Design and Implementation of Smart Irrigation System

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Abstract
The need for smart irrigation system cannot be over emphasized. The traditional way of irrigation is the use of hose attached to taps or watering can which are sprayed by hand and moved from one place to another manually. However, apart from the fact that this method is stressful, this is not easy to practice on large farm lands. Although water, in some parts of the world is in abundance, it is still a scarce resource in some other regions. In this research, the review synthesizes key findings from various studies, highlighting the importance of automation in enhancing water management efficiency and crop performance. This research provides both smart and effective management of water usage and power consumption of irrigation systems. It presents a smart irrigation system that uses environmental information to determine when and where irrigation is required through use of microcontroller, sensors and integration of water pumps with the decision making system.

Keywords: smart, irrigation, sensor, microcontroller, moisture

1. Introduction

Irrigation generally is a time consuming activity especially when done the traditional way. Achieving this in a reasonable amount of time requires a large number of human resources. Recent irrigation systems unnecessarily flood farm lands and thus results in wastage of water and energy used for pumping it.

Traditional irrigation techniques, such as furrow and flood irrigation, are increasingly being supplemented or replaced by automatic systems. Automatic irrigation provides precise control over water application based on real-time conditions (Irrigation Association, 2019) [1].

Automatic Irrigation Systems are of different types, the Drip Irrigation type Provides targeted watering directly to roots, minimizing evaporation and runoff (Hussain *et al.*, 2020) [2]. The Sprinkler type mimic rainfall and can adjust the application rate based on crop needs and weather (Manna *et al.*, 2021) [3]. While Subsurface Irrigation type delivers water below the soil surface, enhancing moisture retention and reducing weed growth (Ross *et al.*, 2022) [4].

Uroromu *et al.* (2019) [5] established that there are several types of irrigation systems currently used in the agriculture industry and other industries. A system utilizing sprinklers, sprays, or guns mounted overhead on permanently installed risers is often referred to as a solid-set irrigation system. Higher pressure sprinklers that rotate are called rotors and are driven by a ball drive, gear drive, or impact mechanism. Rotors can be designed to rotate in a full or partial circle.

Prince R. *et al.* (2024) [6] proposed a machine learning (ML) and IoT-based model that is trained by the datasets of crops and irrigation models with efficient conditions to predict the best crop type according to the environmental conditions and suitable fertilizer with the optimized irrigation system for the area.

It is a fact that most farms around the world have implemented one form of irrigation system or the other, the major irrigation problems farmers face includes the usage of the limited power and water, means to determine where and when irrigation is required and cost. All these problems are as a result of the inability of most existing systems to measure the condition of the farm, which means that the system does not consider the plant needs thereby leading to over watering or under watering. Additionally, most existing irrigation system cannot provide an efficient irrigation scheduling which leads to unnecessary irrigation practice.

The smart irrigation system provides an efficient and cost effective solution to farming. The systems check the soil moisture and when the level is less, the pump is started or switched off automatically when the moisture level is maintained. Smart irrigation system reduces the farmers work as it can make decisions independently and can also save a significant cost on water and energy bills. The advantages of smart irrigation system includes but not limited to; providing high accuracy water supply thereby avoiding water wastage, accurately determining the soil moisture levels, requiring less man power, detecting and controlling temperature and humidity using sensors, producing good quality crops thus improving economic condition and reducing energy wastage and cost.

This research project is aimed at providing a solution to the over watering and under watering issues, reducing energy cost, improving the irrigation scheduling on the farm by implementing soil moisture sensor, and revolutionizing the traditional irrigation system into a fully automated smart irrigation system.

Productivity in crop production depends on both internal and external factors. Two major external factors affecting productivity are the climatic and edaphic (soil) factors. Success and failure of crops is intimately related to these factors. Due to alarming changes in the climate, farmers cannot rely on natural rainwater but through irrigation, maximum profit can be achieved on investment in agriculture.

Irrigation systems if not properly managed results in unnecessarily flooding farm lands and thus results in wastage of water energy. Regulating water supply for irrigation purposes, thus maintaining required level of soil moisture and reducing energy wastage are reasons the need for smart irrigation system cannot be over emphasized.

1.1 Objective(s)

The objectives are to:

- Evaluate the current state of research on automatic irrigation systems, challenges, and emerging technologies.
- Develop a sensory system to monitor the soil and weather condition.
- Develop a system that can control over watering and under watering issues.
- Develop a system that can take record of essential information during the irrigation process.
- develop a system that sends notifications via SMS

2. Literature Review

Irrigation when not automated sometimes performs when it is not required or delayed when needed. This results in water wastage, energy waste and low productivity among others. These problems are mitigated using smart irrigation system through which when and where to irrigate can be determined precisely.

Rafique *et al.* (2021) [7] implemented a system in which the sensory system consists of soil moisture sensor, temperature sensor and light intensity sensor, which was basically used to monitor soil moisture level, temperature level, and light intensity level at the separate test area. Arduino Mega 2560 microcontroller was used to process data from these sensors and a proper irrigation scheduling was developed based on the data collected. A sprinkler system because it has high uniformity of water distribution to the plant was used, which enable it to spread water efficiency and further optimize the water usage during irrigation process. Ultrasonic sensor was also implemented in the system to measure the amount of water used in each irrigation process performed. Offline data storage was implemented using a micro SD card module, in which all the essential information such as sensory system readings and the amount of water used was recorded and stored into a micro SD card. Thus, the system allows user to monitor their farm's condition, and also gives a better view of happenings on their farm.

Alamgir *et al.* (2016) [8] designed a smart irrigation system that deals with the automatic operation of the pump to supply water in the field depending on the soil moisture by programming in ATMEGA328. The system could be operated using solar energy or even the DC voltage converted from AC.

An intelligent irrigation system based on STM32 and BC95 was designed and implemented by Xiaofei *et al.* (2021) [9]. The soil information was received through temperature sensor and humidity sensor, which was sent from the sampling node to the remote terminal serial port. The controller sends the signal to the output end for intelligent irrigation. The practice shows that the wireless communication mode of data transmission using STM32 and NB-IoT (narrow band-internet of things) technology can meet the requirements of reducing the time cost and enhancing the reliability of the system, and can meet the goal of data transmission of intelligent irrigation system and water-saving irrigation.

Uroromu *et al.* (2019) [5] presented a novel automated irrigation system that works by continuously monitoring the soil moisture content and wirelessly activating the pipeline valves to open when the moisture level drops below the minimum threshold for the cultivated crop, causing the land to be irrigated. When the moisture level rises above the maximum threshold, the system deactivates the irrigation pipeline valves, causing them to close and ceasing land irrigation. The design automated irrigation system is customizable and can also be used to upgrade existing drip irrigation systems, surface irrigation systems, and sprinkler irrigation systems to overcome their existing limitations.

Ravi kumar *et al.* (2018) [10] worked on monitoring the soil's moisture content during its dry and wet conditions with the aid of a moisture sensor circuit, calculating the corresponding relative humidity and irrigate it based on its nature using a PC based LabVIEW system, NImyRIO, IOT, GSM and an automatic water inlet setup which can also monitor and record temperature. The system maintains a record of soil moisture, temperature, rainfall in a database for backup. This backup is used for weather forecasting and directs the farmers regarding the type of crop to be cultivated in future. IOT gives the whole information to the operator about the irrigation.

Brijesh *et al.* (2020) [11] designed and Implemented soil moisture based irrigation system that utilizes the soil moisture sensor, which detects the moisture level of the soil. This system further includes a standalone soil moisture control unit operatively connected to the irrigation controller and the soil moisture sensor. The soil moisture control unit includes programming configured to calculate an estimated soil moisture requirement value using a signal from the soil moisture sensor and to automatically send the notification to the farmer about the low moisture level. The farmer needs to authenticate and start the pump with the mobile application or website for crop suggestion with the use of moisture content (mc %). When the soil moisture is maintained the pump is automatically switched off. Notification is sent to the farmer's mobile or website. This system saves water and improves the health of the crops.

Ogidan *et al.* (2019) [12] presented a smart irrigation system suitable for use in places where water scarcity is a challenge.

The paper therefore presents a smart irrigation system that optimizes the available water in the water reservoir thus providing an efficient and effective water usage solution for the irrigation system. The irrigation system is able to automatically start/stop water pumps on the irrigation site based on the soil moisture content acquired from the moisture content sensor as well as the ultrasonic sensor measuring the water level in the reservoir. The measured sensor values are sent to the Arduino microcontroller for configuring the control algorithm. The system prioritizes irrigation operation by determining the number of pumps to be operated at any instance as well as their locations. In this way, different crops can be watered depending on their varying water requirements. In order to implement the design, a laboratory scale architectural model depicting a farm setting with reservoir, direct current (DC) pumps and the control unit was constructed. Experimental results revealed good performance which makes the developed system a suitable tool for studies on irrigation.

Ayush (2019) [13] used correct soil moisture sensors which help to ease out the pain of monitoring and keeping records about the changes in soil moisture. Using the Arduino Mega micro controller with Light-Depended Resistor sensor, moisture sensor and temperature sensor, temperature are measured and analyzed. The soil for certain duration provides information related to the moisture status of the soil. The Arduino Mega collects and process the data received from the Sensors. When a threshold moisture level of the soil is reached, the water is supplied accordingly.

Souparno and Saikat (2018) [14], in their project developed a system such that whenever there is a change in temperature and humidity of the surroundings the sensors senses the change in temperature and humidity and gives an interrupt signal to the micro-controller.

An automatic irrigation system that switches (ON/OFF) a pump motor by sensing the moisture content of the soil using wireless technology was developed by (Sirisha & Krishna, 2017) [15]. Through GSM Modem, moisture content data sensed is sent as an SMS to the user. The project used 8051 series microcontroller, which is programmed to receive the input signal of varying moistures of the soil through sensors. This was achieved by using an op-amp as comparator which acts as interface between the sensing device and the microcontroller. Once the controller receives the signal, it generates an output that drives a relay for operating the water pump.

Aishwarya (2017) [16] proposed an Irrigation System aimed at fulfilling water requirements of the crops, by monitoring the soil moisture and other environmental parameters. The system which was based on Internet of Things, logs the sensor data to the cloud and the farmer can monitor and control all the water pumps remotely over internet using Android application. It consists of wireless sensor node with Arduino publishing sensor data to cloud using Wi-Fi module and controlling the pump using relay.

Singla *et al.* (2019) [17] highlighted how to smartly and automatically control the water supply to agricultural fields according to the need. Sensors used are soil moisture sensor and DHT-11 temperature sensor and all information sent to the farmer mobile application using Wi-Fi Relay Module and Arduino UNO R3.

Priyadharsnee and Rathi (2017) [18] designed a system that monitors the soil parameters like soil moisture, temperature and electrical conductivity and automates the irrigation process. Decision making is done through microcontroller.

3. Methodology

The operation of this system involves data acquisition, data processing, actuation and information display

3.1 Data Acquisition

Here, the micro-controller receives data from the soil moisture sensor in the form of analog values ranging between 0 and 1023. The soil moisture sensor has an inbuilt resistance which is varied according to the moisture present in the soil.

3.2 Data Processing

The microcontroller processes the data acquired from the soil moisture sensor.

3.3 Actuation

The microcontroller uses a relay to switch the pump. The relay both controls the pump and provides complete electrical isolation for the micro-controller. The relay switching the pump ON or OFF is dependent on the program running on the micro-controller.

3.4 Information Display

The LCD receives information from the micro-controller via the I2C interface, displays the soil moisture level in percentage. The LEDs indicate extreme cases of low soil moisture that require pumping or adequate soil moisture level and the direction of water flow as the case may be.

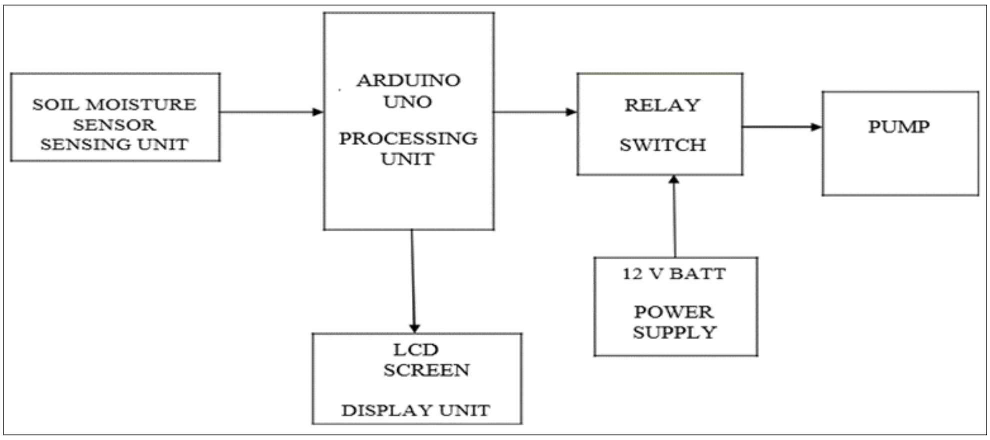

Fig 1: Block diagram of automatic irrigation system

The block diagram of the implemented design is as shown in figure 1. The microcontroller is the Central Processing Unit (brain) of the system. The temperature sensor was connected to the microcontroller and used to measure the temperature on the field. The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade). A Humidity sensor was also connected to the microcontroller and measures and regularly reports the relative humidity in the air. The warmer the air is, the more moisture it can hold, so relative humidity changes with fluctuations in temperature. Also connected to the microcontroller is the soil moisture sensor that estimates volumetric water content. The microcontroller sends signal to the motor to either start or stop pumping water for irrigation depending on the signal received from the various sensors.

3.5 The Circuit

The power supply provides 5V using a converter from 3.7V battery. The positive terminal of the battery was connected to the positive terminal of the converter while the negative battery terminal was connected to the negative terminal of the converter. The converter 5V output was connected to the microcontroller. The relay module controls the operation of the submersible pump.

The temperature and humidity sensors measures ambient temperature and humidity. Their connections are as follows: V_{CC} terminal connected to 5V on the microcontroller, GND terminal connected to GND on Microcontroller. Data (D_o) terminal connected to pin 2 on Microcontroller.

The GSM Module sends SMS notifications. Its V_{CC} terminal was connected to 5V on microcontroller, GND terminal connected to GND on microcontroller, T_X and R_X were connected to appropriate pins on microcontroller for serial communication.

The soil moisture sensor is used to measure the moisture content present in the soil. When the soil moisture value read by the sensor is above the threshold value, low level (0V) will be the digital output and if it is below the threshold level, high level (5V) will be the digital output. The digital pin is used to directly read current soil moisture value to see if it is above threshold or not. The threshold voltage can be regulated with help of potentiometer depending on the soil type and crop type to be planted.

Soil moisture sensor has a comparator (LM393) which helps in converting analog data to digital data easy for the processing purpose. Two probes of 5 cm in length are responsible for collecting and transferring data when it is immersed in the soil. The voltage output from the sensor corresponds to the conductivity of the soil. The moisture content in the soil is determined by the type of the soil and is given as change in resistance value of the sensor. The resistance across soil probes can vary from infinity (for completely dry soil) to a very little resistance (for 100% moisture in soil). This variation in resistance across the probes (R_S) leads to variation in forward-bias voltage.

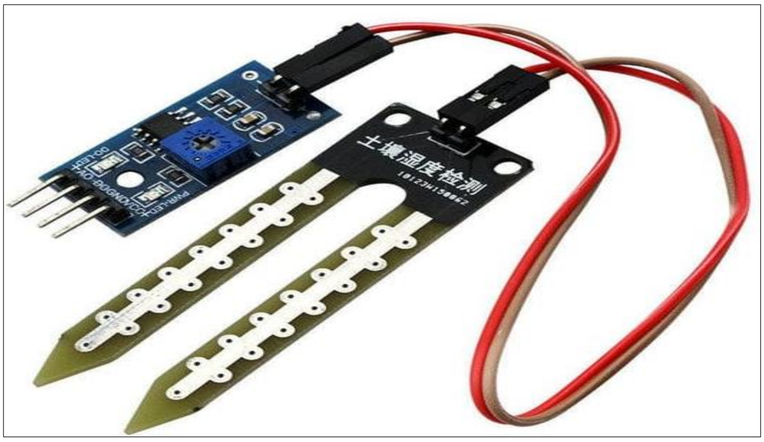

Fig 2: Soil moisture sensor

The Vcc terminal of the moisture sensor was connected to 5V on microcontroller. GND terminal was connected to GND on the microcontroller.

The LCD Screen with I2C Interface displays system status and sensor readings. It was connected as follows: VCC: Connected to 5V on the microcontroller, GND: Connected to GND on microcontroller, SDA: Connected to A4 on the microcontroller, SCL: Connected to A5 on microcontroller.

3.6 Principle of operation

The system was designed to automate the irrigation process based on real-time soil moisture data and also send notifications via SMS. This was achieved using C++ programming language.

When the soil moisture sensor detects low soil moisture, it sends a signal to the microcontroller. The microcontroller in turn sends signal to the relay module connected to a submersible pump thereby activating the pump. The SIM module, which has a SIM card inserted, sends a text message to the registered phone number, indicating that the soil moisture is low. The message also includes the current temperature and humidity values detected by the temperature and humidity sensors connected to the microcontroller.

Once the moisture sensor detects that the soil moisture is back to normal, it sends another signal to the microcontroller to turn off the pump. The SIM module then sends a follow-up text message confirming that the soil moisture is normal, along with the updated temperature and humidity readings.

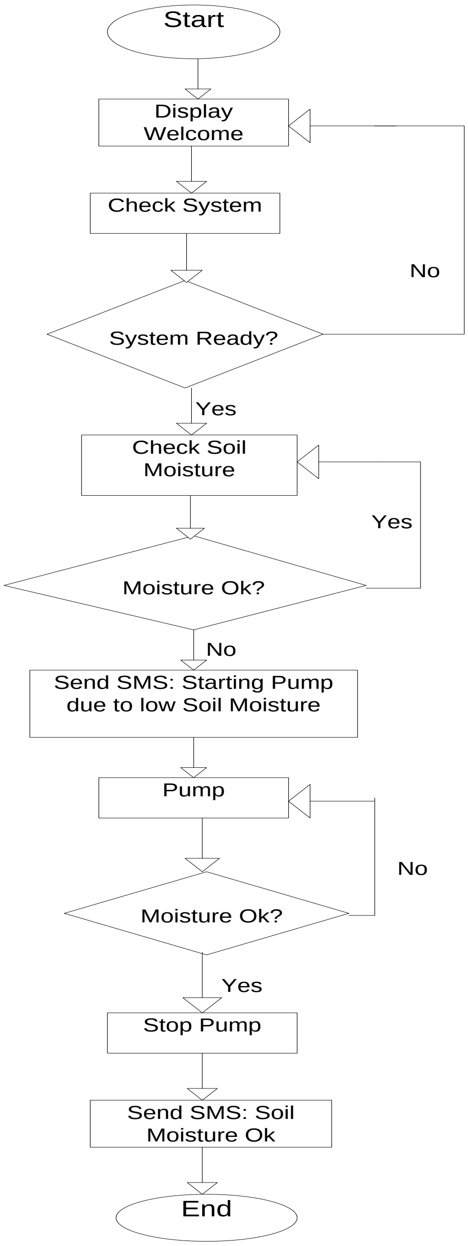

Fig 3: The Flowchart

4. Test, result and discussion

Soil water thresholds are specific values of SWC indicating water availability for plant consumption. These thresholds are used to determine when and how much irrigation is needed (Datta *et al.*, 2017) [19].

Table 4.1: Typical soil water thresholds for different soil textures samples

Soil texture	Field capacity (%)	Permanent wilting point (%)
Sand	10	4
Loam sand	16	7
Sandy loam	21	9
Loam	27	12
Silt loam	30	15
Sandy clay loam	32	18
Sandy clay	32	18
Clay loam	29	18
Silty clay loam	28	15
Silty clay	40	20
Clay	40	22

Source: Ratliff *et al.* (1983) [20]; Hanson *et al.* (2000) [21]

Table 4.2 presents the performance of three different soil types during irrigation: clay, loamy, and sandy which was carried out in the western part of Nigeria in the month of October. Each soil type has distinct characteristics that influence water retention and moisture levels. The table includes information such as the weight of dry soil, standard moisture level (field capacity), target moisture level (within field capacity), the quantity of water needed for optimal moisture content, soil temperature, humidity levels, and the time required to achieve the target moisture level. This data is essential for effectively managing irrigation practices and ensuring optimal plant growth under various soil conditions. Understanding these parameters allows better water resource management and improved agricultural productivity. Soil moisture level depends on factors such as climate, crop types, and environmental conditions.

Field Capacity is expressed as a percentage of water in the soil; with typical Volumetric Water Content in percentage values ranging from 20% in sandy soils to 40% in clay soils. Field Capacity is a property of the soil type only. It is not impacted by the type of crop in the soil (Gould, 2024) [22].

Table 4.2: Result

Parameter	Clay	Loamy	Sandy
Dry Soil Weight (kg)	5.5	5.5	5.5
Weight of Soil after Irrigation (kg)	6.05	5.775	6.05
Field Capacity (%)	20-40	15-25	5 – 15
Moisture Level after Irrigation (%)	30	20	12
Quantity of Water Used (Liter)	1.5	1	1.2
Time Used to Achieve Target Soil Moisture (minutes)	7	4	5
Temperature of the Soil Before Irrigation (°C)	25	24	20
Temperature of the Soil After Irrigation (°C)	25	24	20
Humidity Level of the Soil Before Irrigation (%)	40	35	30
Humidity Level of the Soil After Irrigation (%)	50	45	32

Soil temperature and humidity

The soil temperature before irrigation is consistent across all three types, recorded at 25°C for clay, 24°C for loamy, and 20°C for sandy soil. This relatively warm temperature supports biological processes essential for plant growth, such as seed germination and nutrient uptake. In terms of humidity, clay soil has the highest level at 40%, indicating it retains moisture effectively. Sandy soil exhibits the lowest humidity level at 30%, suggesting it loses moisture more quickly. Loamy soil, with a humidity level of 35%, strikes a balance between moisture retention and drainage.

Quantity of water required

To achieve the desired moisture levels, clay soil requires the most water, at 1.5 liters, due to its dense structure and tendency to hold water tightly. This can make it more challenging for plants to access moisture. Loamy soil, needing only 1 liter of water, reflects its optimal balance between drainage and moisture retention. Sandy soil requires 1.2 liters, which is less than clay but slightly more than loamy soil. This variance highlights the distinct water retention capabilities of each soil type.

Time used to achieve target soil moisture

The time required to reach target moisture levels also varies among the soil types. Clay soil takes the longest at 7 minutes, a reflection of its dense structure and high water retention capacity. Loamy soil requires just 4 minutes, demonstrating its efficient moisture management. Sandy soil takes 5 minutes, indicating that while it drains quickly, careful monitoring is necessary to ensure adequate moisture levels are maintained.

Wet soil weight after irrigation

After irrigation, the weight of the wet soils demonstrates the changes in moisture content. Clay soil weighs 6.05 kg, loamy soil weighs 5.775 kg, and sandy soil also weighs 6.05 kg. The increase in weight after irrigation illustrates how much water has been absorbed, further emphasizing the differences in water retention and the effectiveness of irrigation for each soil type.

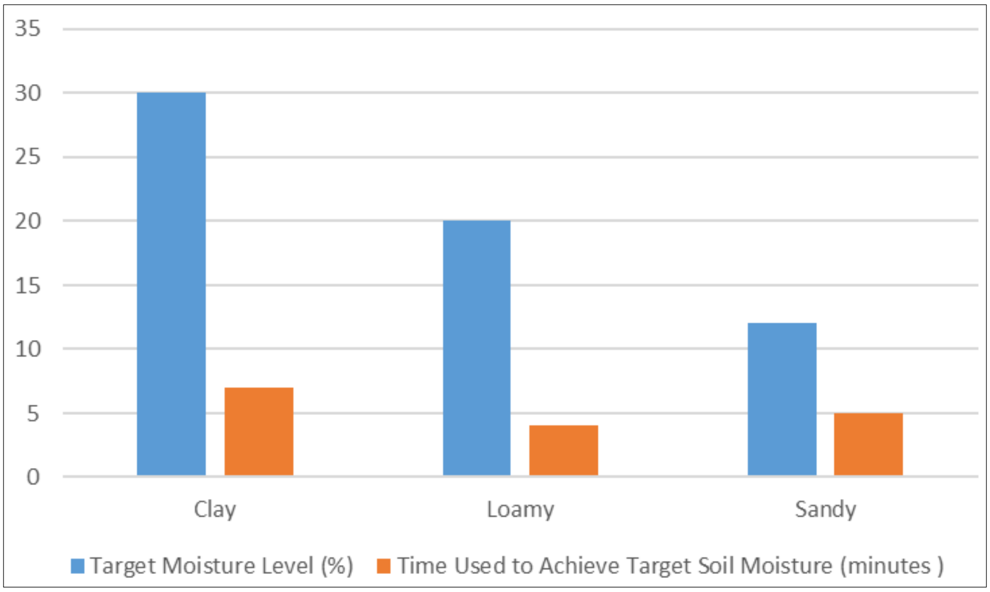

Fig 4: Target Moisture Level and Time to Achieved Target Moisture plot

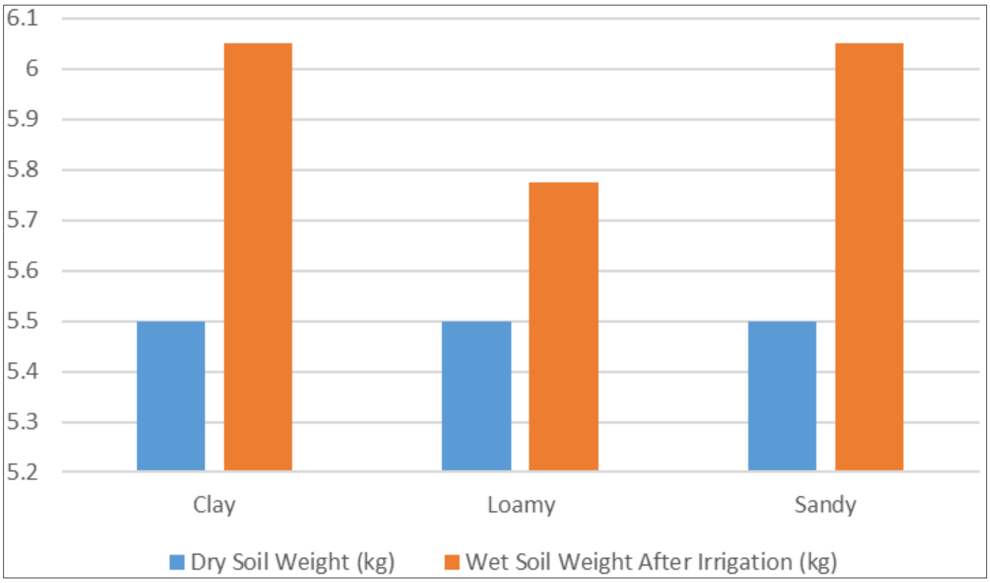

Fig 5: Dry Soil and Wet Soil Weight after Irrigation

5. Conclusion and Recommendation

5.1 Conclusion

The automatic irrigation system designed and implemented in this paper has demonstrated its effectiveness in managing soil moisture levels for different soil types, including clay, loamy, and sandy soils by utilizing a combination of sensors, microcontroller, and a GSM module. The system automates the irrigation process based on real-time data, ensuring optimal water usage and enhancing agricultural productivity. The results indicate that the system efficiently identifies when soil moisture falls below acceptable levels and activates the irrigation pump accordingly. The ability to send SMS notifications provides users with timely updates, allowing better monitoring and management of irrigation schedules. This functionality is particularly valuable in regions where water conservation is critical.

5.2 Recommendations

To enhance agricultural efficiency, developing a mobile application for remote operation will allow users to manage their crops more effectively from any location. Integrating data analytics to assess historical moisture data and weather patterns will allow predictive capabilities for irrigation, thereby enabling the system to anticipate irrigation needs based on forecasted data. Finally, designing the system to be scalable will allow for adaptation to larger agricultural fields and different crop types, broadening its applicability across various farming operations.

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