Smart Farm System for Irrigation and Flood Control Using Sensor Nodes

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ABSTRACT

Agricultural sector plays an important role in economic growth, yet it's not without challenges like drought, flooding etc, which results to poor yield. This work developed a robust smart system to enhance both irrigation and flood control to boost agricultural production. In the system's implementation, Arduino based instrumentation, integrated with temperature, soil moisture and water level sensors was adopted to monitor the agricultural environment, while reporting the status wirelessly through the Radio Frequency (RF) modules operating at a frequency of 433MHz with a wavelength of 0.69m, to the base station. The base station evaluated the received data and either activated or deactivated the irrigation or drainage pump using specified threshold values. The remote reporting of the state of the farm was done by deploying a 900MHz transmitter. The work was validated through an experimental test bed, which was used for field experiments, data collection and evaluation. The operational test of the system showed that the soil sample was effectively irrigated when dried and evacuated excess water when over flooded. These results highlight the potentials of smart technology in monitoring and control of both irrigation and flooding within the farm and in turn boost the productivity.

***KEYWORDS**: Flood; Moisture; Sensors; Irrigation; Testbed*

1. Introduction

Irrigation is the artificial application of a controlled amount of water to the soil through various systems of tubes, pumps, and sprays. Irrigation is used to assist in the growing of agricultural crops, watering livestock, maintenance of landscapes, revegetation of disturbed soils in dry areas and during periods of inadequate rainfall, preventing soil consolidation, dust suppression, etc. It is often studied together with drainage, which is the removal of the surface and sub-surface water from a given area. Within many regions of Nigeria, however, insufficient precipitation during the critical portions of the growing season (September to April) may decrease productivity. In these areas, irrigation of agricultural crops is required to maintain high growth rates and yields.

Irrigation intensity (the volume of water used for irrigation per unit area) varied widely by crop type. The irrigation intensity of these crops decreases in this order: Fruit crops, Hay, Field crop, and vegetable crops (Uroromu et al., 2019). There are several limitations inherently in most current irrigation systems used today. Most of these systems are not able to detect when the crops require moisture or water. It is left to the farmers to decide when the crops need to be watered, and their knowledge and experience in determining this crucial factor affecting optimum crop productivity varies. Also the current irrigation systems are unable to determine when the crops have received sufficient water during and even after irrigation. Most farmers simply estimate the volume of water to be dispersed or distributed during irrigation, but they are unable to determine if and when their crops have received sufficient water. Over–irrigation of crops also has adverse effects on some crops just as inadequate water also has negative effects on optimum crop productivity.

It is not only sufficient for water to be supplied to a field for optimum yield; the need to ensure that the level of water required by the crop does not exceed a threshold level is also of paramount importance. Many farmers have helplessly watched their crops destroyed by flooding which arose as a result of river overflowing their banks owing to heavy rainfall. About 75 per cent of Nigerian farmers were estimated to have been affected by the ravaging effects of drought and flooding in 2020 as shown by a survey conducted by SBMIntel, an Africa focused research firm, in seven states of Nigeria namely Nasarawa, Osun, Benue, Oyo, Kastina, and Lagos. In fact, in Kebbi alone, above 500 000 hectares of farmland were destroyed by flooding, with the cost being upward of 5 billion naira (Abdukareem, 2021). These extreme climatic events witnessed by many states of the country triggered the negative effects being noticed on the prices of staple foods.

2. Literature Review

(Devika et al., 2014) aimed at supplying water to plants when the need arose with little or no human interference. The system consisted of a number of moisture sensor placed at different positions in the field. The moisture sensors measured the level of moisture in the soil and sent the signal to the Arduino if watering was required. The motor/water pump supplied water to the plants until the desired moisture level was reached. However, this system is only suitable for low to medium field because of the wire network interconnectivity necessary for its efficient operation. This short coming is overcome in the proposed system by making it wireless thereby suitable for large farm area.

(Madhu et al., 2014) probed into the design of irrigation system based on Arduino and IoT technology**.** It was designed in an effort to enhance an automatic irrigation strategy that controlled the pumping motorized via turning the machine On or Off. The decision taken by the microcontroller was based on the output of the moisture sensor. When the sensor sensed the dryness of the soil, it communicated the controller which sent signal to activate the water pump for the irrigation of the farm land. The major drawback of this system is its inability to suspend the operation of the irrigation pump when the temperature is high though the soil is dry. This therefore leads to water wastage by evaporation during irrigation. Interfacing thermistor (temperature sensor) with the microcontroller solves this limitation.

(Thilagavatsh et al., 2016) created an automated irrigation mechanism which turned the pumping motor ON and OFF by detecting the dampness/moisture content of the earth. To achieve this aim, the Op-amp was configured here as a comparator. The comparator monitored the sensors and when sensors sensed the dry condition, the system would switch on the motor; the motor is switched off when the sensors became wet. The major drawback of this system was the use of op-amp as the controller. This made the system to be rigid, that is, difficulty in adjusting it to suit changes in some parameters like soil type, etc, because the op–amp is not reprogrammable. Also, its response to signal is slow. The use of microcontroller in the propose design makes it reprogrammable (flexible), scalable, and of high speed.

(Matenge, 2017) aimed at determining the most efficient soil moisture monitoring method in an intelligent remotely monitored system and to automatically water the field when the need arises. The system was controlled by Microcontroller and programmed using LabVIEW Software. It made use of soil moisture sensors and actuators, which collected data and sent it to microcontroller for interpretation. The microcontroller then sent the data to Personal computer or an android mobile phone for real time monitoring and controlling activities by the farmer. This allowed the user/farmer to control farming activities from anywhere automatically without manual labour intervention. But in the event of network failure which is often inevitable especially in a developing world, the plants will be denied of the necessary action of the farmer until the network issue is resolved. Besides, it still requires the input of labour. In this proposed work, the shortfall is well taken care of by completely transmitting all commands wirelessly without human intervention.

(Ufoaroh et al., 2016) made use of a water and herbicide reservoir where water and herbicide are stored. A microcontroller was used as the central control unit that controlled the whole activity of the system. The humidity sensor detects the presence of water in the soil. Temperature sensor, (LM35) is used to detect the environmental temperature. A buzzer sounds an alarm to alert when it is time for herbicide to be applied to the farm. An AC-pump helps to draw out water and liquid herbicide from the reservoir to the sprinkler system and the sprinkler sprays the exact quantity of the liquids required on the farm provided that both the temperature and the humidity of the soil are within the pre-set range. The use of thermistor in this proposed design which is smaller, cheaper, more sensitive, more accurate, and covers wider temperature range instead of LM35 as the temperature sensor makes the proposed system more efficient.

3. Methodology

The method of monitoring the soil moisture will be employed in this work. By this method, the amount of water applied to the agricultural products is minimized and it reduces crop production cost. This proposed system is to be designed to continuously sense the moisture level of the soil. The system responds appropriately by watering the soil with the exact required amount of water and then shuts down the water supply when the required level of soil moisture is achieved. The reference level of soil moisture content was made to be adjustable for the three most common soil samples (sandy, loamy and clayey soils). The moisture sensor is designed using probes made from corrosion-resistant material which can be stuck into soil sample. Voltage levels corresponding to the wet and dry states of the soil sample will be computed by measuring the resistance between the moisture detector probes and matching them to output voltages of a comparator circuit. A micro water pump will be used to deliver the water to the soil. The required irrigation time will be determined by considering the response time of the water pump and the water volume required per irrigation instance.

3.1 Description of the Proposed System

The proposed system is broadly divided into two units namely: the Remote Sensing Unit and the Remote Control System Unit

3.1.1 Design description of the Remote Sensing Unit (RSU)

The figure 1 below shows the block diagram of the entire system

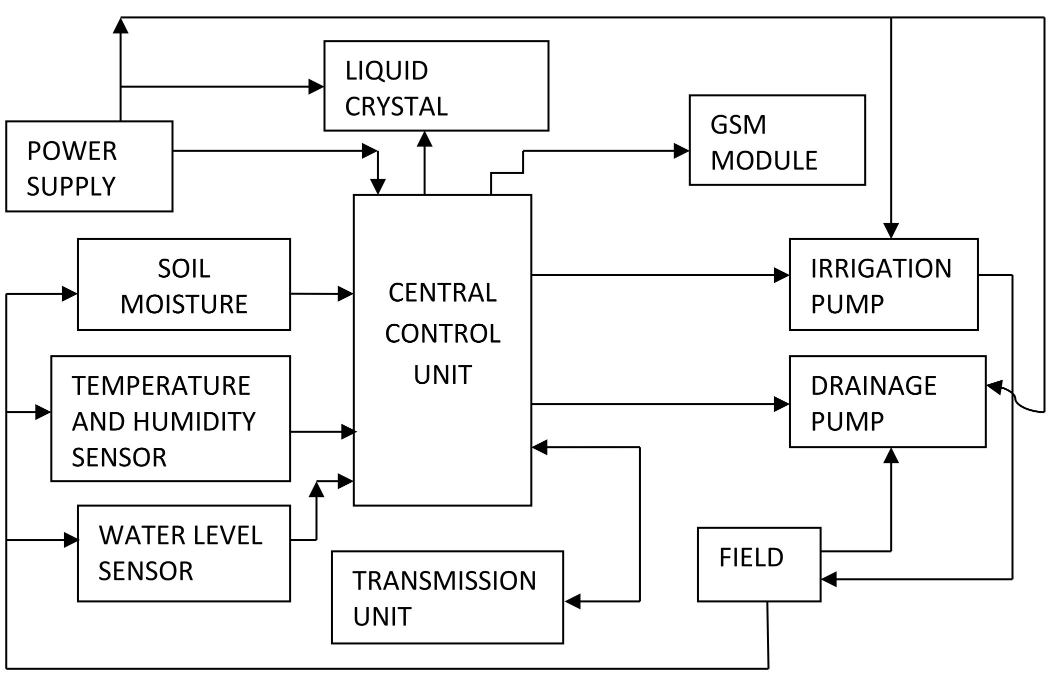

Figure 1: Block diagram of the system

- ***Power supply circuit:*** This is saddled with the responsibility of supplying the needed power to the entire system. A step-down transformer with turns ratio of 16:1 was selected to transform the 240V mains supply voltage to 15V for the power supply.

A full wave bridge rectifier is employed in this project.

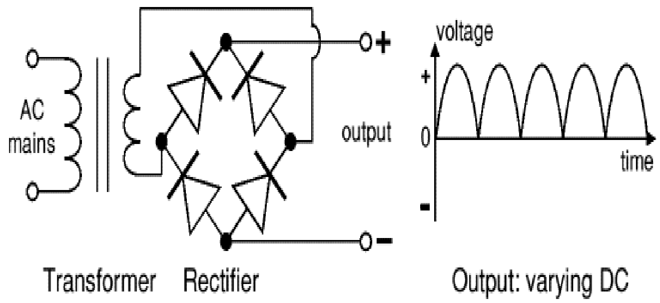

Figure 2: Full wave bridge rectifier efficiency circuit image

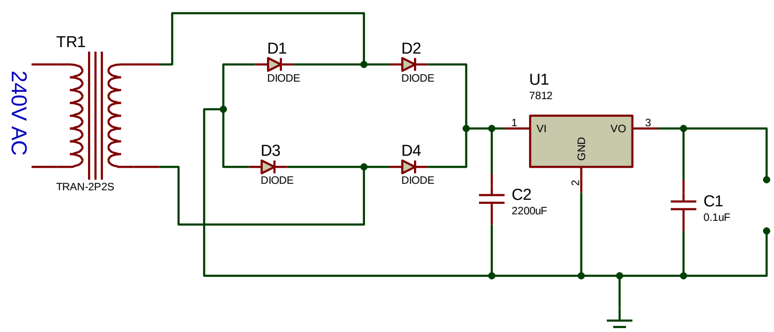

Figure 3: 12V DC Power Supply

However, LM7805 voltage regulator has standard output current of 1A, but the Arduino Microcontroller cannot acclimatize more than 5v and a maximum of input/output pin current of 50mA. Therefore, base on the values that the board needs, the 1A is going to be diminished into a maximum limit of 50mA. To diminish the 1 ampere output current to 50mA, some load need to be placed in series to the output terminal of the regulator. This is calculated as follow:

$$V_{out} = I_{max} R_s \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

$$R_s = \frac{V_{out}}{I_{max}}$$

$R_s = \frac{5V}{50mA}$ =100 Ohms

To regulate the required maximum current by the Microcontroller, 100 Ohms load need to be aligned in series with the output terminal of the 7805 linear voltage regulator.

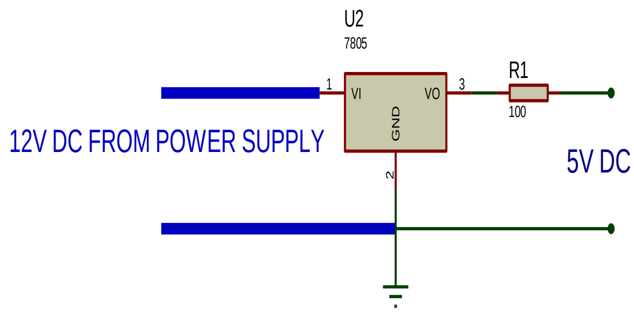

Figure 4: 5V DC Power Supply

Temperature Input: Thermistor is used to measure the temperature of the farm. The output of the thermistor serves as analog input, A1 of the onboard analog to digital converter (ADC) of the controller (Arduino board). The temperature of the farm is needed to be known before irrigation can begin. The microcontroller compares the reading from the thermistor with the preset value $(0 - 35^0 C)$. So long as the value from the thermistor is greater than the set range, the microcontroller will suspend the command that will activate irrigation until the value of the thermistor reduces to the set value, even though the reading from the soil moisture shows that the soil is in need of watering. This is to avoid waste that comes as result of evaporation.
In determining the biasing resistor for the thermistor, the following values were gotten from the data sheet of the thermistor in use:

$$V_{RT} = 3.3\text{v}, I_B = 0.77\text{mA}$$

$$\text{But} \quad \text{Vcc} = 5\text{v},$$

$$V_{RB} = \text{voltage across the biasing resistor} = 5\text{v} - 3.3\text{v} = 1.7\text{v}$$

$$V_{RB} = I_B R_B \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

$$R_B = V_{RB} / I_B$$

$$R_B = 1.7 \text{ x } 103/0.77$$

$$R_B = 2.2\text{k},$$

Therefore, the value of 2.2KΩ will be used to bias the resistor.

Moisture sensor Input: To get accurate readings out of the soil moisture sensor, it is recommended that it first be calibrated for the particular type of soil to be monitored. Different types of soil can affect the sensor, so the sensor may be more or less sensitive depending on the type of soil you use. To do this, the analog output of the sensor was connected to an analog pin of the arduino, A0, and a program was written to note what values the sensor outputs when the soil is as dried as possible and when it is completely saturated with moisture. The following values were seen on the serial monitor:

- when the soil was dry (850)
- when the soil was completely wet (400)

Based on the calibration values, a program was written to define the following ranges to determine the status of the soil:

< 500 is too wet

500-750 is the target range

> 750 is dry enough to be watered

The figure below shows the output of the program in the serial monitor of arduino IDE

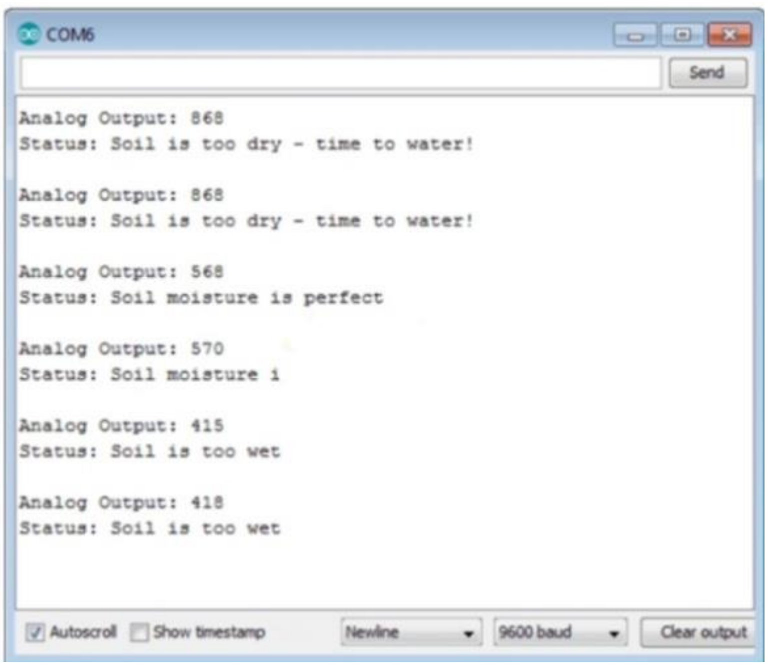

Figure 5: Serial monitor display of the analog calibration

The module also has a built-in potentiometer for calibrating the digital output (DO). By turning the knob of the potentiometer, one can set a threshold so that when the moisture level exceeds the threshold value, the Status LED will light up and the module will output LOW. Now to calibrate the sensor, the probe was inserted into the soil when the soil was ready to be watered and the pot turned clockwise so that the Status LED is ON and then turned counterclockwise until the LED goes OFF. With this, the sensor is calibrated and ready to be used. The output on the serial monitor is shown below

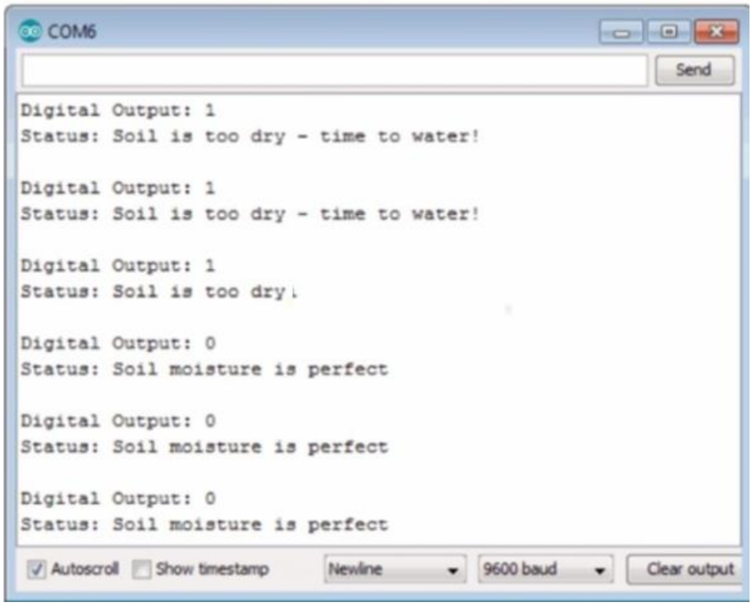

Figure 6: Serial monitor display of the digital calibration

- **Water level sensor Input:** This is basically to monitor the occurrence of flood in the farmland. It is constructed using two metallic probes with the lower one connected to 9v current and the upper one connected to a transistor via a resistor. Figure 7 below shows the construction.

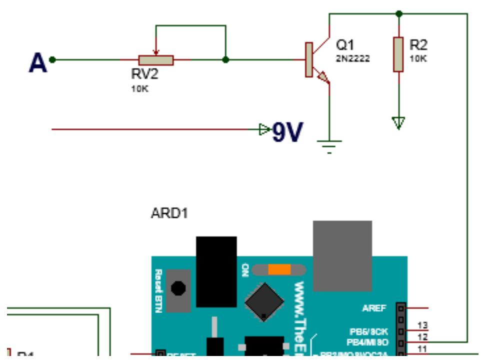

Figure 7: The designed water level sensor

When the level of water in the farm rises to point A as shown in the figure above, the transistor switches and the VCC attached to the collector of the transistor flows to the ground through the pull up resistor of 10kΩ as a recommended value of pull up resistor for arduino controller, thereby creating a change of state of arduino digital pin 12 from high to low. The controller, on sensing this change, activates the drainage pump for evacuation. The evacuation continues even when the water level falls below the point A, until the reading from the moisture sensor rises to 650. In other to properly bias the transistor used for the sensor, a proper calculation of the based transistor must be known. From the transistor data sheet; $\text{Base Voltage} - \text{emitter Voltage}\ (V_{BE}) = V_B - V_E \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots$.3.3

Where V_B = base voltage, and V_E = emitter voltage.

Given that $V_B = 5V$ and $V_E = 0V$

$$V_{BE} = V_B - V_E = 5 - 0 = 5V$$

Minimum current required to turn the transistor on is given by $I_B = 0.5mA$

Hence$R_B = \frac{V_B}{I_B} = \frac{5X10^2}{0.5} = 10000\Omega$ = 10KΩ

Therefore 10KΩ was used as the biasing resistor for the transistor used in the water level sensor design.

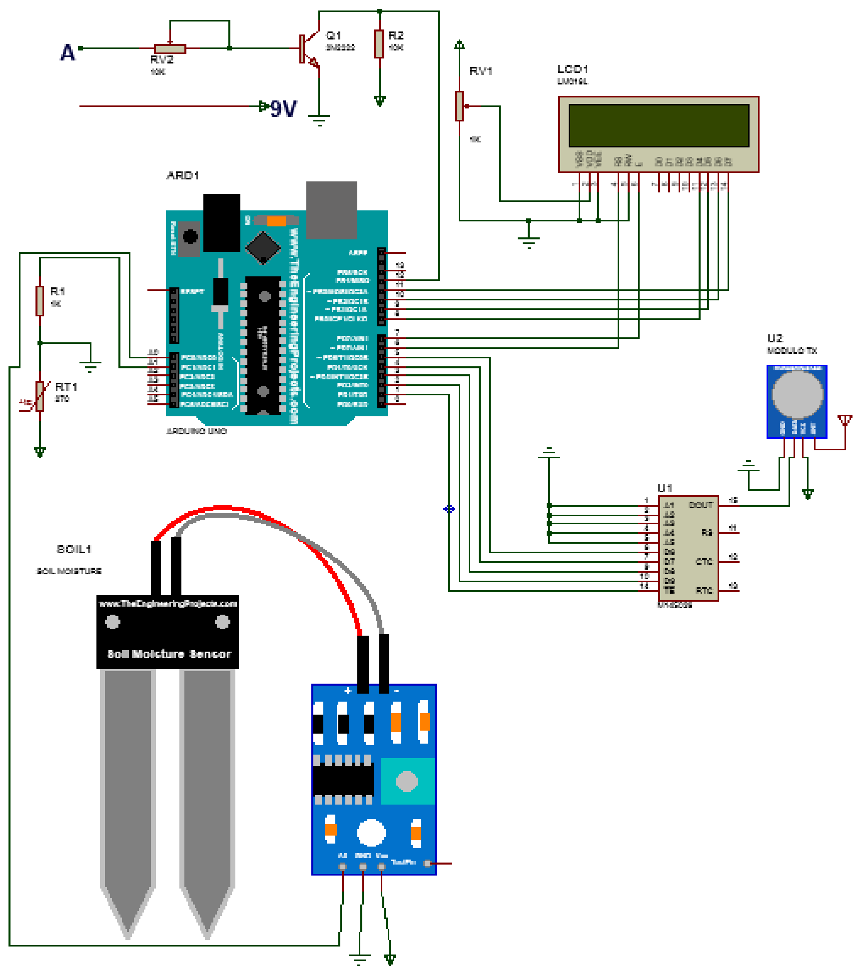

Figure 8: Snapshot of the schematic diagram of the remote sensing unit.

3.1.2 Design description of the remote control system unit (RCSU)

RF Receiver Unit

The resistor required to biased the transistor connected to this pin (VT) is calculated as below

From the transistor data sheet;

$$\text{Source Voltage} - \text{emitter Voltage } (V_{BE}) = V_{cc} - V_B \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

Where V_B = base voltage, and V_{cc} = source voltage.

But $V_{cc} = 5V,\ outputvoltageofArduinoUno.$

$V_{BE} = 0.6V for$ Silicon transistor.

Therefore, $V_B = V_{cc} - V_{BE} = 5 - 0.6 = 4.4V$

But $I_C = I_B \beta$,

β = Gain of the system, which is gotten from the data sheet, for this design it is used as 100, while the $I_C = \frac{V_c}{R_c}, V_c = Collector\ voltage, R_c = Collector\ resistor$,

Therefore $I_C = \frac{5}{10} = 0.5A$

With this $I_B = \frac{I_C}{\beta}$ ………….. ……………………………………………………3.5

$$= \frac{0.5}{100} = 0.005A$$

Minimum current required to turn the transistor on is given by $I_B = 0.005\Omega$

Hence,

$R_B = \frac{V_B}{I_B} = \frac{4.4}{0.005} = 880\Omega$, which is approximately 1KΩ.

Therefore for the biasing of the transistor, 1k was used.

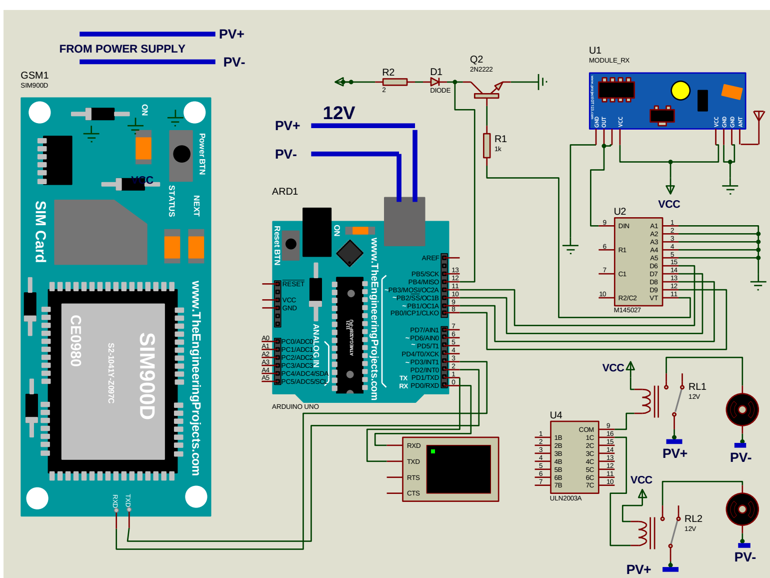

Figure 9: The complete circuit diagram of the remote control unit of the system

4. System Implementation, Testing and Discussion of Results

The implementation of the electronic circuitry involved the simulation of the system design, physical simulation of the circuit using a breadboard to ensure proper operation and the final implementation of the circuit on a Printed Circuit Board. The designed system was implemented onto a single chip and packed with protective device for onward installation in the experimental testbed. The designed system was used to monitor and control the environmental activities in the testbed. The basic operation of the control unit is the control of motor by the microcontroller through a relay, which would be energized via the codes written for the control and stored in the microcontroller.

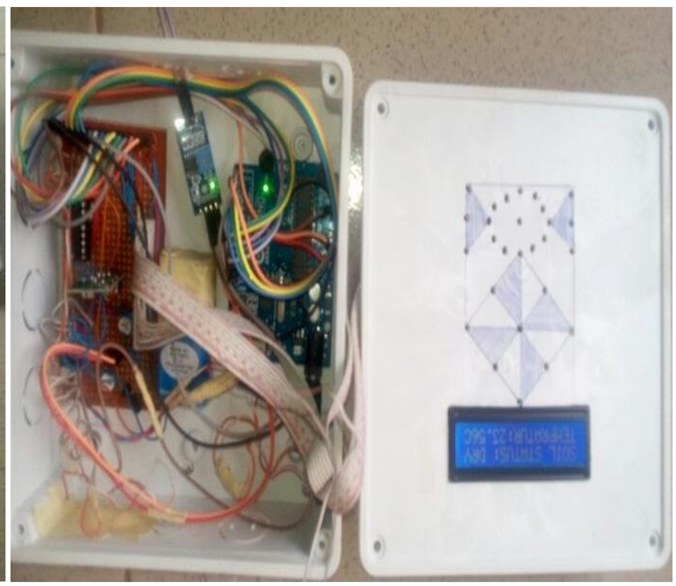

Figure 10: Developed wireless sensor node after packaging with battery.

Figure 11: Developed wireless sensor node showing internal circuitry.

Figure 12: Developed Remote Control System Unit (RCSU) developed

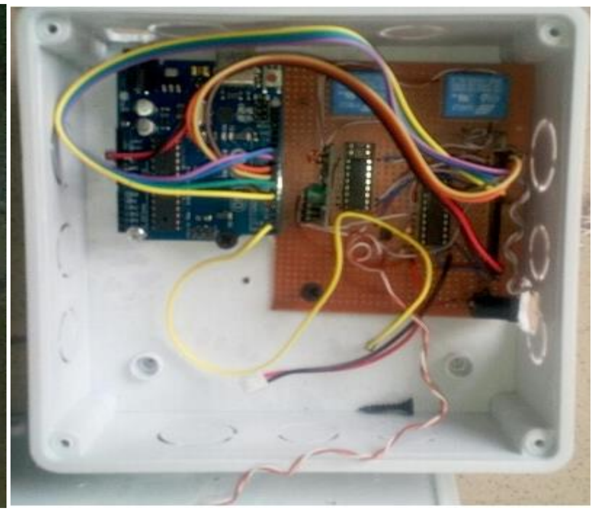

Figure 13: Internal circuitry of the developed Remote Control System Unit (RCSU)

4.1. Experimental Testbed & Installations

In order to realize the aim of this research work, an experimental testbed was designed and used for field experiments and for data collection and evaluation. Figure 17 shows the testbed incorporated with the developed Remote Sensing Unit (RSU) and the Remote Control System Unit (RCSU).

4.2 Data Collection

The designed wireless sensor nodes were integrated with the testbed and these nodes report their status periodically to the base station that would use the data to make decision on irrigation or flood control option based on the specified threshold values. Data was collected from the testbed three times in a day for analysis and evaluation.

4.3 Results and Analysis

The recorded data was exported to MATLAB for evaluation and analysis, using the data collected from the experimental testbed, temperature variations within the period of experiment is plotted as shown in figure 14. Similarly, figure 16 shows the evacuation time for different level of flooding.

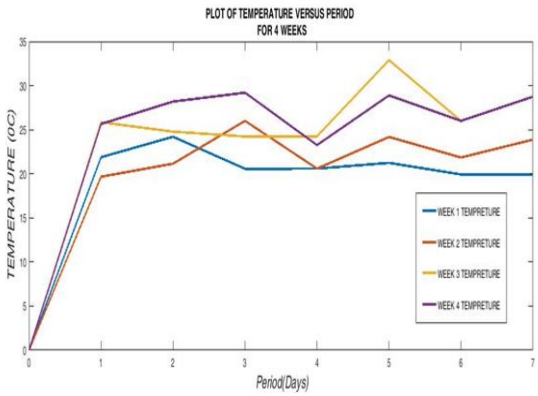

Figure 14: Graph of soil temperature

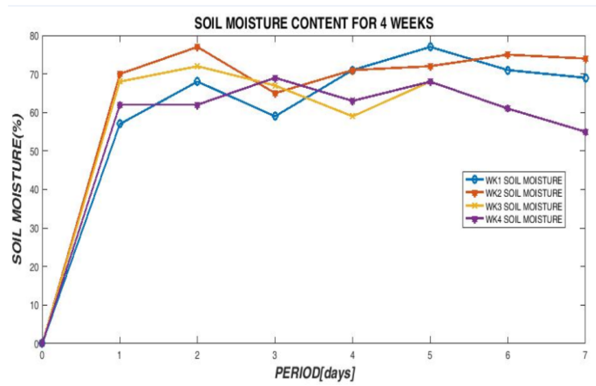

Figure 15: Graph of moisture level variation

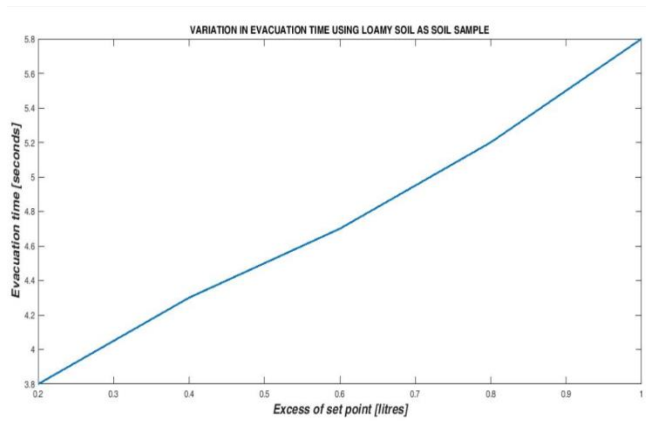

Figure 16: Graph of the system's response to flooding

Figure 17: System testbed incorporated with the Wireless sensor node and the Remote control system.

From the figures above, this work has shown that the designed system was able to monitor and control the specified environmental factors within the experimental testbed region. From figure 14, the system was able to maintain the atmospheric temperature at the range suitable for the irrigation of the investigated crops. Figure 15 represents soil moisture values obtained from sensor nodes during the experiment. In our experimental setup, if the soil moisture values are above the threshold value, then the plants are in unsafe state and need to be watered on urgent bases in order to avoid further damage. Figure 16 shows the response of the system to flooding**.** With this, the system was able to detect when there was flood in the testbed and automatically activated the drainage pump until the moisture in the soil was brought to the normal level.

Conclusion

The system eliminates the on-place switching mechanism used by the farmers to put ON/OFF the irrigation system while at the same time conserving the available water supply. Integrating features of all the hardware components used have been developed in it.

The prototype of the system was tested to function automatically and it worked according to specification and quite satisfactorily. The moisture sensor measures the moisture level (water content) of the different soils while the thermistor measures the temperature of the soil so as to ascertain the right temperature necessary for irrigation. If the moisture level is found to be below the desired level, the moisture sensor sends the signal to the microcontroller which triggers the DC Motor pump to turn ON and supply water to field area provided the prevailing temperature of the soil is suitable for irrigation. When the desired moisture level is reached, the system halts automatically and the DC Motor pump is turned OFF. Thus, the functionality of the entire system has been tested thoroughly and it is said to function successfully.

The components that were used in designing the system are readily available and are relatively affordable. This system, being smart as it is, tends to reduce the cost of labour thereby drastically cutting down the total cost of producing agricultural products. This system can be implemented in agricultural fields for enhancement of agricultural products.

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