Development of an Arduino-Based Automated Irrigation System for Sandy Soil in Igbesa, Ogun State

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ABSTRACT

Agriculture relies on effective irrigation for crops to grow, especially in areas like Igbesa, Ogun State, where sandy soil is most commonly used for planting. A lot of farmers, especially in the rural communities of Igbesa, operate using the manual methods of irrigation, which results in water wastage and low farm produce yield. In light of this, this paper aims to design, implement and study the performance of an automated irrigation system for sandy soils in Igbesa, Ogun State. Sandy soil is a type of soil texture packed with lots of minerals that cannot retain moisture effectively due to its loose particles, and they are commonly found in various parts of southwestern Nigeria. This system uses an Arduino Uno R3 microcontroller with a resistive soil moisture sensor that detects the moisture changes in sandy soils and triggers a mini-DC motor pump when the moisture level of the sandy soil falls below a given threshold set in the software code in the Arduino IDE. Results indicate that effective irrigation scheduling helps the sandy soil retain moisture and the device operate effectively when the moisture readings detected by the resistive soil moisture sensor decrease within seconds of detection. The early adoption of an automated irrigation system by rural farmers in Igbesa will not only increase farm produce yields but also reduce the cost of hiring personnel to perform manual irrigation methods on farmlands.

Keywords: Arduino Uno, Igbesa, Sandy Soil, Soil Moisture Sensor

INTRODUCTION

Water is a critical input for agricultural production and plays an important role in food security [1]. Despite the fact that it has been well established that water plays an important role in agriculture, many farmers in the southwestern region, especially in the rural area of Igbesa communities, still rely on manual methods of irrigation that lead to poor yields during harvest. A large quantity of food consumed in Nigeria is produced through small-scale agriculture (i.e. rural farming) [2]. These farmers constitute approximately eighty per cent of the country's farming population and have low agricultural productivity [2]. In Igbesa Area of Ado-Odo/Ota Local Government Area of Ogun State, one of the major challenges facing local farmers is the prevalence of sandy soils in most farmland areas. Sandy soil is one of the several types of soil texture used for farming operations. They are defined by some characteristics which include, but are not limited to, coarse particle structure, low organic content matter, high percolation rates and poor water retention capacity, which makes them a key concern in this paper[1][3].

The rapid development of technology makes human activities easier, especially in the agricultural sector [4]. The Arduino Uno is a popular platform for irrigation because of how easy it is to program, its low cost and its open source [5]. To reduce the negative effects of water loss on crops, especially on sandy soils that lose moisture easily, farmers can invest in automated water management technologies [6]. Shemul et al. [7] focused only on the effectiveness of the system without taking into consideration the type of soil structure and how much moisture the soil structure can lose or retain. Debo-Saiye et al. [8] tested sandy soil, clay soil and loamy soil at dry levels and reported significant irrigation durations for each of them. The sandy soil test results displayed the lowest

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pump-on times (1.5 seconds at 50% dryness, 2.5 seconds at 70% and 4.3 seconds at 100%) compared to clay soil (2.3 seconds, 7 seconds and 13 seconds). This confirms that sandy soils drain faster and require shorter watering intervals. In a study carried out by Okoye et al. [9], the three different soil types are clay, loamy, and sandy and they were tested using the Arduino irrigation method. Okoye et al. [9] used five samples of the three soil types at various degrees of dryness in percentage (100, 75, 50, 25, and 0). Their findings indicated that the longest irrigation duration was the clay soil (for 18 seconds when completely dry), followed by the loamy soil (for 15 seconds), whereas the shortest duration was needed for irrigation of sandy soil (for 8 seconds). This confirms that the sandy soil loses moisture faster and needs more frequent watering. Other existing prototypes being developed outside the Nigerian context primarily monitored the effectiveness of the system without taking into consideration the specific agro-climatic conditions of soil textures in areas such as Igbesa, in Ogun State, Nigeria, that fall within the Guinea Savanna-Forest transition zone. Further studies also revealed that most existing prototypes use a single moisture threshold to control the DC pump without taking into consideration how different soil types respond to wetting time and drying time. This study addresses this gap by developing an Arduino Uno-based automated irrigation system that monitors the moisture level in sandy soil and triggers the pump automatically when the moisture level drops below a set threshold specifically calibrated for sandy soil conditions in Igbesa, Ogun State, Nigeria.

Aim and objectives

This paper presents the design, construction and testing of an Arduino Uno-based automated irrigation prototype specifically calibrated for sandy soil in Igbesa, Ogun State. The system uses an Arduino Uno R3 that has the ATMEGA328p; the system also uses a resistive soil moisture sensor to measure the soil moisture level and triggers a DC pump through a one-channel relay module whenever moisture drops below a set threshold. The objectives of this study are to design a functional, low-cost automated irrigation circuit for sandy soil conditions, to implement the prototype using locally available components and to evaluate the system's response in terms of accuracy and reliability under controlled conditions.

MATERIALS AND METHOD

The manual method of irrigation used by farmers in Igbesa, Ogun State, usually involves manual watering with metal watering cans or buckets, which does not take into consideration the amount of moisture content in the soil. This section describes the design and implementation of an automated irrigation system developed at the Robotics and Innovation Center, Ogun State Institute of Igbesa, using components that can be found in the local markets.

System block diagram and flowchart

Figure 1 shows the block diagram of the automated irrigation system, illustrating the connection between the power supply, soil moisture sensor, Arduino Uno microcontroller, single-channel relay module, DC water pump and sandy soil sample.

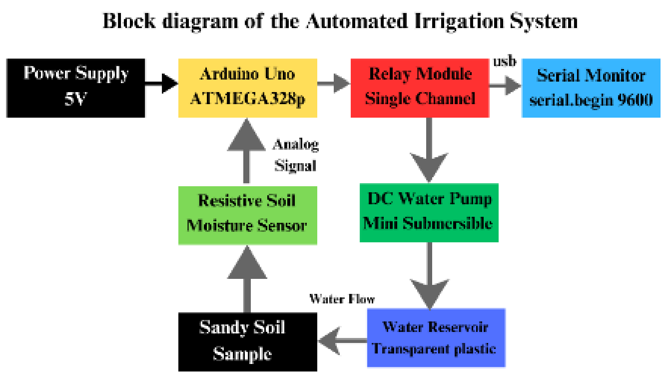

Figure 1: Block diagram of the automated irrigation system.

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Figure 2 presents the flowchart of the control algorithm that shows the process of the automated irrigation system programmed on an Arduino Uno microcontroller.

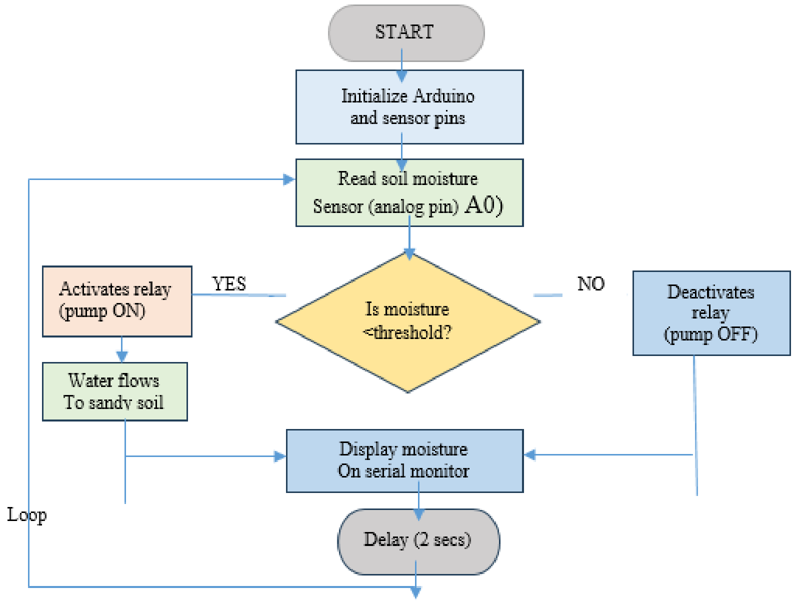

Figure 2: Flowchart of the irrigation control algorithm

Hardware components

To implement the control logic outlined in the system framework, each component was selected based on local availability and compatibility with the Arduino Uno R3. Table 1 presents the hardware components used in the prototype and their specifications.

Table 1: List of Hardware Components and Specifications

Components	**Specifications**
Arduino Uno R3	ATmega328P, 14 digital I/O, 6 analog inputs
Soil Moisture Sensor	Resistive, analog/digital output
Relay Module	5 V single channel
DC Water Pump	Mini submersible 3 – 5 V DC
Power Supply	5 V USB for Arduino and battery for pump
Container	Clear plastic jar with a metal filter fitted in it for sand
Connecting Wires	Male to female and male to male

Circuit design and connection

The soil moisture sensor used in this study has four pins and two moisture-detecting probes. The four pins are GND, A0, D0 AND VCC. The moisture sensor also has an LM393 comparator and a pot for adjustment for calibration. The soil moisture sensor module was connected to the Arduino Uno R3 through three of its pins. The VCC and GND pins of the sensor were connected directly to the 5 V and ground rails of the Arduino Uno board, while the analog Output was connected to the analog input A0.

The signal input pin (IN) of the 5 V single-channel relay module was connected to digital pin D7 on the Arduino Uno board. The operation power of the relay module was provided by 5 V and GND of the Arduino.

Also, on the other side of the relay module, the positive terminal of the DC mini submersible pump was attached to the NO pin of the relay, COM was attached to the positive of the battery, and the negative lead of the pump

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was connected directly to the negative terminal of the battery. This connection was used because the Arduino digital output pins are rated at a maximum of 40 mA [5], which is not sufficient to drive the pump motor directly.

The Arduino Uno R3 was connected to a laptop computer through a USB cable, which served as both a power source for the board and as a serial communication link for uploading the Arduino program code and also to monitor the status of the system using the serial monitor embedded in the Arduino IDE. All hardware components were assembled and placed on a flat wooden board and connected using jumper wires.

System architecture and control algorithm

The system works as a closed-loop control system and it has three main operational stages. The first stage is sensing. In this first stage, the soil moisture sensor is inserted into the sandy soil sample to measure the moisture content of the soil and provide a signal to the Arduino system. Stage two is called the processing stage whereby the analog value received from the sensor probe through pin A0 is compared by the Arduino to a preset moisture threshold to determine if the pump should be switched on or off. Finally, there is an actuation stage. In the actuator stage, the pump is turned on or off depending on the result of the previous step, hence water flows to the sandy soil. This final stage stages closes the loop of operation. In doing so, the process makes sure that the soil receives water only when its moisture level drops below the preset levels to avoid underwatering or over watering. A similar system was developed by Mishra et al.[10].

The control code was developed in C/C++ using the Arduino IDE and then uploaded to the Arduino Uno board via the USB interface. No additional libraries had to be included as all functionalities were already available with the standard functions including analogRead() to read sensors, digitalWrite() for controlling relays and the use of the serial library for output monitoring at a baud rate of 9600. During each cycle of the loop, the Arduino board reads the analog voltage on pin A0. If the reading shows that the soil is dry (greater than the specified threshold value), digital pin D7 is set HIGH to activate the relay and turn the pump ON. If the readings indicate adequate moisture (value below the threshold), digital pin D7 is set LOW to deactivate the relay and turn the pump off. This sequence of actions is repeated every two seconds with the readings and conditions being displayed on the serial monitor as shown in the flow chart in Fig.2. The threshold-based control algorithms used by Abubakar et al. [11] and Olayaki-Luqman et al. [12] were similar to the current design.

RESULTS AND DISCUSSION

Prototype assembly

The automated irrigation system was assembled and tested on a flat wooden board. Figure 3 shows the complete prototype setup with the Arduino Uno R3 board connected to a laptop via USB, the relay module, battery and the clear plastic container holding the sandy soil sample in a dry state before irrigation.

Figure 3: Prototype setup showing the automated irrigation system in dry soil condition before irrigation.

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The soil moisture sensor probe and the water delivery hose were inserted into the sandy soil from the top of the container, as shown in Fig. 4. The water reservoir section of the container held the submersible pump at the bottom, while the sandy soil was held with fitted nails in a metal filer above that separated the soil from the water. This arrangement allowed water to be pumped upward into the soil and drained back through the metal filter into the reservoir.

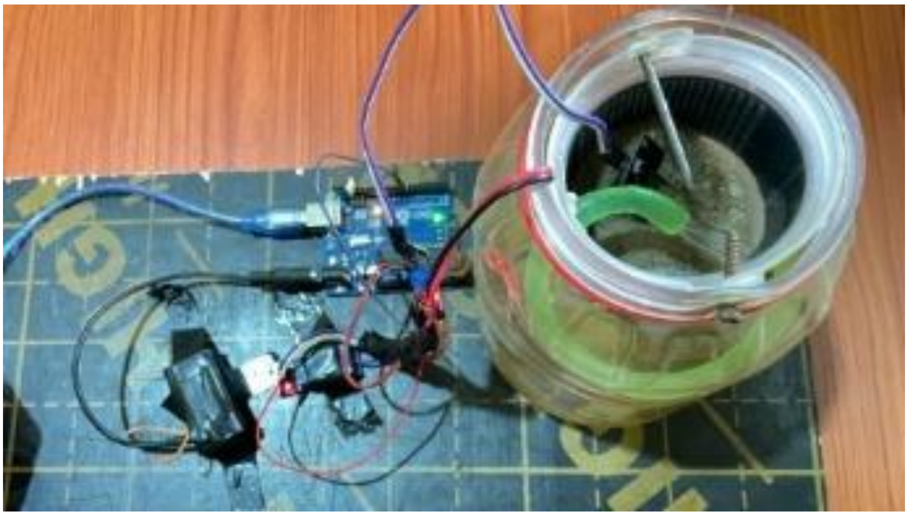

Figure 4: Top view of the soil moisture sensor probe and water being delivered into the sandy soil sample by the water delivery hose.

System testing and sensor reading

Three irrigation cycles were carried out in order to test the performance of the system. At the beginning of each irrigation cycle, the sandy soil was dried up to a point where the dryness was higher than 60%. Once the threshold was surpassed, the Arduino activated the relay and started pumping water from the reservoir into the soil using the hose. The water pumped continuously until the dryness level was lower than 30%. Then the relay deactivated which caused the pump to shut down. The analog reading, the percentage of dryness, pump time to run, and final pump status were recorded during each of the three irrigation cycles.

The soil moisture sensor gives readings from 0 to 1023, where the former value shows that the soil is has moisture content, while the latter signifies that the soil is dry. The percentage of dryness indicated by the soil moisture sensor (in brackets in Table 2) is found by dividing the analog value by 1023 and multiplying by 100. For instance, an analog reading of 912 corresponds to approximately 89% dryness. Table 2 shows the results of all three irrigation cycles.

Table 2: List of Hardware Components and Specifications

Cycle	Initial Reading (Dryness %)	Final Reading (Dryness %)	Pump Duration (s)	Pump State
1	912 (89%)	245 (24%)	18	OFF
2	887 (87%)	268 (26%)	16	OFF
3	935 (91%)	231 (23%)	20	OFF

DISCUSSION OF RESULTS

The results revealed a satisfactory responsiveness of the system in terms of soil moisture levels. Whenever the soil moisture exceeded the predetermined threshold value, the pump started operating until sufficient moisture levels were attained. Hamoodi et al. [13] used a similar method in their Arduino irrigation system and successfully obtained a reliable response to soil moisture changes. Winston and Osikibo [14] have demonstrated in their study an improved automatic irrigation system. The slight difference in pump duration across cycles can be explained by the variation in initial dryness level at the start of each cycle. A much drier condition requires a

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longer pumping time to bring the moisture to the desired level. Hashan and Haidari [15] observed a similar occurrence in their automatic water controlling system, where the pump run time varied depending on the initial soil moisture condition. Laxmi and Saxena [16] noted in their review that the resistive soil moisture sensors produce variable analog readings depending on the soil type and dryness level, which directly affects the duration of each irrigation cycle. Minz et al. [17] also reported comparable pump behavious in their Arduino-based automatic system, where the pump switched off automatically immediately the soil moisture reached the already set threshold.

The dryness level of 60 percent for pump on and the 30 percent dryness level for pump off were used due to previous tests being carried out on sandy soil from the Igbesa, Ogun State region. Calibration was done by immersing the soil sensor into a dry soil sample and adding water slowly as the analog readings were recorded on the serial monitor. At 60%, the soil was determined to need action, whereas at 30%, enough water had been provided. The difference between the two levels also acted as a hysteresis interval to avoid frequent relay switching because frequent switching may end up destroying the pump and relay contacts after some time. This very fast drying process between the cycles can be attributed to the characteristics of sandy soil with large particle sizes and large pore spaces allowing the easy escape of water. Small holder farmers in Ogun State face recurring water stress due to these soil conditions, making automated irrigations systems particularly relevant for the area [6].

CONCLUSION

An Arduino-based automated irrigation system for sandy soil was developed and tested in this study. Soil moisture sensor was used to detect soil moisture in the sandy soil obtained from Igbesa, Ado-Odo Local Government area of Ogun State, while the relay switch was used to control the supply of water using DC mini submersible water pump from a reservoir whenever soil moisture fell below the set point. The testing was carried out through three irrigation cycles, and it was observed that the pump turned on and off according to variations in the moisture levels in the soil. The results showed that at the beginning of each cycle, the soil had high dryness levels of about 87% to 91%. The pump turned on and worked for an average time of 18 seconds per cycle to reduce dryness levels in the range of from 23% to 26%.

RECOMMENDATION

The system should be tested by growing crops using sandy soil and conducting trials in outdoor field environments to gauge how well the system operates in the long term. It is imperative that a solar power source be considered for testing purposes to ensure that it works independently of power grid electricity. Further studies should also be done to test the system on different soil types found in the igbesa area to compare and check correctly the irrigation requirement and pump duration cycle across soil conditions.

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