# Smart-Solar Irrigation System (SMIS) for Sustainable Agriculture

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**Abstract.** This study seeks to develop an automated solar-powered irrigation system. This will provide a cost-effective solution to the traditional irrigation method. This project is aimed at designing a system that harnesses solar energy for smart irrigation and allows for more efficient way to conserve water on the farmland. The system developed is portable and is designed to be adaptable to existing water system. The system incorporates wireless communication technology established using NRF module. For easy operations, the system can be controlled via an Android app-enabled with Bluetooth network. The user experience allows selection of either manual control for scheduled irrigation or automatic control using wireless sensors.

## 1 Introduction

Agriculture is the foundation of Africa's economy and the major source of food in any nation, therefore, improving this sector plays a crucial role in building sustainable systems and growing any economy. Around 70% of Africans are rural dwellers and are mostly of the poor populace which depends majorly on agribusiness to maintain sustainability and employment. Agribusiness is the principal wellspring for sustenance for 60–70% of the populace in sub-Sahara Africa. This sector is confronted with several difficulties making it hard to meet its main role of nourishing the country [1].

The increasing growth of the global population with over 7 billion individuals and an estimated increase of 9.6 billion by the year 2050 [2] shows that there is a need to double generation and production within a discreetly brief time. This will be essential in achieving the Sustainable Development Goal (SDG) 1 and 2, "NO POVERTY" and "ZERO HUNGER". There is a need to change the traditional agricultural practice in order to meet the rising demands of food security thus contributing effectively to the reduction of poverty and hunger in the economy.

Recently, 90% of food production in sub-Saharan comes from small-scale farmers, cultivating on an exact piece of the 70% of arable land accessible, depending on rainfall


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as opposed to irrigation [3]. Agriculture practice in Africa is faced with numerous challenges some of which includes:

1. Poor Power Supply to Farms
2. Poor Irrigation, Fertilization and Drainage System
3. Poor Transportation Network
4. Limited access to funds
5. Poor Farm Mechanization

These challenges have made agricultural practice frustrating for the farmer and also contributed to the poor turn-out in large-scale farming. This study, however, focuses on automated irrigation system with a clean and affordable power supply which is a major factor associated with large-scale farming in Africa.

Automating Irrigation system is an intelligent or artificial application of water for effective agriculture and cultivation production. This condition is essential for insufficient rainfall with its focus on supplying satisfactory quantity of water at the right time for improving growth and development of farm produce. In agricultural irrigation, the effects of the applied amount of water, the timing of irrigation and water utilization are particularly important. With the increasing water requirements in irrigation systems, there is a need for an automated water system with scheduling features to save about 80% of the water thus, improving water efficiency and agricultural productivity in general particularly under conditions of water scarcity [4]. The rest of the paper is divided into sections where: Sect. 2 gave a comprehensive description of the literature review and Sect. 3 gave a detailed methodology. The system implementation and testing is discussed in Sect. 4 and the conclusion and future recommendation is summarized in Sect. 5.

## 2 Literature Review

The major limitations in sustainable agricultural development and advancement in the sub-Saharan include the crude way in farm practices and production, low efficiency and poor technological adaptation. Thus, current headway is the need for a system that makes the agricultural process simpler and stress-free for farmers thereby increasing the annual/seasonal production through creating an agro-driven environment. Several works has been done by researchers globally, in developing a smart irrigation controller system.

### 2.1 Related Work

Various methodologies have been adapted to implement most of the smart irrigation systems over the years. This technology includes the use of wireless communications, weighing lysimeter technique, SCADA systems for supervisory and Artificial Neural Network (ANN).

### 2.2 Irrigation System Based on Wireless Communication Technologies

This section describes the various types of wireless communication protocols and its standards that are being adopted in agriculture varying from Zigbee wireless protocol, Bluetooth, Wifi, GPRS, etc. The fast advancement of wireless communication and embedded micro-sensing electromechanical systems (MEMS) technologies has made wireless sensor networks (WSN) possible.

[5] designed an autonomous solar-powered irrigation system using GPRS, Zigbee, and Radio connectivity. The system designed to consist of two major units; the wireless sensor units and the wireless information unit linked together using radio transceivers. The wireless sensor is configured using ZigBee technology and firms the sensors, a microcontroller, and power sources. Several wireless sensors can be utilized in-field to configure a distributed sensor network for the automated irrigation system. [6] presented a soil moisture sensor to estimate the soil volumetric water content. The sensor is based on the soils dielectric constant also known as soil bulk permittivity. In his design, the temperature of the soil was measured using LM35 wrapped-in. The temperature and the soil moisture level measured are read using an Arduino Uno and the analog values are converted appropriately and the result is displayed on the LCD while it is also sent to the control room located few distances away from the farmland sent wirelessly using Bluetooth technology.

[7] proposed an automated wireless watering system which has a user-friendly interface to notify with information regarding the system status. The system was designed to enable the user with the option of operating it manually or automatic and also provides a data history of the activities of the system. [8] proposed a wireless sensor technology to automate the Indian agricultural systems. The proposed system was able to control several data such as Humidity, Soil Moisture, and Soil pH using the wireless sensor nodes which serve as inputs to the Peripheral Interface Controller (PIC). These data are continuously monitored by the controller and a GSM modem was incorporated to send SMS to the farmer. The summary of the cons and pros of wireless communication technology is depicted in Table 1.

**Table 1.** Pros and cons of a wireless communication technology.

| Wireless communication technologies | |
|---|---|
| Pros | Cons |
| 1. Enables remote monitoring and control by User or farmer | This is a major barrier to implementing IOT enabled irrigation because it tends to increase the cost by acquiring internet services |
| 2. Enables collecting, storing and sharing of data through web servers for agricultural improvements | |
| 3. Mobile Application and GSM communication are easily integrated with the system and enable instant notification of system operations | |

## 2.3 Irrigation System Based on Weighing Lysimeter Technique

A lysimeter is a device used in agronomy to measure the volume of incoming water (rainfall and irrigation) and water coming out (drainage, evapotranspiration) of a container containing an isolated mass of soil [9]. [9] designed an irrigation system based on a weighing lysimeter for potted plants. The system consist of a triangular platform that supports the pot rests on three load cells located at their vertices and are used to measure the weight. In order to measure the irrigation water, a high-precision low-range flow meter was required. [4] developed a prototype smart watering system for small potted plants. The system consists of a microcontroller (ATmega328), moisture and temperature sensors, water pump and the servo engine. The pros and cons of the lysimeter techniques are represented in Table 2.

**Table 2.** Pros and Cons of weighing Lysimeter technique.

| Weighing Lysimeter | |
|---|---|
| Pros | Cons |
| 1. Accurate crop evapotranspiration data is gathered | Complex and not cost effective |
| 2. Efficient in irrigation timing and drainage use | Limited to potted crops only and requires a lot of precision<br>Implementation on large scale farming is difficult |

## 2.4 Irrigation System Based on SCADA Software

Supervisory Control and Data Acquisition (SCADA) is a PC framework for the gathering and examination of real-time information [10]. This utilizes a focal framework that examines and controls the entire configuration of other systems, which is stretched over distances of long range. [10] developed and implemented a solar-powered irrigation system using SCADA software. The parameters used are the soil moisture condition, suns position, water level condition, etc. The pros and cons are listed in Table 3.

**Table 3.** Pros and Cons of SCADA softwares.

| SCADA | |
|---|---|
| Pros | Cons |
| 1. SCADA systems are good software's for supervision and monitoring and processes real-time data | SCADA systems are expensive and difficult to implement on a small scale farms |

## 2.5 Irrigation System Based on Artificial Neural Network

Recently, "Machine to Machine (M2 M) and ANN" communications is getting more attention, the capacity of information transfer among gadgets to servers or Cloud through core networks enables ANN systems to learn fast. ANN control systems can be utilized to accomplish the definitive point of water management on farmland [11]. [12] proposed the application of ANN controllers using MATLAB for irrigation purposes. The parameter used in the proposed study is based on natural temperature and water content in the soil. The experiment was demonstrated using environmental conditions, evapotranspiration and the kind of crop. However, the measure of water required for the water system is assessed and related outcomes were evaluated. [13] developed an intelligent IOT based Automated Irrigation system where sensor information relating to soil dampness and temperature gathered and likewise, kNN arrangement machine learning calculation sent for analyzing the sensor information for expectation towards flooding the soil with water. This is a completely automated with devices communicating with the other and apply the intelligence in irrigation. This has been created utilizing minimal cost embedded systems like Arduino Uno, Raspberry Pi3.

Considering the existing work on automating irrigation system there are needs for a more enhance Agric-support system with efficient power, cost-effective and functional system in rural areas and beyond. Table 4 shows the overview of related study based on automatic irrigation system.

## 3 Design Methodology

This section gives a detailed description of the proposed system design and its specification. Considering the cost of manpower, cost of powering a pumping machine, and cost of effectively monitoring of an irrigation process within a large expanse of farmland, there is a need for a smart irrigation system. The Solar Smart Irrigation System (SMIS) is designed to specific requirements. These requirements are categorized as follows;

1. Hardware requirements
2. Software requirements

### 3.1 Hardware Requirement

This stage is divided into two main parts namely the central control unit and the sensor units. The central control unit act as the brain of the entire system and its major role is to coordinate and manage the activities of the different parts of the system which include the solar panel, battery, microcontroller (ATmega328), solenoid valve and the float channels. While the sensory units consist of the soil moisture sensor for gathering data about the soil moisture content and send feedback to the central control unit automatically. Wireless communication was established between the central control unit and the sensory part using near radio frequency (NRF4L). Each of the sensor unit and the central control unit is designed to have an independent solar power supply built with the system. The block diagram of the system is shown in Fig. 1.

**Table 4.** Overview of related works.

| Author | Power | | | Micro-contoller | | | | | | | Operation mode | | Sensor types | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | AC | DC | Solar DC | Arduino | Other | Zigbee | GSM | GPRS | SCADA | Webserver | Automatic | Manual | Moisture sensors | Humidity sensor | PH sensors | Temperature sensors |
| [14] | * | | | * | | | | | | * | * | | * | * | | * |
| [15] | | | * | | * | | | * | | * | * | * | * | | * | * |
| [4] | | * | | * | | | | | | | * | | * | | | * |
| [10] | | | * | | * | | | | * | | * | * | * | | | |
| [16] | | | * | | * | | * | | | | * | | * | | | |
| [17] | * | | | | * | | * | * | | | * | | * | | | * |
| [18] | | | * | * | | | | | | | * | | * | | | |
| [19] | | | * | | * | | | | | | * | | * | | | |
| [20] | | * | | * | | | | | | | * | | * | | | |
| [21] | | | * | | * | | | | | * | * | | | | | |
| [9] | | * | | * | | | | | | * | * | | * | | | |
| [6] | * | | | * | | * | | | | | * | | * | | | * |

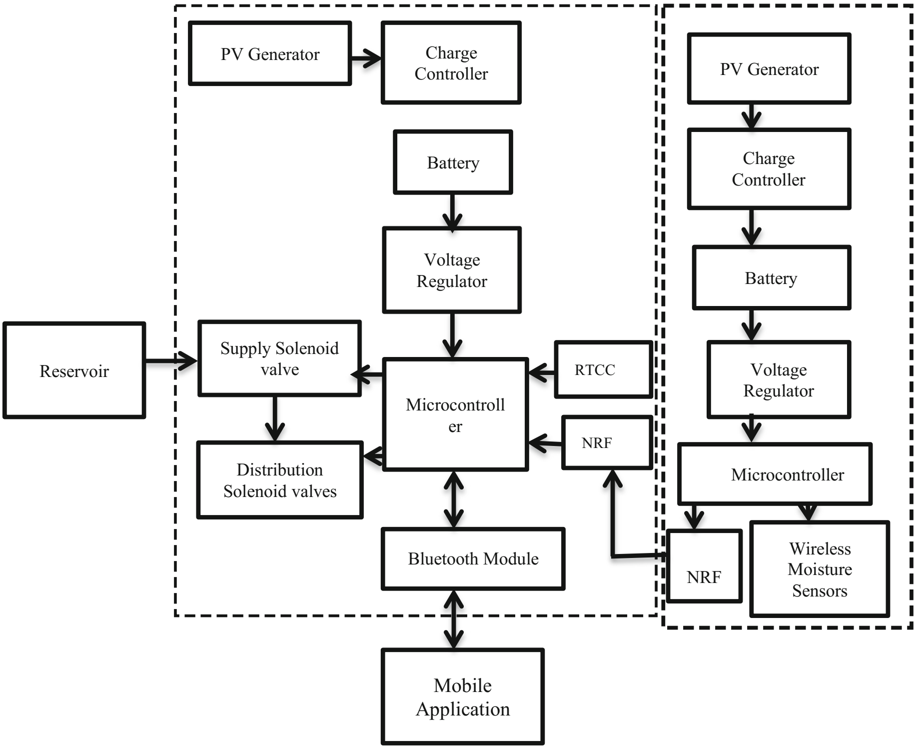


**Fig. 1.** The architecture of the proposed Solar Smart Irrigation System (SMIS)

In a bid to design a portable and compact irrigation system, the design of the water flow was considered to be built and housed within the main controller. The flow of water is channeled from the reservoir or storage tank to the inlet of the controller where the actuators are placed. This system is designed to have two outlets for each sensory unit as shown in Fig. 2.

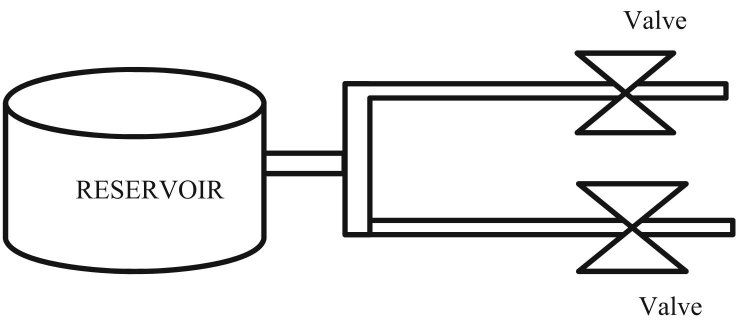


**Fig. 2.** Schematics Piping Channels of the proposed system

### 3.2 Software Requirement

The SMIS was designed to enable the user operates the system manually from a control room using Bluetooth technology. The mobile application is built to function on Android Operating System. The choice of Bluetooth network as a communication link between the mobile application and the hardware device is based on the power consumption, cheaper and less complexity when compared with ZigBee or Wi-Fi technology. The flexibility of the proposed system allows users to decide the mode of the system operation and it, however, allows interoperability of mode operations from automatic or manual. The flowchart diagram for the proposed SMIS system is depicted in Fig. 3 and the algorithm for the mobile application is shown in Algorithm 1.

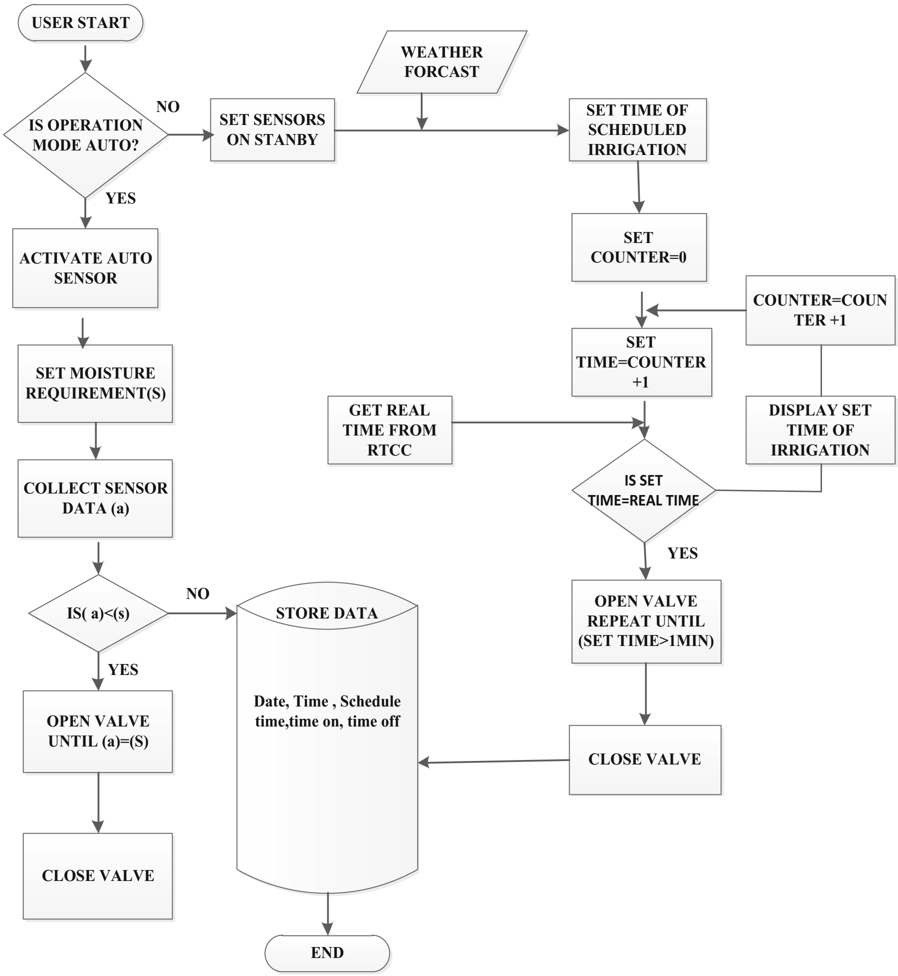


**Fig. 3.** The flow diagram for the Proposed SMIS system

Algorithm 1. Algorithm for the Mobile Application

```
   Input { procedure (mode): auto, manual sensor data ‘data’, soil

moisture threshold       s, current time tc, time on to, set time ts}
Output: {open valve Vo, closed valve Vc }
Start
     Step 1: if (mode == auto)
     {
            activate_sensory_unit()
            while True: # run in a loop
            data = sensor_data();
     Step 2: if (data < s)
     {
            if (Vc == True)
            {
            open_valve()
            continue;
            }
     Step 3: else if (Vo == True)
            {
                   continue
            else{
                   close_valve
                   }
            }
     Step 4: else if (mode == manual)
            {
            if (to== ts)
            {
                   while True: # run in a loop
            }
            if (tc== to)
            {
                   open_valve()
            }
            else if (tC > tS)
                   {
                   close_valve()
            } else {
                   Continue
            }else {
            return 'mode must be either manual or auto !!'
            }
     }
End;
```

## 4 System Implementation and Testing

This section described the implementation of the system with discussion of required equipment used in effectively developing the system and the distinctive programming used in implementing the objectives of the system. In addition, different parts of the system were examined and tested in order to ensure that the proposed system plays up to its required capacity.

### 4.1 Hardware Implementation

The hardware implementation consists of the following engineering practical steps which include the circuit Boarding Process, PCB Design, Soldering of Components, and Packaging.

**Circuit Boarding Process:** The control unit and the sensing unit were simulated on a bread board to ascertain the workability of all components before the system is completed. During the course of bread boarding, copper jumper cables were us to establish connections between components and the Arduino microcontroller. The soil moisture sensor connected to the wireless transmission link was also simulated. 5 V power supply from the USB was used in the simulation process.

**PCB Design:** Printed Circuit Board (PCB) is cards made for connecting modern electronics components together. It represents the electrical schematics in the physical implementation. However when partitioning the PCB layout, the component positioning is very important. Components are grouped into logical functional blocks. The PCB layout of this system was properly designed using Proteus software.

**Soldering of Components:** After the boarding process is completed and the PCB design is ready, the components were placed on the PCB pad and soldered on the traces to establish a permanent connection as shown in Fig. 4.

**Packaging:** The Control Unit part of the system was packaged using plastic casing with the solar panel mounted on it. In packaging the system some design consideration was taking into account to ensure smooth operation of the system. The solar panel was properly positioned on the top layer of the casing. The inlet and outlet piping system were properly sealed and aligned to avoid water leakage. The sensory unit was packaged in a plastic casing fitted with a cylindrical pipe to enable the soil moisture sensor to penetrate the soil as depicted in Fig. 5. The Figs. 6 and 7 shows the snapshot of control unit and the sensory unit.

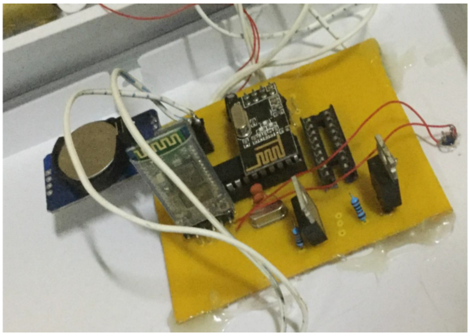

**Fig. 4.** The soldered components of the control unit

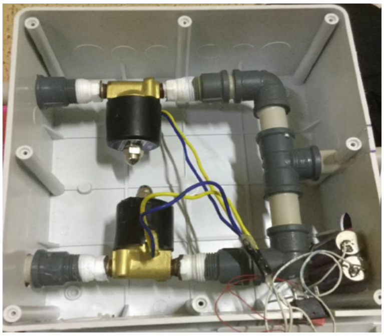

**Fig. 5.** The packaging of the Control Unit

Fig. 6. The Control Unit

Fig. 7. The Sensory Unit

### 4.2 SMIS Mobile Application Implementation

The Android mobile application was developed using React Native. React Native is a JavaScript framework for building native mobile applications. It allows for large amounts of inbuilt components like camera, GPS, and APIs. React Native has the native ability just like normal Android Java, Native Mobile and is faster.

Other JavaScript packages are used to implement this project together with React Native. These are a subset of libraries that enables some special features. For the implementation of the Bluetooth communication, react native – Ble-Plx was deployed. Geo Location API is deployed to get to the location of the system. Open Weather API was also deployed to get the real-time weather of the location. Figure 8 shows the screenshot of the SMIS mobile application.

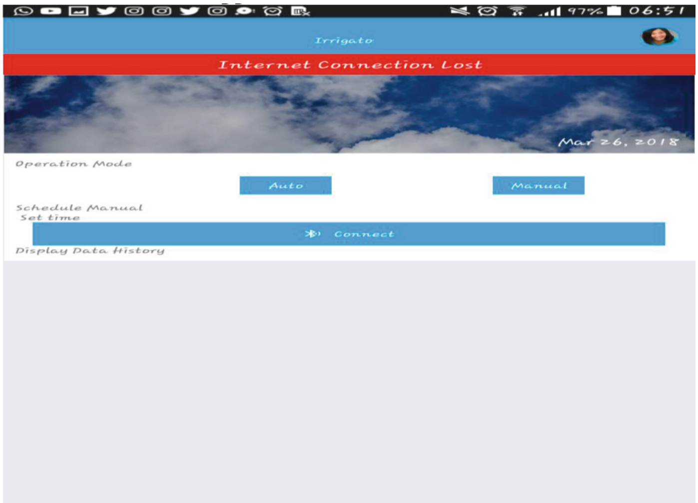


Fig. 8. Screenshot of SMIS mobile application

### 4.3 Testing

In this section, different tests were conducted to monitor and verify the operations and performance of the developed system. The key tests conducted in this project are:

1. Unit Testing
2. Integration Testing
3. System Testing

**Unit Testing:** The system developed consists of different components and two (2) major subsystem which was coupled together to obtain the whole system. Tests on units independent of one another were carried out such as the resistance and capacitance values before circuit connections. The solar panel was tested in order to ensure that it provides the necessary voltage and current supply when it is connected to charge the battery. The transistors, capacitors, and resistors were also tested in order to ensure that they were functioning properly. The NRF and Bluetooth module were individually tested to ensure functionality and connection from varying range. The power supply unit of each subsystem consists of 5 V solar panel connected to charge the storage battery of 3.7 V. The test was carried out using millimeters to take the readings of the solar panel and the battery to ascertain how much voltage is stored and how long it takes to be fully charged. The control unit consists of the microcontroller, solenoid valve, the Bluetooth module and the NRF receiver for communication with the sensor unit. The sensory unit consists of the soil moisture sensor and the NRF transmitter. Each unit was tested to ensure compatibility and functionality within the subsystem.

**Integration Testing:** The interaction between separate subsystems of the project was evaluated using the integration testing including the user application software. Table 5 shows the various voltage levels obtained at different outputs of the system. The expected values obtained during the system design and the practical values obtained during the implementation of the project are also compared.

**Table 5.** Test results of the system power efficiency.

| S/N | Outputs/Inputs | Expected values | Practical values |
|---|---|---|---|
| 1 | Battery Output at full charge | 7.4 V | 7.8 V |
| 2 | Input at the Solenoid Valve | 3.3 V | 3.8 V |
| 3 | Input at microcontroller | 5 V | 5 V |
| 4 | Input at NRF module | 3.3 V | 3.5 V |
| 5 | Input at Bluetooth module | 3.3 V | 3.6 V |

**System Testing:** The full operation of the system was tested from the user's experience using the mobile application developed for control of the systems full operation. The complete system was tested for correct operation by applying the system to irrigate different soil samples. Figure 9, shows the amount of time the system took to irrigate different soil samples in different initial states.

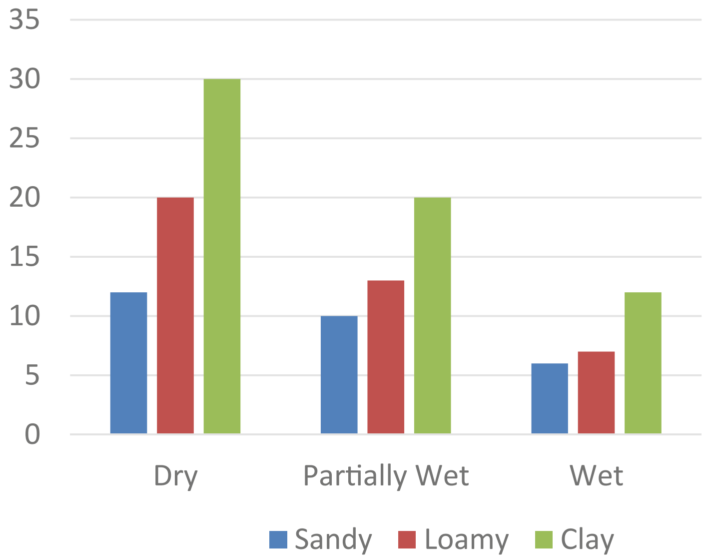


**Fig. 9.** Graph of irrigation time against soil samples.

The result from Fig. 9 shows the time taken for the different soil sample in a one-square meter container to get irrigated in the three (3) initial states. It can be deduced from the graph that the system was able to irrigate a effectively a dry soil, sample for the soil type: sandy soil, loamy and clay soil at 12 s, 20 s and 30 s respectively. While irrigating a partial wet soil for sandy, loamy and clay gave a 10 s, 13 s, and 20 s respectively. The time taken to irrigate a wet soil sample for sandy, loamy and clay are 6 s, 7 s, and 12 s respectively.

## 5 Conclusion

The climatic changes in sub-Sahara Africa nations has made sustainable agriculture quite challenging due to the harsh sun radiation, scarcity of water which is completely up to individual's water generation. These factors however, have been coined towards the development of a smart solar irrigation system with the aim of addressing the challenges of power consumption and water management for sustainable agriculture in the sub-Sahara Africa. The system incorporates solar panels as its power source which enables the system to work effectively without the need of an AC source. Water management is achieved by the timely operations of the solenoid valve controlled by the microcontroller. The experimental result shows effectiveness of the proposed system with the practical values being so close to the expected result. In conclusion, the efficiency of the system guarantees that only the right amount of water need is supplied to the farmland and it can operate both automatically and manually for scheduled irrigation. Further study is to enhance the system over the internet using advanced mobile application.

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