

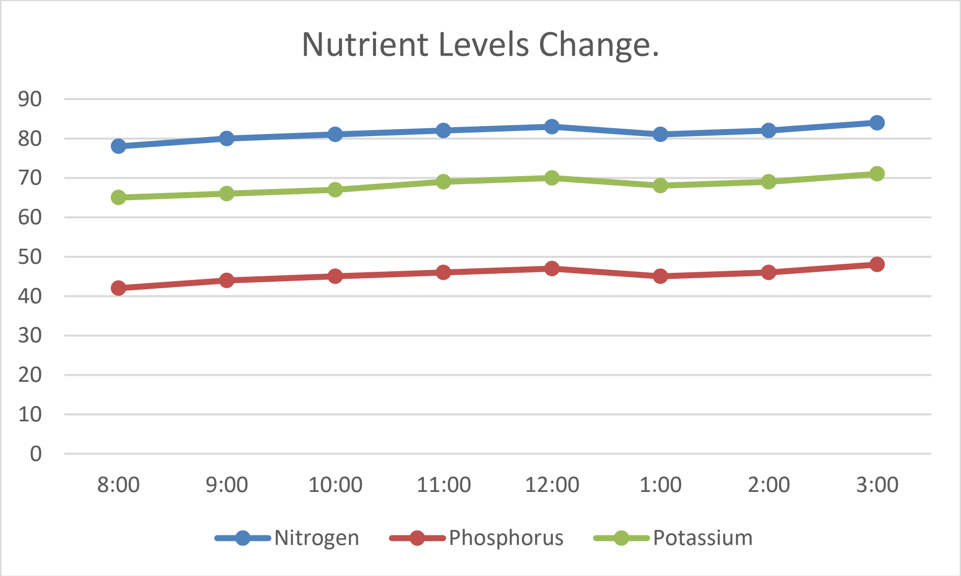

Figure 5. *NPK sensor readings*

The performance of the system was evaluated based on the accuracy of sensor readings, responsiveness of the irrigation control mechanism, and overall system reliability. The results demonstrated that the proposed system effectively integrates sensor-based monitoring with automated irrigation control to improve water management in agricultural environments.

Table 1. Experimental results of the proposed smart irrigation system

Time	Soil Moisture (%)	Canal Water Level (cm)	Water Level Status	Pump Status	Solenoid Valve Status	Irrigation Status
08:00 AM	36	120	Sufficient	OFF	ON	ON
09:00 AM	38	115	Sufficient	OFF	ON	ON
10:00 AM	41	110	Sufficient	OFF	OFF	OFF
11:00 AM	43	108	Sufficient	OFF	OFF	OFF
12:00 PM	39	70	Low	ON	OFF	OFF
01:00 PM	37	65	Low	ON	OFF	OFF
02:00 PM	40	95	Sufficient	OFF	OFF	OFF
03:00 PM	35	105	Sufficient	OFF	ON	ON
08:00 AM	36	120	Sufficient	OFF	ON	ON

The experimental results demonstrate that the proposed smart irrigation system effectively monitors soil moisture levels and automatically controls irrigation operations. When soil moisture levels dropped below the predefined threshold value of 40%, the system activated the solenoid valve and allowed water to flow through the canal gate. Once the soil moisture level increased above the threshold, the irrigation system was automatically turned off. This automated mechanism ensures optimal water distribution and prevents over-irrigation. The NPK sensor successfully measured soil nutrient concentrations during the experiment. The measured nitrogen, phosphorus, and potassium levels were within acceptable ranges for plant growth, indicating that the soil maintained adequate fertility conditions. Real-time monitoring of soil nutrients allows farmers to make informed fertilization decisions and optimize crop nutrition management.

Figure 6. *Final implemented circuit*

The ultrasonic water level sensor also played an important role in ensuring safe irrigation operations. By monitoring the canal water level, the system verified the availability of sufficient water before activating irrigation. This feature enhances the reliability of the system and prevents potential irrigation failures.

So, the proposed smart irrigation system demonstrated reliable performance in monitoring environmental conditions and controlling irrigation automatically. The integration of soil moisture monitoring, nutrient sensing, and automated canal gate control provides a comprehensive solution for improving irrigation efficiency and supporting sustainable agricultural practices.

6. Conclusion

The proposed smart irrigation system combines automated canal gate control with NPK soil analysis to ensure efficient water and nutrient management. Using a microcontroller, the system enables real-time monitoring and reduces water wastage while improving crop productivity. Overall, it offers a cost-effective and sustainable solution for modern agriculture, with potential for future enhancements using IoT and AI technologies.

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Author Declaration

All authors declare that the manuscript is original, has not been published, and is not under consideration elsewhere. The authors report no competing interests and confirm that all have made substantial contributions and approved the final manuscript, with **Midhun Halder** and **Md. Niaz Mostakim** is contributing equally. No external funding was received. This study does not involve human or animal subjects. Data is available from the corresponding author upon reasonable request, and the corresponding author assumes full responsibility for the submission and communication process.

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