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Design and Implementation of an Intelligent IoT-Based Smart Irrigation System with Real-Time GSM Alerts for Efficient Water Management

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Abstract

In an era of increasing demand for agricultural production and sustainable resource management, one of the major challenges in modern agriculture is the inefficient use of water resources in irrigation practices. Traditional methods, which often rely on manual inspection and intuition, frequently result in over-irrigation or under-irrigation, leading to water wastage, environmental degradation, and reduced crop yields. Existing irrigation systems suffer from a lack of precision in water distribution, resulting in inefficient utilization and potential harm to crops and soil health. This research stands as an innovative endeavor to address water resource efficiency, precision and enhance crop yield. This research leveraged on modern technologies such as Arduino Nano, LCD screen, GSM module, soil moisture sensor, and pump motor, to develop an automated irrigation system that integrates real-time soil moisture data with instant SMS alerts. The system utilized a soil moisture sensor to measure soil moisture levels, and upon reaching predetermined thresholds, it activates the pump motor for automated irrigation. Furthermore, the GSM module ensures that farmers receive timely SMS notifications, providing them with crucial information about soil conditions and irrigation status. The system achieved a high communication success rate, peaking at 99%, ensuring reliable real-time updates for farmers. These results confirm the system's reliability, efficiency, and potential to support sustainable agricultural practices.

Keywords: Irrigation; Soil Moisture; Arduino Nano; GSM; LCD

1. Introduction

Irrigation is the artificial application of water to land or soil, either manually or automatically. It supports the growth of agricultural crops, maintains landscapes such as gardens, lawns, and floral areas, and aids in the restoration of disturbed soils in arid regions or during periods of insufficient rainfall. Modern irrigation also enhances crop production by protecting plants, controlling rapid weed growth in fields, and preventing soil consolidation, which occurs due to reduced soil moisture [1]. Around 70–80% of the water used by humans globally is used for crop production in agriculture. In order to transform the planet, an efficient irrigation management system is required due to climate change, drought, and decline in yearly rainfall, and population growth. [2, 3]

One of the major challenges in modern agriculture is the inefficient use of water resources in irrigation practices. Traditional methods, which often rely on manual inspection and intuition, frequently result in over-irrigation or under-irrigation, leading to water wastage, environmental degradation, and reduced crop yields [4]. Over-irrigation depletes

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valuable water resources, damages soil structure, and diminishes its fertility, while under-irrigation causes crop stress and stunted growth. Additionally, traditional irrigation methods are labor-intensive, requiring frequent manual monitoring of soil moisture levels, which is time-consuming and prone to human error [5]. In an era where water scarcity is exacerbated by population growth and climate change, this inefficiency is unsustainable and demands an urgent, precise, and automated solution to optimize water usage, reduce manual effort, and enhance agricultural productivity. Existing irrigation systems suffer from a lack of precision in water distribution, resulting in inefficient utilization and potential harm to crops and soil health. They often lead to over-irrigation, causing water runoff, soil erosion, and nutrient leaching, which further depletes soil quality. Additionally, the absence of real-time monitoring and control capabilities prevents timely interventions, making it difficult to optimize water usage and ensure efficient irrigation management [6-8]. To address these inefficiencies, this research proposes an Intelligent IoT-Based Smart Irrigation System with Real-Time GSM Alerts for Efficient Water Management.

The Internet of Things (IoT) plays a crucial role in modernizing agriculture by enabling seamless communication between devices, sensors, and users. In irrigation systems, IoT technology allows real-time data collection, remote monitoring, and automated control, significantly improving water management efficiency. By integrating sensors with IoT-enabled controllers, farmers can access real-time information on soil moisture, temperature, and environmental conditions through mobile applications or cloud platforms. This connectivity reduces manual labor, minimizes water wastage, and ensures crops receive optimal irrigation. Also, IoT facilitates predictive analytics, helping farmers make data-driven decisions to enhance productivity and sustainability [9-11],

In this research, the Arduino Uno serves as the central processing unit, controlling the operation of various components to ensure optimal irrigation. The soil moisture sensor, an integral part of the system, plays a pivotal role by continuously monitoring soil moisture levels in the cultivated land. When the soil moisture falls below a predetermined threshold, the system triggers the pump motor, initiating the irrigation process. The inclusion of a GSM module offers a crucial layer of connectivity to the system. It enables the seamless transmission of real-time data and alerts to the farmer's mobile device via SMS notifications. These SMS notifications provide critical information about the current soil moisture levels, irrigation status, and any potential system anomalies. Such prompt feedback empowers the farmer with the ability to remotely monitor and control the irrigation process, even from a distance.

Furthermore, the integration of an LCD screen allows for on-site monitoring, ensuring that farmers have immediate access to essential information, thus reducing the need for continuous physical inspection of the fields. The real-time data displayed on the LCD screen serves as a visual aid that complements the SMS notifications, enabling the farmer to make informed decisions regarding irrigation. This system is specific for a crop and hence its usage is limited. Proper scheduling of irrigation is critical for efficient water management in crop production, particularly under conditions of water scarcity. The effects of the applied amount of irrigation water, irrigation frequency and water use are particularly important. To improve water efficiency there must be a proper irrigation scheduling strategy.

2. Literature Review

This section presents various irrigation techniques that have been employed by previous researchers to address the traditional irrigation challenge.

The research of [12] presented the design of a smart irrigation system. In this paper the smart irrigation system was developed using electronics and software engineering to automate irrigation and enable real-time monitoring. It incorporates four sensors Light Dependent Resistor (LDR), Soil Moisture Sensor, Humidity Sensor, and Temperature Sensor to measure key environmental parameters affecting crop growth. The LDR determines light intensity and time of day, assisting in irrigation scheduling, while the Soil Moisture Sensor detects moisture levels to regulate water supply. The system is controlled by a PIC microcontroller, programmed in C++, and features an LCD display for on-site monitoring. Additionally, a mobile application provides real-time updates on temperature, soil moisture, and light intensity, allowing farmers to monitor and manage irrigation remotely. The results showed that the system effectively automated irrigation, ensuring optimal water distribution without human intervention, reducing manual labor, and improving water efficiency. However, its application was limited to a single plant or crop, suggesting the need for future enhancements to support larger agricultural areas with multiple crop types.

In the work of [13], the design on an indigenous automatic irrigation system was proposed. In this work, the developed irrigation system utilizes a locally made soil humidity sensor to monitor soil moisture levels and regulate water supply accordingly. When the soil moisture falls below the required threshold, the system sends a signal to a relay-connected pump, which opens a valve to initiate irrigation. Once the desired moisture level is achieved, the system automatically turns off the water supply using a similar mechanism. Additionally, the system includes six buttons for time-based irrigation control, allowing farmers to irrigate crops that require water at specific times of the day. However, the study does not mention any form of real-time remote notification system, such as SMS alerts or IoT-based monitoring, which limits the farmer's ability to monitor irrigation status from a distance.

In [14] an automatic irrigation system was developed using multi-sensor functionality, incorporating temperature and moisture sensors to monitor soil conditions. The system is controlled by an Arduino MEGA 2560, which processes sensor data and determines the irrigation schedule based on a variant algorithm that adapts to different soil types. When the soil moisture falls below the required threshold, the automated pumping system is activated, turning ON the water pump to irrigate the crops. Once the desired moisture level is reached, the system turns OFF the pump to prevent over-irrigation. Additionally, a mobile monitoring system was integrated, allowing users to remotely track real-time farm conditions and manually control the irrigation process if necessary. The system was successfully implemented on large-scale farms at Management and Science University, Shah Alam, Selangor, Malaysia to test its effectiveness. The implementation of this system led to a significant reduction in water consumption, ensuring that crops received optimal irrigation without wastage. The need for manual labour in farm irrigation was also reduced, making farm operations more efficient. Additionally, the mobile application provided farmers with remote access to irrigation data and manual control options, improving flexibility in farm management. However, despite its benefits, the system has limited adaptability to highly diverse soil and crop conditions, as the variant algorithm may not be universally effective across all farm environments. Additionally, while the mobile monitoring system allows manual control, it still relies on human intervention in certain cases, which may limit full automation.

[15] Worked on the development and implementation of an automatic plant watering system. The methodology involves designing and constructing an automatic irrigation control system using readily available and affordable components to eliminate manual irrigation stress while conserving water. The system was tested on three soil types—sandy, loamy, and clayey—where irrigation duration was measured based on soil dryness levels. The results showed a linear relationship between soil dryness and irrigation duration. At 50% dryness, irrigation lasted 2.0s for sandy and loamy soils and 2.5s for clayey soil, while at 70% dryness, irrigation increased to 3.0s, 7.5s, and 8.0s for sandy, loamy, and clayey soils, respectively. Loamy soil required more water than sandy soil, and clayey soil took the longest to irrigate. However, a key weakness of the system is the absence of IoT integration for real-time communication, preventing remote monitoring and automated adjustments based on real-time environmental conditions, which could enhance efficiency and reduce water wastage.

The research of [16] proposed an IOT based smart irrigation system for Agriculture Transformation. The work presented an IoT-based irrigation system using an Arduino UNO, a Bluetooth module, and a soil moisture sensor to enable real-time monitoring of soil moisture levels. The system allows farmers to set customized moisture thresholds for different crops, ensuring irrigation is activated when moisture falls below the defined level. This prevents both overwatering and underwatering, leading to improved agricultural efficiency. The results demonstrate that the system is user-friendly, unlike previous complex models, making it easier for farmers to operate and interpret. However, the Bluetooth module used suffers from limited range which restricts remote monitoring and control to short distances.

In [17] artificial intelligence technology was proposed to enhance irrigation. The system integrates soil moisture sensors, AI algorithms, and IoT connectivity to optimize water usage. During controlled environment testing, the system achieved an 80% accuracy rate, demonstrating its potential to improve irrigation efficiency and reduce water waste. However, a key weakness is that the system has not yet been deployed in rea-time, raising concerns about its feasibility, affordability, and accessibility, particularly for farmers in underdeveloped regions where informal labour dominates the agricultural sector.

Furthermore, [18] proposed an irrigation system using AI and IoT. The research utilized advanced technologies such as IoT and AI to optimize irrigation, aligning with Agriculture 4.0 principles. Sensors were deployed in controlled environments to collect plant growth data, which was then analysed using various machine learning models, including K-Nearest Neighbors (KNN), Support Vector Machine (SVM), and Naïve Bayes (NB). Among these, KNN demonstrated the best performance, achieving an accuracy of 98.4% and a root mean squared error (RMSE) of 0.016.However, despite the promising results, the study is limited to a controlled simulation environment and has not been deployed in real-time agricultural settings. The absence of real-world implementation raises concerns about its practical applicability, scalability, and adaptability to dynamic field conditions.

Research [19] proposed an Automatic Plant Water System. The Automatic Plant Watering System (APWS) was designed to enhance water management in agriculture through the use of strategically placed soil moisture sensors and a centralized control unit. These components work together to continuously monitor and regulate soil moisture levels. The system is adaptable to different soil types and allows customizable moisture thresholds for various plant species.

Additionally, it integrates real-time weather forecasting to make intelligent irrigation decisions, reducing issues related to overwatering or underwatering. The APWS operates autonomously, features a user-friendly interface, and improves water use efficiency, leading to sustainable farming practices and increased crop yields. However, the system lacks IoT communication capabilities, limiting remote monitoring and control.

In [20] an automated plant watering system that monitors soil moisture levels to determine the optimal time for irrigation was proposed. The system was built using hardware components such as an Arduino UNO microcontroller, soil moisture sensors, pumps, relays, wires, and sprinklers, with software instructions to control these components. This economical watering system was designed to ensure plants receive water based on their specific needs, thereby reducing water wastage and preventing conditions that encourage disease-carrying organisms. The system was tested and demonstrated effective performance in both small gardens and large crop fields. However, while the system effectively automates plant watering and reduces water wastage, the study does not address large-scale implementation challenges, such as scalability, power source sustainability.

3. Material and methods

The methodology in this research focused on both hardware and software implementation for developing an Intelligent IoT-Based Smart Irrigation System with Real-Time GSM Alerts for Efficient Water Management. The hardware component involved the power supply unit, main controller hardware (Arduino Nano board), SIM 800L GSM module, LCD, buzzer, motor driver, moisture sensor, mini water pump. While for the software design, Proteus and Arduino IDE are used.

3.1. Hardware Implementation

The Intelligent IoT-Based Smart Irrigation System with Real-Time GSM Alerts for Efficient Water Management's hardware framework is the physical component of the design, which includes a detailed description of each component and how it interacts with the system as a whole. This includes a thorough explanation of how every piece of hardware, including the liquid crystal display, GSM module, water pump, motor driver, and moisture sensor, works together to enable the intelligent IoT-Based Smart Irrigation System. The accompanying block diagram, which is depicted in Figure 1, offers a high-level illustration of the operating flow of the system. Hardware Design.

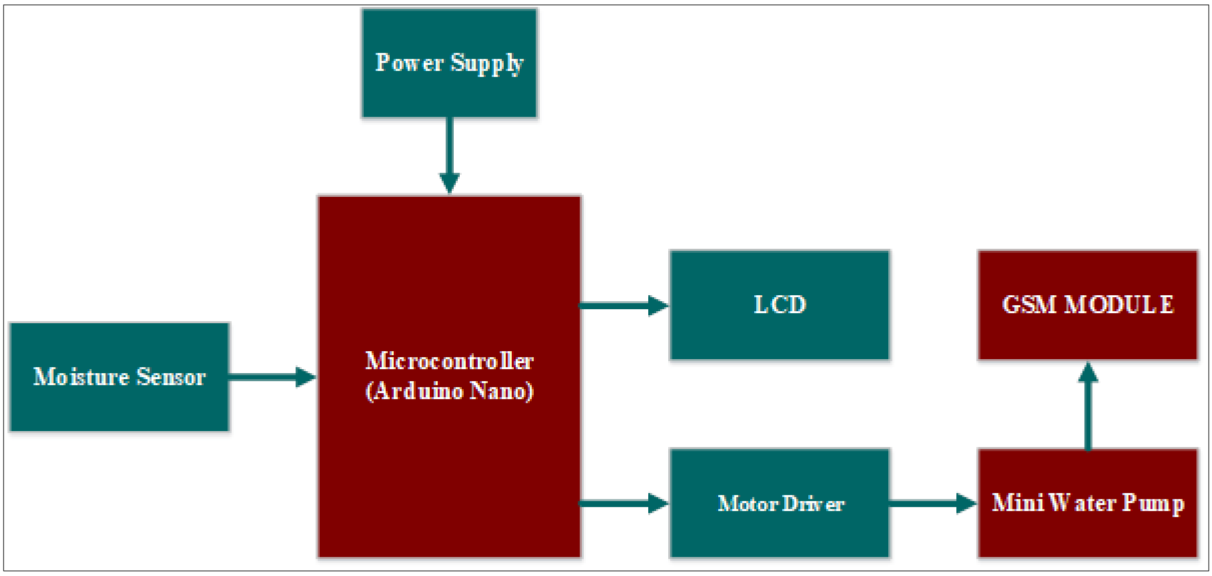

Figure 1 System Block Diagram

3.1.1. Power Supply Unit

In this research, he power unit consists of a transformer, a bridge diode rectifier, filtering capacitors, and voltage regulators. It efficiently converts high-voltage 220V AC into a stable 5V DC output. The process begins with a step-down transformer, which utilizes electromagnetic induction to lower the 220V AC input to 12V AC by adjusting the turns ratio between its primary and secondary windings. This 12V AC is then directed to a bridge diode rectifier, where a full-wave rectification process converts the alternating current into a unidirectional 12V DC by allowing current to flow in only one direction. However, the rectified output still contains ripples, which are minimized through a filtering stage using capacitors. These capacitors charge during voltage peaks and discharge during troughs to smooth out fluctuations. The voltage regulator precisely controls the stabilized 12V DC, ensuring a consistent 5V DC output. Figure 2 depicts the framework of the power supply unit.

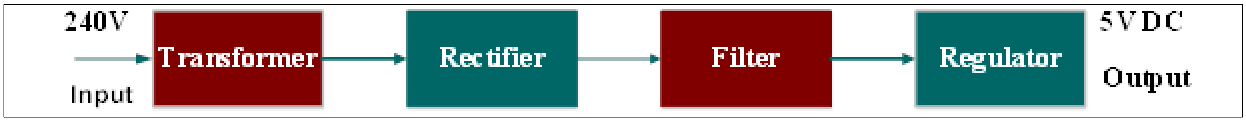

Figure 2 Framework of power supply unit

3.1.2. Microcontroller Unit (Arduino Nano)

The Arduino Nano microcontroller served as the central processing unit responsible for managing real-time data from the sensory unit and controlling the irrigation system accordingly. The sensory unit, consisting of a soil moisture sensor, was deployed to monitor soil moisture levels by measuring the water content in the soil at designated locations. This data was processed by the Arduino Nano in figure 3, using predefined threshold values, analyzed soil conditions and determined the optimal operation of the irrigation system to ensure efficient water usage. The system included an LCD for real-time status display, a motor driver for controlling the mini water pump, and a GSM module for sending real-time alerts to users regarding irrigation activities and soil moisture conditions. The compact and power-efficient design of the Arduino Nano, along with its adequate processing power and compatibility with essential sensors, made it ideal for this research.

Figure 3 Arduino Nano Board

3.1.3. Soil Moisture Sensor

The soil moisture sensor depicted in figure 4 served as the key sensing component responsible for monitoring soil water content in real time. It was deployed within the irrigation system to detect moisture levels by measuring the conductivity or dielectric constant of the soil at designated locations. The sensor transmitted this data to the Arduino Nano, which analyzed the readings against predefined threshold values to determine whether irrigation was required. If the soil moisture level dropped below the set threshold, the Arduino activated the motor driver to turn on the mini water pump, ensuring optimal water distribution.

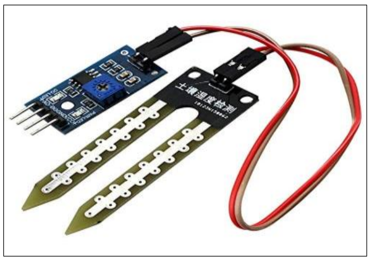

Figure 4 Soil moisture sensor

3.1.4. Liquid Crystal Display

The Liquid Crystal Display (LCD) served as the primary visual output unit responsible for providing real-time information about the irrigation system's status. The display module, typically a 16x2 LCD, was deployed to present critical data such as soil moisture levels, pump status, and system alerts in an easy-to-read format. This data was received from the Arduino Nano, which continuously updated the display based on real-time sensor readings and system operations. The LCD played a crucial role in enhancing user interaction by offering immediate feedback on the irrigation process without requiring additional external devices. The 16x2 LCD employed in this research is depicted in figure 5.

Figure 5 Liquid Crystal Display

3.1.5. GSM Module

The SIM800L GSM Module served as the primary communication unit responsible for sending real-time alerts regarding irrigation system activities and soil moisture conditions. The module, specifically the SIM800L, was deployed to facilitate wireless communication by sending SMS notifications to users, ensuring remote monitoring of the irrigation process. This data was transmitted from the Arduino Nano, which processed real-time soil moisture readings and determined when irrigation was necessary based on predefined threshold values. If soil moisture levels dropped below the set threshold, the Arduino activated the motor driver to turn on the mini water pump while simultaneously triggering the SIM800L module in figure 6 to notify users.

Figure 6 GSM module SIM800L

3.1.6. Water Pump

The Mini Water Pump served as the primary actuator responsible for regulating water flow within the irrigation system. The pump was deployed to deliver water to the soil when moisture levels dropped below a predefined threshold, ensuring efficient and automated irrigation. This activation was controlled by the Arduino Nano, which processed real-time data from the soil moisture sensor and determined when irrigation was necessary. Upon detecting low moisture levels, the Arduino Nano triggered the motor driver, which supplied the required voltage and current to operate the mini water pump. The pump remained active until the soil moisture sensor registered adequate water content, at which point the system automatically deactivated it to prevent over-irrigation and water wastage. The Mini Water Pump used in this research is depicted in figure 7.0.

Figure 7 Mini water Pump

3.2. Software Implementation

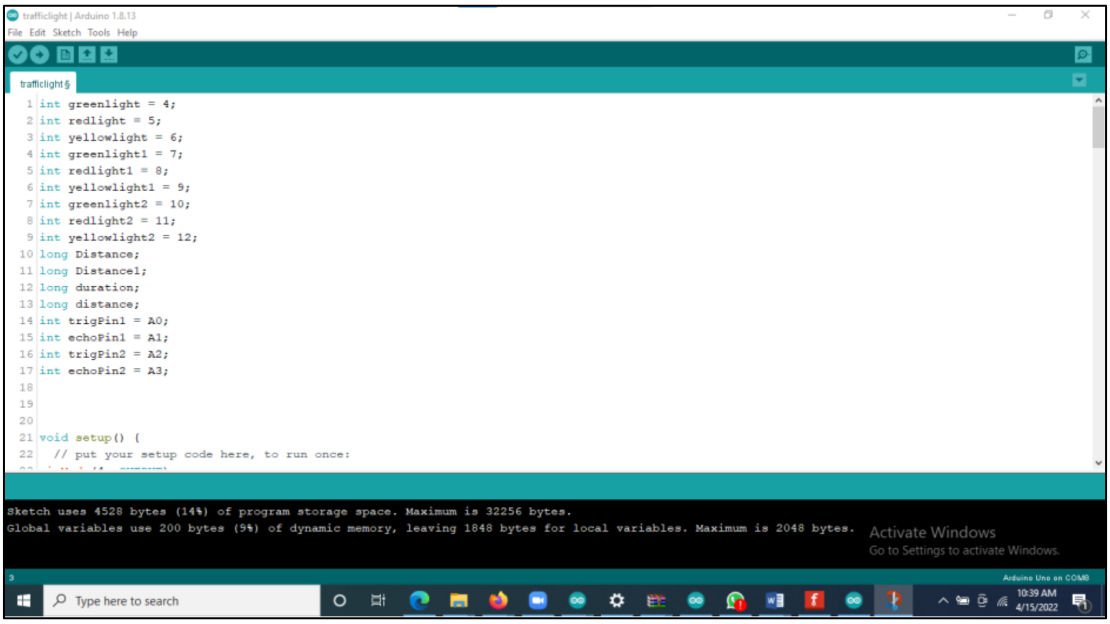

Figure 8 Arduino IDE

The embedded platform was mostly programmed using the C programming language, which made it easier to carry out the system's assigned tasks. The Arduino Integrated Development Environment (IDE) was used to code the software, and its logical structure strictly followed the guidelines of C as depicted in figure 8. The Arduino programming board, which acts as the platform for uploading the software, and the microcontroller unit (microcontroller unit) interact primarily through this IDE. To create this communication architecture, the Arduino IDE was installed on the computer. For authoring, developing, and deploying code to the microcontroller unit, the Arduino IDE uses a "Sketch" tool that offers a full environment. Initialization, assignment, and command execution are the three main categories into which this sketch can be systematically divided. The initialization section specifies the input and output pins that will be used in the overall architecture and includes necessary libraries, like the Wi-Fi library, to expand the program's capability. In order to guarantee that the microcontroller unit interfaces with peripheral devices correctly, the assignment section specifies the pin configuration, designating the chosen pins as either input or output. Additionally included in this section are built-in functions like serial connectivity, which permits real-time data transfer and debugging. Lastly, the sketch's command or instruction section contains the fundamental logic that determines how the program operates. It offers an organized method for testing and improving the microcontroller unit's performance in carrying out its intended functions by defining the repetitive activities that it must accomplish.

3.2.1. Arduino IDE

An open-source program called the Arduino Integrated Development Environment (IDE) was created especially for using and creating Arduino devices. With a wealth of features and tools to make programming better and easier, it offers a complete programming environment. Code editing is the main function of the Arduino IDE, which has several helpful features like syntax highlighting, auto-completion, and error highlighting. Numerous code management tools in the code editor allow users to work with multiple files simultaneously and switch between them easily.

3.2.2. Proteus Software

Proteus software was extensively utilized for designing and simulating the necessary circuits that interface with the irrigation system components. The system requires accurate soil moisture data, typically gathered by sensors such as soil moisture sensors, which detect water content in the soil. Using Proteus, circuit designs for these sensors were created, ensuring proper signal conditioning, amplification, and data acquisition for reliable sensor output. Proteus facilitated the testing of the sensor circuits in a simulated environment, optimizing the sensor interface before real-world implementation. This step ensured that the sensors could effectively monitor soil moisture levels and transmit data to the system, forming the basis intelligent irrigation control. The microcontroller circuit was designed within Proteus, as shown in figure 9, integrating the Arduino code that determines optimal irrigation scheduling based on real-time soil moisture readings. By simulating different soil moisture conditions within the software, the functionality of the irrigation control algorithms was validated, ensuring that the system could adapt to varying soil conditions in real time. Furthermore, Proteus allowed for the integration of control circuits for components such as the LCD, motor driver, mini water pump, and the SIM800L GSM module, providing a comprehensive simulation of the entire smart irrigation system.

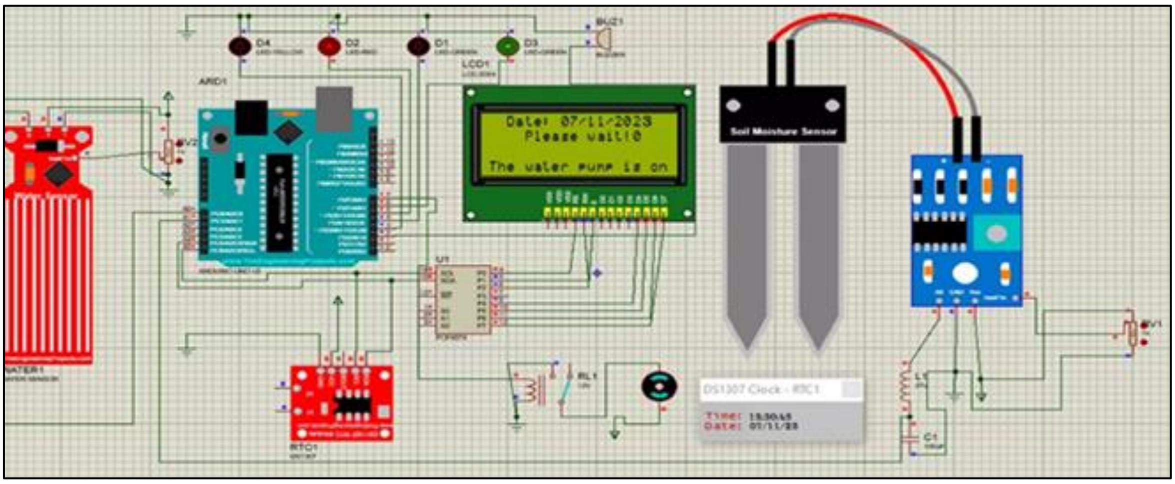

Figure 9 Circuit Design

3.3. Design Analysis

The power unit's filter stage capacitor is chosen based on the ripple on the output of the bridge diode rectifier. The ripple factor is calculated as the root mean square (rms) of the relationship between the ripple voltage (Vrms) and the rectifier's output voltage (Vo). To choose the appropriate capacitor, this information is utilized. To guarantee that the output voltage is steady and within acceptable bounds, the maximum ripple voltage rms permitted in the supply for this study is 2vpp. This minimizes fluctuations that can negatively impact sensitive components. Equation 1 supports the selection of capacitor employed in this study.

$$C = \frac{1}{2\,x\,f\,x\,V_{pp}} \quad \ldots\ldots\ldots\ldots\ldots..(1)$$

Where
C is capacitor value,
f is power supply frequency,
V_{pp} is ripple Voltage.

For this research,

F=50hz

$V_{pp} = 2$

$$C = \frac{1}{2\,x\,50\,x\,2} \quad = 5000\,fardads$$

The capacitor rating was 5000 farads (but what was available for use was 4700 farads).

Also, to determine the total current consumed by the overall circuit, the current consumed by the components in the circuit needs to be known.

LCD current = 20mA
Water Pump= 300mA
Microcontroller current = 200mA
Moisture sensors current = 20-30mA (90mA)

GSM module = 250mA
Hence the total current consumed by circuit is approximately 860mA.

The flowchart of the System flowchart is shown in figure10.

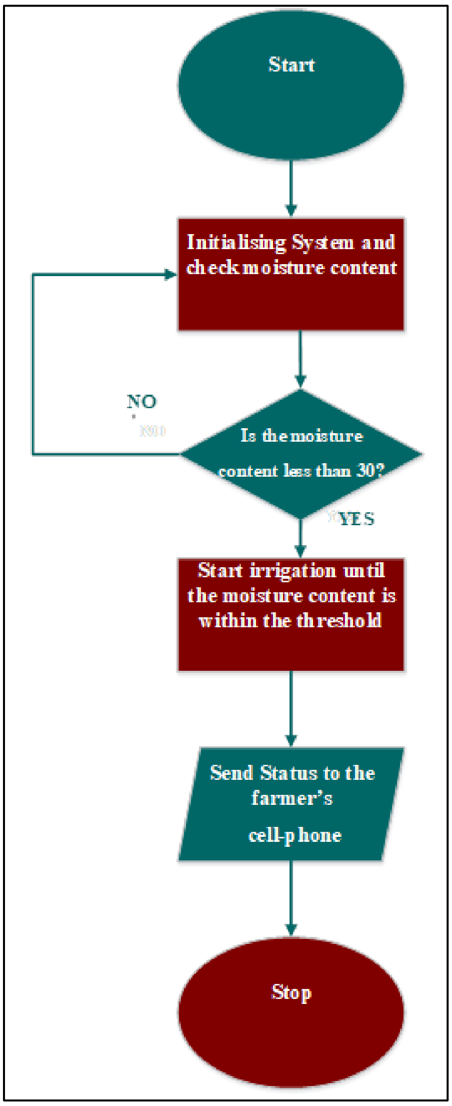

Figure 10 System Flowchart

4. Results and discussion

This section presents the results obtained from the study on the design and implementation of an intelligent IoT-based smart irrigation system with real-time GSM alerts for efficient water management.

4.1. Hardware Implementation

System Packaging and Hardware Configuration was the initial phase, which focused on designing a well-structured irrigation model to support the integration of sensors, water pumps, and control units. This layout was carefully developed to incorporate the necessary operational constraints and facilitate organized, efficient wiring across the system. The next phase was Component Assembling and Circuit Integration. After the irrigation framework was designed, components including wire housing casings, the microcontroller, and water flow sensors were strategically mounted and connected. This assembly process ensured robust connectivity and system integrity for optimal functionality. Sample image from the assembling of components is presented in figure 11.

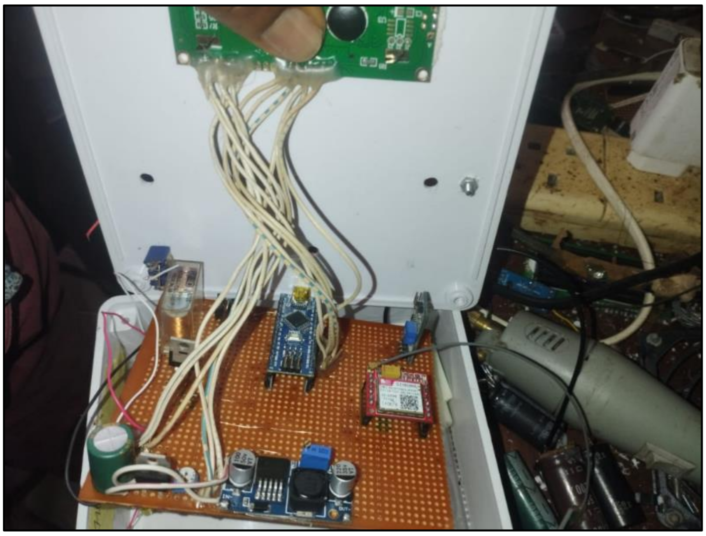

Figure 11 Assembling of components

4.2. Software Implementation

The Arduino IDE and Proteus were the main pieces of software utilized in the development of this research. Through the Arduino IDE, a C program was created to enable communication and interaction between the various components. The micro controller was tasked with carrying out a number of tasks. The proteus was used to model and construct the complete circuit. The codes were inserted into the microcontroller on the proteus environment and then emulated after they had been successfully executed on the Arduino IDE.

4.3. Result and Testing

4.3.1. Soil Moisture Levels over Time

The table 1 and figure 12 present the soil moisture level readings recorded at different timestamps, demonstrating the effectiveness of the intelligent IoT-based smart irrigation system with real-time GSM alerts for efficient water management. At 8:00 AM, the soil moisture level was 30%, gradually decreasing to 22% by noon, indicating water loss due to evaporation and plant uptake. A slight recovery to 28% at 2:00 PM suggests possible irrigation activation in response to the low moisture threshold. The peak moisture level of 32% at 4:00 PM further supports the system's ability to regulate irrigation dynamically. However, the drop to 20% and 18% by 6:00 PM and 8:00 PM, respectively, highlights the need for continuous monitoring and automated water replenishment.

Table 1 Soil moisture level over time

Time stamps	Soil moisture level (%)
2023-11-01 8:00am	30
2023-11-01 10:00am	25
2023-11-01 12:00pm	22
2023-11-01 14:00pm	28
2023-11-01 16:00pm	32
2023-11-01 18:00pm	20
2023-11-01 20:00pm	18

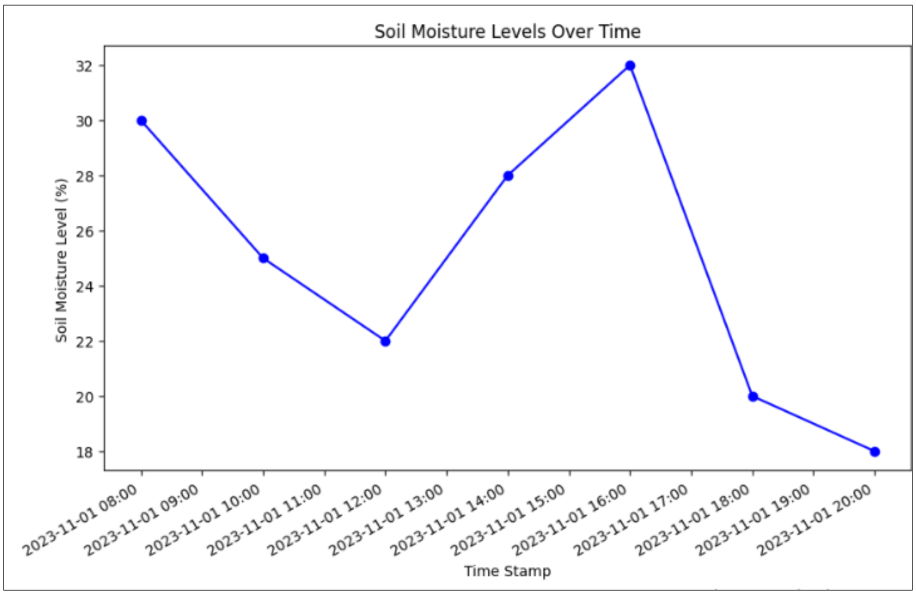

Figure 12 Soil Moisture level over time

4.3.2. Power Consumption Analysis

Table 2 and Figure 13 presents the power consumption analysis of various components in the intelligent IoT-based smart irrigation system. The data illustrates the energy usage of key system elements, including the Arduino Nano, GSM module, LCD screen, soil moisture sensor, and overall power supply unit at different timestamps. The Arduino Nano's power consumption fluctuates between 78mA and 88mA, while the GSM module, responsible for sending real-time alerts, varies between 95mA and 110mA, reflecting its dynamic communication activity. The LCD screen, which displays system status, consumes between 48mA and 55mA, whereas the soil moisture sensor operates within a range of 28mA to 35mA, indicating periodic measurements. The total power supply remains stable, ranging from 11.8W to 12.3W, ensuring efficient operation.

Table 2 Power consumption analysis

Time Stamp	Arduino Nano (mA)	GSM Module (mA)	LCD Screen (mA)	Soil Moisture Sensor (mA)	Power Supply Unit (W)
2023-11-01 08:00am	80	100	50	30	12
2023-11-01 10:00am	82	95	52	35	12.2
2023-11-01 12:00pm	85	105	48	28	12.1
2023-11-01 14:00pm	78	98	55	30	11.8
2023-11-01 16:00pm	88	110	50	32	12.3
2023-11-01 18:00pm	86	98	53	31	12.4
2023-11-01 20:00pm	84	101	51	33	12.2

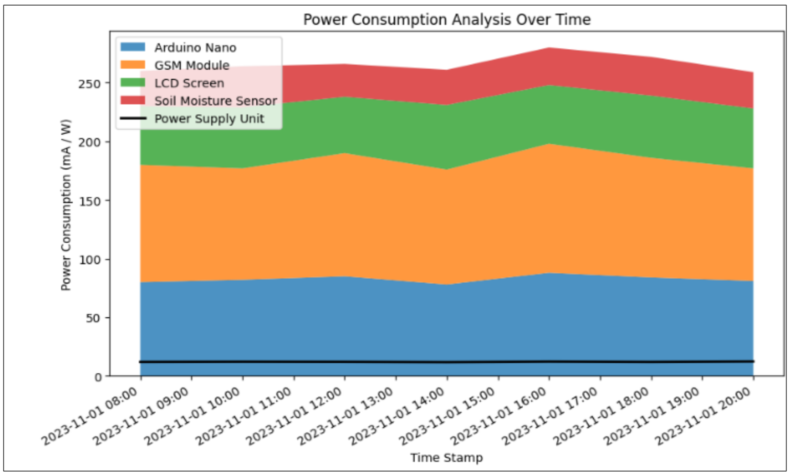

Figure 13 Power Consumption Analysis

4.3.3. Communication Success Rate

The data in table 3 and Figure 14 indicates consistently high success rates, ranging from 94% to 99%, demonstrating the system's reliability in transmitting real-time alerts and data. The highest success rate of 99% at 2:00 PM suggests optimal network conditions, while slight variations at other times, such as 94% at 8:00 PM, may be due to network fluctuations. The overall stability of the communication system ensures that farmers receive timely updates on soil moisture levels and irrigation status, enabling efficient water management and reducing the risk of crop stress due to inadequate irrigation. The mathematical formula for computing the percentage of successful communication is represented by equation 2.

$$Communication\ success\ rate\ (\%) = \left(\frac{Number\ of\ successful\ communicaton}{Total\ number\ of\ communication\ Attempts}\right) \times 100 \qquad (2)$$

Table 3 Communication success rate

Time Stamp	Communication Success Rate (%)
2023-11-01 08:00am	95
2023-11-01 10:00am	98
2023-11-01 12:00pm	97
2023-11-01 14:00 pm	99
2023-11-01 16:00 pm	96
2023-11-01 18:00 pm	98
2023-11-01 20:00 pm	94

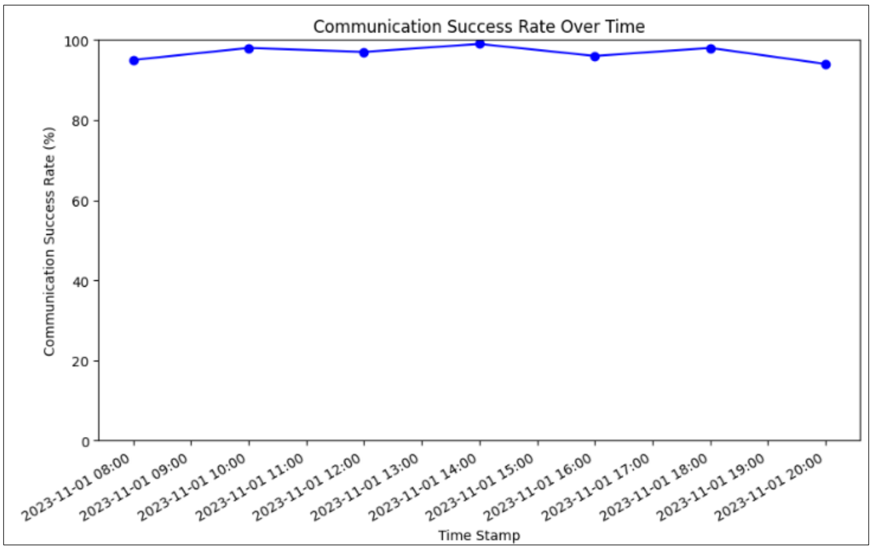

Figure 14 Communication success rate.

5. Conclusion

The design and implementation of an intelligent IoT-based smart irrigation system with real-time GSM alerts was successfully achieved. The prototype system performed as expected, demonstrating reliability and efficiency in operation. The components used are readily available, cost-effective, and function reliably to automate irrigation control. By eliminating the need for manual intervention, the system not only reduces labor but also optimizes water usage, ensuring sustainability. Soil moisture readings showed dynamic regulation, with moisture levels fluctuating, indicating the system's ability to respond to changing soil conditions through automated irrigation. The power consumption analysis revealed stable and efficient operation, with key components such as the Arduino Nano, GSM module, and overall power supply functioning within optimal ranges. Additionally, the system achieved a high communication success rate, peaking at 99%, ensuring reliable real-time updates for farmers. These results confirm the system's reliability, efficiency, and potential to support sustainable agricultural practices. Future study should consider exploring the integration of renewable energy sources, such as solar power, to further enhance the system's energy efficiency and sustainability. Also, implementing advanced machine learning algorithms could improve irrigation scheduling by predicting soil moisture trends based on weather forecasts and historical data

Compliance with ethical standards

Disclosure of Conflict of interest

The authors declare that they have no conflicts of interest.

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