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DEVELOPMENT OF A DIGITAL SOIL MOISTURE SENSING-BASED IRRIGATION SCHEME

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ABSTRACT

This study proposed using an automated watering system to provide for plant needs while using less water and labor. A system can be operated by an automatic irrigation system without the need for human intervention. The system comprises of soil moisture sensor, a PIC Microcontroller and a relay interface board. The irrigation system consists of lanes through which each segment of the land is flooded and the flooding is controlled using valves. There is also a motor pump that is used to fill the water Tanker. The three soils were dried in a frying pan until all the moisture was gone to produce the results. For the red soil, the black soil, and the sandy soil, 250 grams were measured. Sensor values were obtained after each addition of $25cm^3$ of water. For the three soils—black soil, sand soil, and red soil—the value of the soil sensor in dry soil was 1021, 1022, and 1020, respectively. The resistance value dropped dramatically to a range of 500 after adding 50 cm^3. The resistance value decreased as there was more water added. The drop in soil resistance started to decrease at a considerably slower rate at about 100 cm3 of water. This is so that more water cannot significantly increase soil resistance because the soil is already saturated with water at this time. Three states were established for the sensor after calibration. The states are dry, damp, and soggy. Upon reaching the dry condition, the microcontroller activates the water pump via a relay circuit.

Keywords: Irrigation, soil sensor, moisture sensor, wireless sensor network

INTRODUCTION

Healthy plants have a high water transpiration rate, which raises the air humidity in the greenhouse. A high relative humidity (over 80–85%) should be avoided because it can lower plant transpiration and raise disease incidence. Condensation on plant surfaces and the structure of the greenhouse can be avoided by using sufficient venting or repeating heating and venting. The humidity of the greenhouse air rises during the hotter summer months due to the use of cooling devices. Controlling the humidity inside the greenhouse might be difficult when it's warm and humid outside. Evaporative cooling systems are extremely beneficial for greenhouses situated in arid, desert conditions because they may evaporate massive volumes of water into the incoming air, causing significant temperature decreases (Arun, Nandan, Vardhan & Rajath, 2022).

Plant irrigation is typically a labour-intensive task that takes a lot of manpower to complete in a fair length of time. Traditionally, humans carried out each stage. Nowadays, some systems make use of technology to cut down on labour costs or plant-watering times. Such systems have very little control, and a lot of resources are still being squandered. One of these overused resources is water. One technique for the watering plant is mass irrigation. Given that the plants receive more water than they require, this strategy results in enormous losses. In greenhouses, the surplus water drains through the holes in the pots or percolates into the soil. The contemporary perception of water is that of a free, renewable resource that can be used in abundance. However, this is not a reality; as there is a cost component to water availability.

In addition to the excess cost of water, labour is becoming more and more expensive. As a result, if no effort is invested in optimizing these resources, there will be more money involved in the same process. Technology is probably a solution to reduce costs and prevent the loss of resources.

This research aims to build an automatic plant irrigation system that senses soil moisture using a microcontroller, with critical consideration being paid to installation costs. A household user must be able to complete the installation easily. Since there is a need to limit water loss and optimize the efficiency of water used, water savings were also a significant factor. Since lowering labour costs is the goal, less oversight and calibration must be required. The system must function consistently and optimally. Additionally, power usage needs to be watched. The replacement parts for maintenance must be easily accessible and installable in the event of failure. Finally, it is important to look into the prospect of expanding the system's application (maybe in greenhouses).

Water is artificially applied to the soil or land during irrigation. It is used to support the development of crops, the upkeep of landscapes, and the re-vegetation of disturbed soils in arid regions and during dry spells. The water is forced via the lateral lines and eventually arrives at the irrigation emitter (drip) or sprinkler heads when a zone is

activated. A fitting and the pipe can be attached to many sprinklers thanks to the pipe thread inlets on the bottom of the device. The top of the sprinklers' heads is often set flush with the ground. The head will emerge from the earth and water the chosen area once the water is pressured until the valve closes and turns off that zone. The sprinkler head will retract back into the earth once there is no longer any water pressure in the lateral line. To minimise evaporation losses, emitters are often placed on the soil's surface or buried a few inches (Abolafia-Rosenzweig, Livneh, Small & Kumar, 2019).
In this study, an automated irrigation system is proposed to meet plant needs while reducing water input and human involvement. An automatic irrigation system does the operation of a system without requiring the manual involvement of persons. Every irrigation system such as drip, sprinkler and surface gets automated with the help of electronic appliances and detectors such as computers, timers, sensors and other mechanical devices.

Significance of the Study

The need for quick advancements in food production technologies is driven by the ever-rising demand for food. We are unable to fully utilize agricultural resources in a country like Nigeria where the economy is built primarily on agriculture and the climate is isotropic. The main causes are a lack of rain and a lack of water in inland reservoirs. Continuous water extraction from the ground is lowering the water table, which is causing a lot of lands to steadily encroach upon areas of unirrigated land. Unplanned water consumption, which results in enormous water waste, is another extremely important factor for this. This problem can be rectified if we use a microcontroller-based automated irrigation system in which the irrigation will take place only when there will be an acute requirement for water.

REVIEW OF RELATED WORKS

This section of the paper highlights some related studies to this work. Singh, Jha and Nandwana (2012) presented a solution for an irrigation controller for the cultivation of vegetable plants based on the fuzzy logic methodology. In this system, the amount of water given to the plants depends on their size, and moisture control of soil, which is affected by the temperature of the environment, evaporation due to wind velocity and water budget. The technology provides plants with appropriate and controlled watering. Power for the pump controller is supplied using solar energy conversion technology. For a field of extreme aridity, Touati, Al-Hitmi, Benhmed, and Tabish (2013) offered a workable approach based on an intelligent and efficient system. The system comprises a

Zigbee-GPRS remote monitoring and database platform and a feedback FLC that logs important field metrics using certain sensors. Without undergoing any physical modifications, the system is installed in already-existing drip irrigation systems. These sensors' data are collected by FLC, which then applies fuzzy rules to determine the ideal timing and duration of irrigation. A centre-pivot irrigation system and wireless subterranean sensor networks were combined to create the autonomous precision irrigation system that Dong, Vuran, and Irmak (2013) reported. By using wireless underground sensors to monitor the soil conditions in real time, the centre pivot system with wireless underground sensor assistance will be able to handle irrigation on its own. A continuous-move centre pivot irrigation system and hydraulic drive were used in experiments. Utilizing valve control hardware and software, Coates, Delwiche, Broad, and Holler (2013) pushed commercial wireless sensing and control networks. A unique node firmware, actuator hardware and firmware, an internet gateway with control, communication software, and a web interface were all developed for the valve actuation system. The system uses a single-hop radio range using a mesh network with 34 valve actuators for controlling the valves and water meters.

Dursun and Özden (2014) proposed an efficient water usage system by pump power reduction using a solar-powered drip irrigation system in an orchard. Artificial Neural Networks (ANN) evaluate soil moisture content to deliver an equitable distribution of water for the desired location. By doing this, water consumption will be reduced and wasteful irrigation will be avoided. The daily water and energy consumption of the orchard decreased by 38% points thanks to this technology. Goumopoulos, O'Flynn and To execute autonomous closed-loop zone-specific irrigation, Kameas (2014) outlined the creation of an adaptable decision support system and its integration with a wireless sensor/actuator network. The implementation of automatic inferential and validation processes is supported by the use of ontology in the definition of the application logic, which stresses system flexibility and adaptability. A machine learning process is applied for inducing new rules by analyzing logged datasets for extracting new knowledge and extending the system ontology to cope. Chang, Huang and For greenhouse organic crops, Huang (2019) offered a machine learning-based accurate and intelligent irrigation system with LoRa P2P networks that could automatically and smoothly pick up irrigation knowledge from experienced farmers. The suggested system first determines how much water is needed for each irrigation based on the trained irrigation model combined with environmental data, such as air temperature/humidity, soil temperature/humidity, light intensity, etc., and then uses the long-distance and low-power LoRa P2P network to automatically irrigate the crops. The proposed intelligent and accurate irrigation system was shown to be a great fit for contemporary greenhouse-based agriculture, according to experimental results. The goals of Blasi et al. (2021) were to enhance the irrigation process and provide irrigation water to the greatest extent possible by using artificial intelligence to build a smart irrigation system that regulates the irrigation mechanism using the necessary tools for sensing soil moisture and temperature, giving alerts of any change in the parameters entered as the baseline values for comparison, and installing system sensors. Every ten minutes, the sensors took a reading of the soil's temperature and humidity. When the humidity was high, they stopped the automatic irrigation operation, and when it was low, they let it. The Decision Tree (DT) technique, a machine learning algorithm that trains the system on a portion of the collected data to develop the model that will be used to analyse and predict the remaining data, was used to build the model for the smart automatic irrigation system. The system's forecast accuracy was 97.86%, indicating that irrigation water provision for agriculture may be accomplished with it.

DESIGN AND IMPLEMENTATION

As shown in Figure 1, The three main components of the system are the output section, the control section, and the moisture-detecting section. YL-69 soil sensor was used to measure the soil humidity (a resistance-type sensor). The ATMega328 microcontroller, which is based on the Arduino platform, was used to create the control unit. The output was the device used to switch on and off the irrigation system based on the amount of soil moisture present. Hardware and software designs went through two stages.

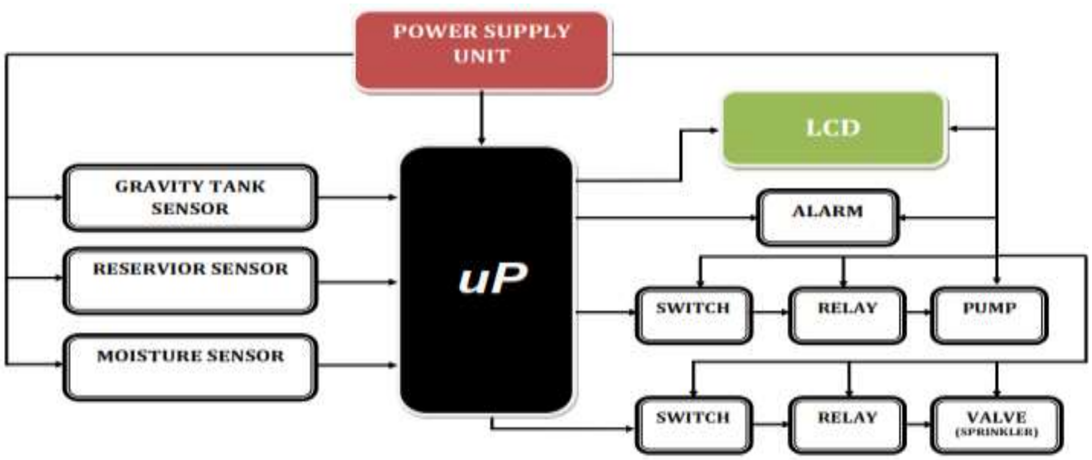

Figure 1: Block diagram

The project consists of three useful components. They are the water pump and motor, as well as the gravity tank and reservoir sensors. As a result, the Arduino IDE software is used to program the Arduino Board. The moisture sensor's job is to gauge the soil's moisture content. The water pump motor hydrates the plants. The motor in this project is controlled by an Arduino Uno. To connect the Arduino to the motor driver and the driver to the water pump, follow the schematic. 230 volts can power the motor. The moisture sensor gauges the amount of soil moisture and signals the Arduino if watering is necessary. The motor/water pump supplies water to the plants until the desired moisture level is reached.

Power Supply

The speed at which electrons move produces electrical power. Because of the technological age, many devices require electricity to carry out specific tasks. It costs money to be able to control electrical power. The bottom line, or cost, is always present in today's world. Devices that can manipulate electrical power for use in a variety of applications are called power supplies. Power supplies can be pricey, but there are less expensive alternatives that can deliver the same results. A power supply must be dependable enough to prevent damage to the connected devices and incorporate conversion processes. To produce those precise outputs, both features require particular components arranged in particular orientations.

This is a simple approach to obtain a 12V and 5V DC power supply using a single circuit. The circuit shown in Figure 2 uses two ICs 7812(IC1) and 7805 (IC2) for obtaining the required voltages. The AC mains voltage will be stepped down by the transformer T1, rectified by bridge B1 and filtered by capacitor C1 to obtain a steady DC level. The IC1 regulates this voltage to obtain a steady 12V DC. The output of the IC1 will be regulated by the IC2 to obtain a steady 5V DC at its output. In this way, both 12V and 5V DC are obtained. Such a circuit is very useful in cases when we need two DC voltages for the operation of a circuit. By varying the type number of the IC1 and IC2, various combinations of output voltages can be obtained. If 7806 is used for IC2, we will get 6V instead of 5V.Same way if 7809 is used for IC1 we get 9V instead of 12V.

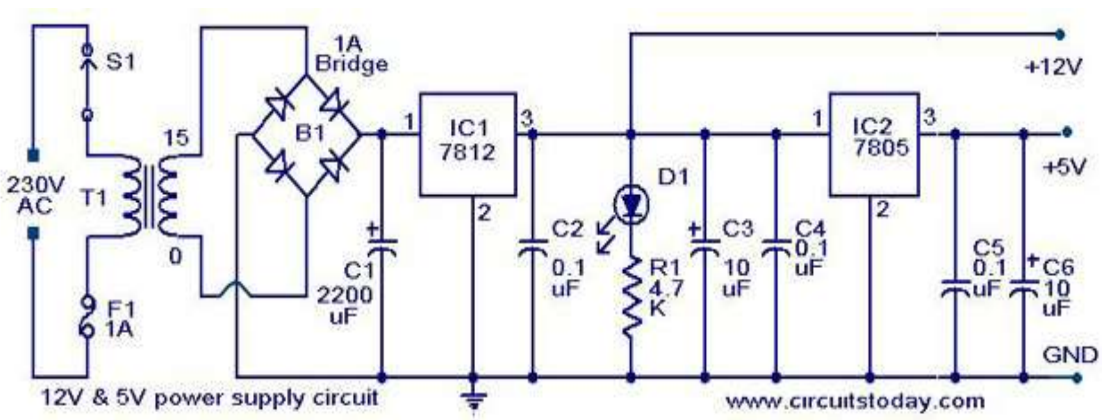

Figure 2: Power Supply Circuit Diagram

Relay Switching Circuit/Connection

The relay is used to switch the system. Because relays are switches, the terminology used for switches also applies to relays. Using one of three methods to energize the coil, a relay can switch one or more contacts on one or more poles. Normally open (NO) contacts connect the circuit when the relay is activated; the circuit is disconnected when the relay is inactive or normally closed (NC) contacts disconnect the circuit when the relay is activated; the circuit is connected when the relay is inactive or change over

(CO) or double-throw (DT), contacts control two circuits: one normally-open contact and one normally-closed contact with a common terminal.
Whenever a relay is driven from a circuit that has delicate components such as integrated circuits or transistors, a diode is always included across the relay coil to prevent the relay from damaging the circuit.

Soil Moisture Sensor Connection to Arduino

A digital PCB drive was used to interface the soil moisture sensor with the Arduino. There is a digital potentiometer on the PCB drive. When connected in digital mode, the "digipot" is used to change the sensor's sensitivity. The out-of-the-PCB drive has four connection pins as shown in Table 1.

Table 1: PCB pins

Sign	Connect
Vcc	Connected to 5VDC
GND	Connected to ground
A0	Analogue value output connector
D0	Digital value output connector （0 or 1）

As shown in Figure 3, the analogue configuration was selected as its more stable compared to the digital configuration. The PCB drive pin A0 was connected to the Arduino analogue pin A0.

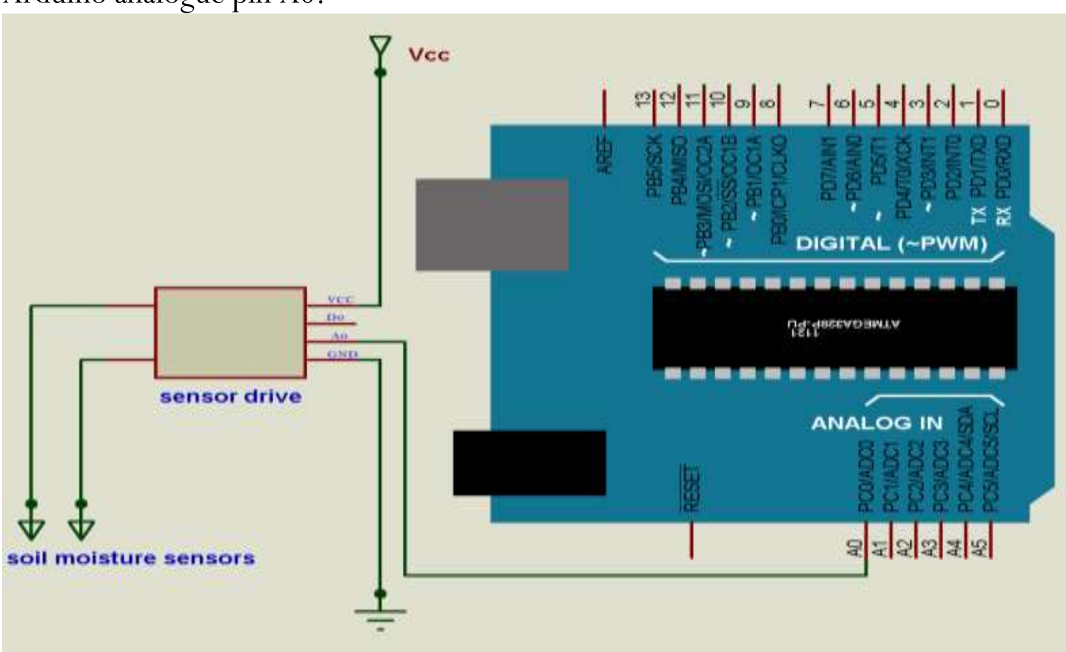

Figure 3: Connection to Arduino board (Abdulhamid & Njoroge, 2020)

The output of the sensor to the Arduino analogue pin A0 was resistance. The resistance to the flow of current between the sensor probes changes with soil moisture level and soil type. The current passing through the sensor probes (I_{out}) for different soils and different soil moisture levels was calculated as shown in equation 1:

$$Iout = \frac{Vcc}{\{Soil\ Resistance\ value\ (R_S)\}} \qquad (1)$$

The LCD interface with Arduino

As shown in Figure 4, to affect display a 16x2 Liquid Crystal Display (LCD) was chosen. LCD pins D4, D5, D6 and D7 were used as data lines in a 4-bit mode configuration. These pins were connected to Arduino pins 5, 4, 3 and 2 respectively. Pin 15(A) was connected to Vcc and pin 16 (K) was connected to GND. These pins (A and K) are for the LEDs integrated into the LCD circuit board. LCD's pin E (Enable) was connected to digital pin 11 on the Arduino board. Pin RS (Register Select) on the LCD was connected to Arduino digital pin 12. The R/W pin of the LCD was connected to GND (ground). The figure below shows the LCD-microcontroller interface (Abdulhamid & Njoroge, 2020).

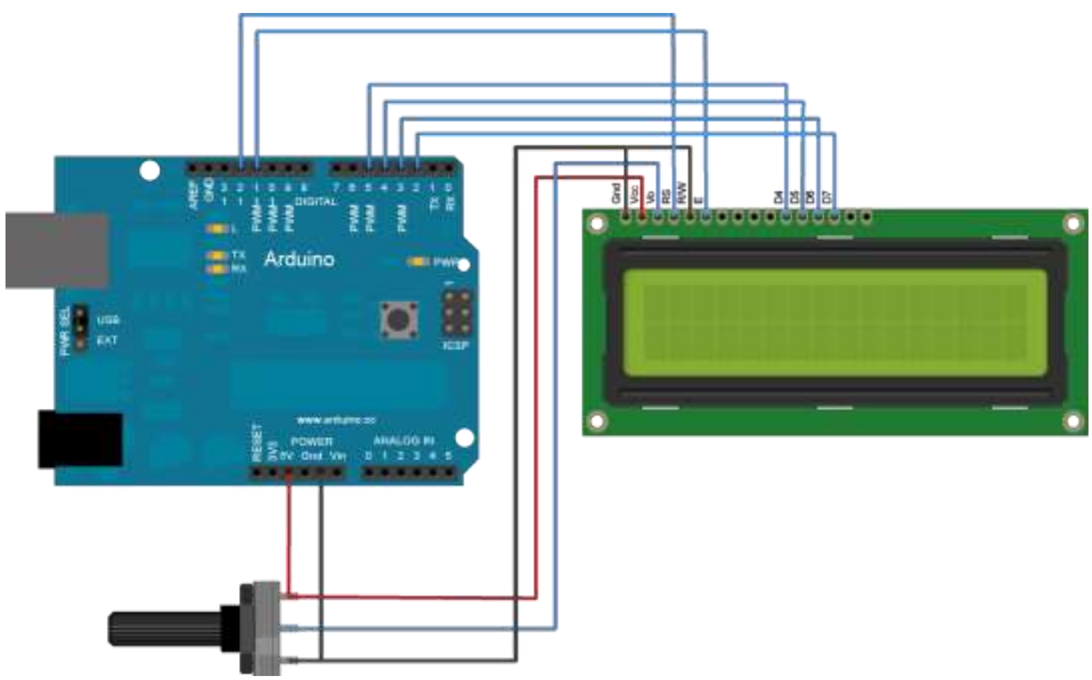

Figure 4: LCD Connection to Arduino Board (Abdulhamid & Njoroge, 2020)

The Water Pump Connection to the Arduino

To implement the final bit of the automated irrigation system, an electric motor (240VAC) was selected as the water pump. The first two units of the system i.e. sensing unit and the control unit (microcontroller) are powered by 5VDC. To interface, the two units a 5VDC relay (SLT73-5D-1Z) was used as the isolation unit. The microcontroller was connected to the relay via an NPN transistor (2N4123). To protect the transistor; while turning it on, a resistor was used. The resistor limits the current flowing through the transistor. As was the case with LEDs ohms law was used as shown below.

$$R_{min} = \frac{(5-0.7)V}{40mA} = 107.5\Omega$$

A resistor of 470Ω was selected and thus the current through the transistor was limited to;

$$I = 4.3V / 470 \ ohm = 9.12 \ mA$$

To protect the microcontroller from the back e.m.f during switching a diode was connected across the relay. This is shown in Figure 5.

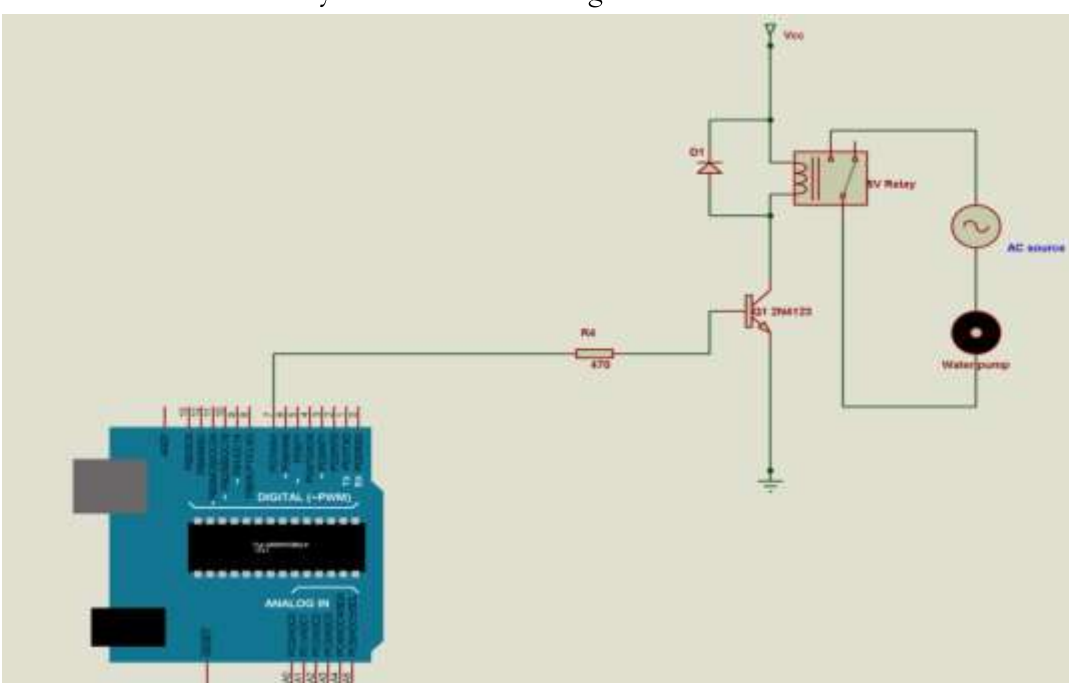

Figure 5: Relay interfacing of Arduino to the 230VAC pump

Software Design (Programming)

Proteus allows engineers to run interactive simulations of real designs for circuit simulation. It has a range of simulator models for popular micro-controllers and a set of animated models for related peripheral devices such as LED and LCDs, keypads and more. It is possible to simulate complete micro-controller systems and thus develop the software for them without access to a physical prototype.

It has simulated our hardware model using the software Proteus ISIS. The simulator models such as Atmega328, LED, LCD, Switches, pot, Relay, Resistors, Transistor and sources were used and results were verified with hardware results.

The Arduino Uno can be programmed with the Arduino IDE software. The Arduino microcontroller is an easy-to-use yet powerful single-board computer that has gained considerable traction in the hobby and professional market. The Arduino is open-source, which means the hardware is reasonably priced and the development software is free. The Arduino Uno board features an Atmel ATmega328 microcontroller operating at 5 V with 2 Kb of RAM, 32Kb of flash memory for storing programs and 1 Kb of EEPROM for storing parameters. The clock speed is 16 MHz, which translates to executing about 300,000 lines of C source code per second. The board has 14 digital I/O pins and 6 analogue input pins. There is a USB connector for talking to the host computer and a DC power jack for connecting an external 6-20 V power source, for example, a 9 V battery when running a program while not connected to the host computer. Headers are provided for interfacing to the I/O pins using 22 g solid wire or header connectors.

The Arduino programming language is a simplified version of C/C++. If you know C, programming Arduino will be familiar. If you do not know C, no need to worry as only a few commands are needed to perform useful functions. An important feature of the Arduino is that you can create a control program on the host PC, download it to the Arduino and it will run automatically. Remove the USB cable connection to the PC, and the program will still run from the top each time you push the reset button. Remove the battery and put the Arduino board in a closet for six months. When you reconnect the battery, the last program you stored will run. This means that you connect the board to the host PC to develop and debug your program, but once that is done, you no longer need the PC to run the program.

TESTS, RESULTS AND DISCUSSION

Working Principle of the Overall System

The system consists of Soil Moisture Sensor, a PIC Microcontroller and a Relay interface board. The irrigation system consists of lanes through which each segment of the land is flooded and the flooding is controlled using valves as shown in Figure 6. There is also a motor pump that is used to fill the water Tanker.

Figure 6**:** Simple wiring diagram of the system

Simulation results using MultiSim

By varying the resistance (700 kΩ) in the potential divider circuit as a representation of the dry/wet condition of the sample soil, the circuit was tested and the results are shown in Table 2.

Table 2: Simulation results

S/N	Soil Moisture level	The output of the sensor circuit (in Volts)	The output of the main pump controlling circuit (in Volts)
1	Below lower level	2.375	0
2	Increasing but below higher level	3.262	0
3	More than higher level	5.265	10
4	Decreasing but higher than lower level	4.372	10

The working of the relay for various test conditions is shown in Table 3.
Table 3: Operation of relay for various soil moisture conditions

S/N	Voltage range	Soil condition	Q	Amplifier output (digital)	Relay reference pin voltage	Relay 'NO' contact	Water pump operation
1	> 5V	Excess wet	0	1	1	open	OFF
2	< 5V & > 3V	Optimally wet	0	1	1	open	OFF
		Optimally dry	1	0	0	closed	ON
3	< 3V	Dry	1	0	0	closed	ON

Soil Condition Analysis

The VWC Of sand soil, red soil and black soil were calculated. The raw data collected from the soil moisture sensor was recorded as shown in Figure 7. The soil was measured in an equal amount of 250 grams. Water was added to the soils in steps and the sensor values were recorded.

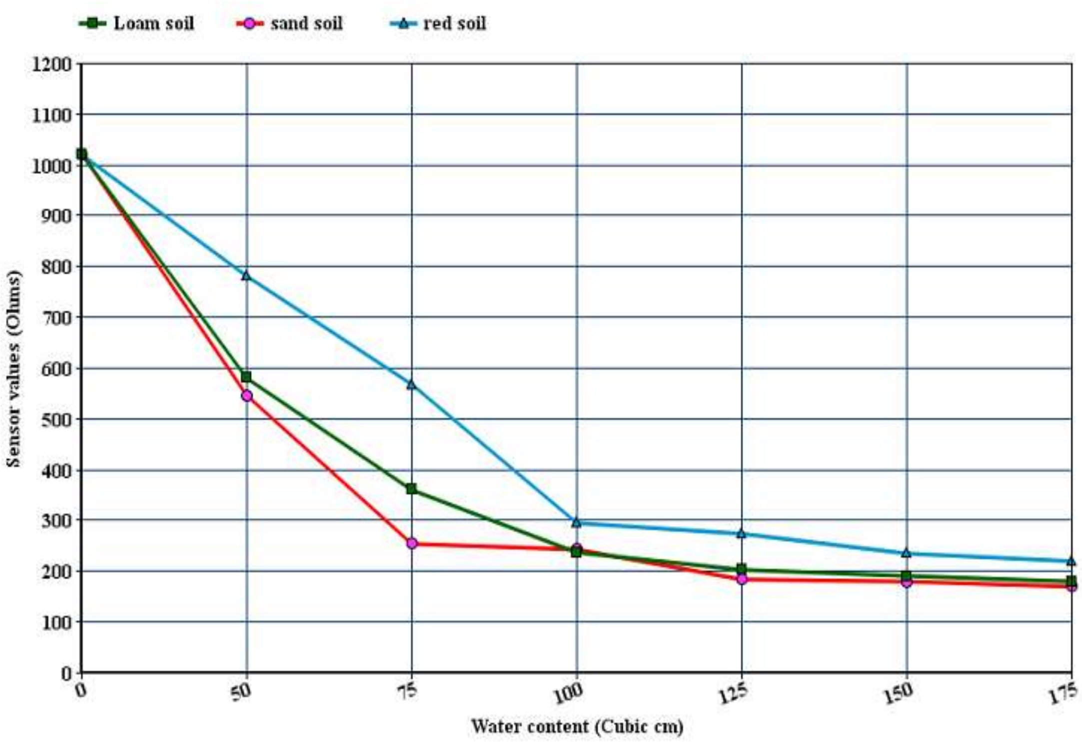

Figure 7: Graph of Soil Condition

The SMS (YL-69) used is a resistance sensor type. Its output is the resistance in the soil between the two SMS probes. The obtained graph is an exponential one. The value of the soil resistance decreases with an increase in water content to a certain point.

The three soils were dried in a frying pan until all the moisture was gone to produce the results. For the red soil, the black soil, and the sandy soil, 250 grams were measured. Sensor values were obtained after each addition of 25cm^3 of water. For the three soils—black soil, sand soil, and red soil—the value of the soil sensor in dry soil was 1021, 1022, and 1020, respectively. The resistance value dropped dramatically to a range of 500 after adding 50 cm^3. The resistance value decreased as there was more water added. The drop in soil resistance started to decrease at a considerably slower rate at about 100 cm3 of water. This is so that more water cannot significantly increase soil resistance because the soil is already saturated with water at this time. Three states were established for the sensor after calibration. The states are dry, damp, and soggy. The control unit (microcontroller), upon reaching the dry condition, activated the water pump via a relay circuit. Three separate LEDs and an LCD were used to display the three states. The running status of the pump was also displayed on the LCD. An output voltage regulator with a 5V output was used to connect a 9V alkaline battery to the control circuit and sensor circuit.

In this design, the hardest phase is laying out the geotextile. A list of acceptable soil types, a chart outlining the water requirements of typical houseplants, and an installation manual should all be offered to the consumer. The pipe network must be simple to set up as well. The manufacturer might include or suggest a tank and a matching pipe. It could be necessary to perform more complex work to connect the valve to the water mains.

Water savings for the system as a whole have not been investigated. However, prior studies in actual agricultural environments have shown that the geotextile and the moisture probe function as expected. An experiment showed that it is difficult to maintain a constant soil moisture level with only human feedback. In the short periods over which this system has been tested, virtually no human intervention was required. Only the system's functionality and the presence of a full water tank, if applicable, must be confirmed by the user. On the other side, there is no means to alert the user in an emergency such as a component failure, overflow, or an empty tank.

To evaluate the dependability and durability of the system, more testing should be carried out in a real home or greenhouse setting. To assess the significance of labour and water savings, these experiments should also be carried out for a longer period. Furthermore, just a small number of plants from a single species were used for all measurements and tests. Varied plants require different amounts of water, and they are not all equally resistant to water supply shortages.

All the components were selected to achieve some degree of power efficiency. All the electronic components consume less than 400mW constantly. The probe consumes a maximum of 41mW, but only for one minute per 5:20-hour duty cycle; on average, it should require less than a milliwatt. The valve is the element that uses the most power (8.41W maximum, 26mW average). On average, the whole system should require less than 450mW of electricity with a peak consumption of less than 8.9 W.

The irrigation system does not require routine maintenance other than to replenish the water tank (if utilized), clean the geotextile, pipes, and valve, and repair damaged parts. The majority of replacement parts are available in hardware or electronic stores.

CONCLUSION AND RECOMMENDATION

As a result, a digital soil moisture sensing-based irrigation scheme has been created and successfully put through testing. It was created by integrating functionality from every piece of hardware used. Every module's presence has been thoughtfully considered and arranged, which helps the unit function as best it can. The system's ability to run autonomously has been evaluated. The moisture sensors gauge the various plants' moisture content (or moisture level). If the moisture level is below the specified level, the moisture sensor sends a signal to the IC (Microcontroller), which activates the Water Pump and turns on the Rotating Platform/Sprinkler to provide the appropriate plant with water. The mechanism shuts down automatically and the water pump is turned off when the required moisture level is reached. As a result, the system's functioning has been rigorously tested and is said to work as intended.

Recommendation

To improve the effectiveness and efficiency of the system the following recommendations can be put into consideration:

i. Cost-effective techniques to overcome the limitation of requiring a soil-specific calibration should be employed.
ii. Automated irrigation was successfully designed and assembled. It serves to

reduce the consumption of water used, the human monitoring time and the labour associated with standard methods.

iii. Integrating a technology which can be used, such that whenever the water tank and reservoir are finished, it triggers the LED and alarm indicating "Empty" regarding the status of the pump.

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