LOW-COST ADJUSTABLE AUTOMATIC IRRIGATION SYSTEM BASED ON SOIL MOISTURE AND WATERING TIME USING A SINGLE ARDUINO MEGA2560 FOR DRY LAND CULTIVATION

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Abstract. Accurate watering is an important aspect of optimum plant growth. It is necessary to continuously obtain the soil moisture status as the basis for watering time. Real-time monitoring can play an important role in monitoring the readily available moisture in the soil. This paper presents the adjustable automatic soil moisture control design for dry land cultivation based on soil moisture and watering time. We used a low-cost capacitive sensor and Real Time Clock 1307 as soil humidity and timer sensors. The automatic control employs a single Arduino Mega2560 microcontroller for a data acquisition system, including a real-time clock, memory card, keypad, display, and irrigation actuators. The calibration was based on the soil sensor voltage provided by the capacitive sensors and the measured soil moisture content using the Gravimetric method. Then, the calibration model is embedded in the Arduino. The range of desired points of soil moisture and watering time could be set and adjusted using the keypad. There are three default set points of soil moisture (i.e., 40% to 42%, 60% to 62%, and 80 to 82%) and watering time (08:00, 12:00, and 17:00).

Keywords: automatic irrigation, capacitive soil moisture sensor, watering time, microcontroller, dry land

A. Introduction

Precision agriculture aims to optimize crop yields while minimizing the use of resources through the integration of advanced technologies. A key aspect of precision agriculture is the efficient management of water resources, particularly in areas prone to drought or where water scarcity is a significant concern[1,2]. Water is also one of the essential factors influencing plant growth, crop yield, and overall agricultural productivity. Especially in dryland agriculture, where water availability is often limited, an efficient and cost-effective irrigation system is important to maintaining crop production and improving yields[3,4].

Traditional irrigation methods, such as manual watering or fixed-time systems, are often inefficient because they do not consider the soil's varying moisture levels. Over-irrigation and under-irrigation result in sub-optimal crop growth, wasted water, and increased costs. To address these challenges, automated irrigation systems that adjust based on real-time soil moisture levels and customizable irrigation schedules have emerged as a viable solution. However, many existing automated systems are complex and expensive, making them less accessible to smallholder farmers and communities in developing regions[5].

Accurate watering is an important aspect of optimum plant growth. It depends on water requirements for specific plants. Watering is based on continuously monitoring soil moisture as the basis for watering time. It is necessary to continuously obtain the soil moisture status as the basis for watering time. Real-time monitoring can play an important role in monitoring the readily available moisture in the soil [6].

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To address these challenges, automatic irrigation systems based on plant water requirements are increasingly being adopted. These systems use sensors and automation technologies to monitor soil moisture, weather conditions, and other environmental factors. By providing plants with the precise amount of water needed, automatic irrigation enhances water use efficiency, promotes healthier plant growth, and reduces human intervention.

This approach integrates real-time data, smart controllers, and efficient water delivery mechanisms to create a system that adapts to changing environmental conditions and plant needs. As a result, automatic irrigation systems optimize water usage and support sustainable agricultural practices, especially in regions facing water scarcity.

Automatic irrigation systems, based on soil moisture levels or predetermined watering times, offer a more precise approach to irrigation. These systems utilize soil moisture sensors or timers to determine the optimal time and amount of water delivered to plants. By continuously monitoring soil conditions, moisture-based systems ensure that plants receive water only when required, reducing water waste and promoting healthier growth. On the other hand, timer-based systems allow irrigation to occur at pre-scheduled intervals, offering flexibility in water delivery but with less real-time adaptability[7].

This paper presents a low-cost, adjustable automatic irrigation system based on either soil moisture or watering time, using a single Arduino Mega2560 as the central controller. The system is designed to provide an affordable, easy-to-install solution for dry land cultivation. The system ensures optimal water usage by utilizing soil moisture sensors to monitor real-time conditions and adjust watering schedules accordingly. Additionally, the flexibility of the Arduino platform allows for customization and scalability, making the system adaptable to various crops and environments[8,9].

B. Methods

The design of a low-cost adjustable automatic irrigation system is shown in Figure 1. We used a low-cost capacitive soil moisture sensor and Real Time Clock 1307 as soil moisture sensor and timer sensor, respectively. The automatic control employs a single Arduino Mega2560 microcontroller as the center of the automatic control system. The adjustable setting point of desired soil moisture and time is done with a 4x4 keypad. The relays and solenoid valves are used as irrigation actuators. The automated system also has a memory card and a 3.5-inch TFT LCD as data logger and display, respectively.

The range of desired points of soil moisture and watering time could be set and adjusted using the keypad. There are three default set points of soil moisture (i.e., 40% to 42%, 60% to 62%, and 80 to 82%) and watering time (08:00, 12:00, and 17:00) with frequency. Hence, there are three irrigation actuators for soil moisture-based irrigation control systems and nine for time-based irrigation.

We used 9 capacitive soil moisture sensors (Figure 2). Its principal work primarily measures capacitance changes brought on by dielectric changes. The capacitive soil moisture sensor is a conductive copper plate in the center and a ground plate around the outside. The capacitive measurement measures the soil's dielectric, which is mostly affected by water [10]. Unlike resistive soil moisture sensors, capacitive soil moisture sensors are more corrosion-resistant [11]. A seal was used to coat the top of the sensor to ensure that water would not get into the circuit since the exposed circuitry on the top of the capacitive soil moisture sensor should not get wet.

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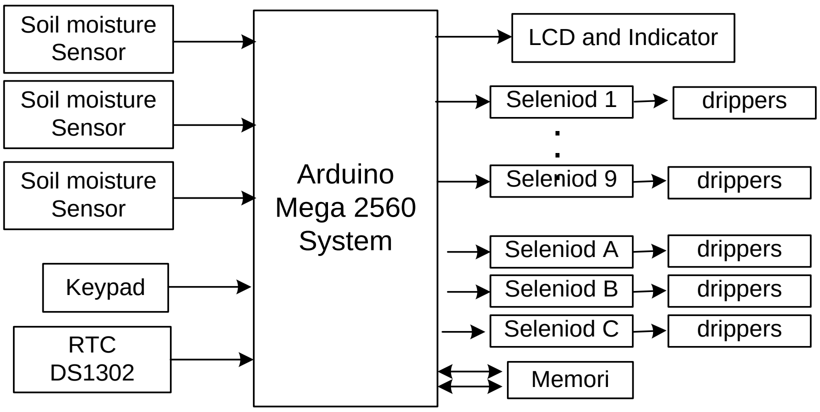

Figure 1. Diagram of automatic irrigation system based on soil moisture and watering time

Figure 2. Capacitive soil moisture sensor

The calibration process of the capacitive soil moisture sensor was based on the voltage output from the capacitive sensors and the measured soil water content using the Gravimetric method. Then, the most fitted calibration model is embedded into the Arduino Mega2560.

The procedures of the Gravimetric method for calibrating the capacitive soil moisture sensor [12–14] include the following:

A. The soil sample preparation
   1) Numbering of aluminum cans and weighing of each can.
   2) Weighing ~ 10 g of each sample of field-moist soil into its tin.
   3) Place tins into the oven at 105 °C overnight (24 hours) or until constant weight.
   4) Removing tins from the oven, weighing each tin, and recording the dry weight.

B. Cleaning
   1) Dispose of soil into buckets.
   2) Rinse aluminum tins, dry them, and turn them onto the cabinet.

C. Calculation

There are two different ways to calculate the wet-based Gravimetric method: the dry and wet weights. The calculation of the wet weight base is shown in Eq.1. The wet-based Gravimetric method can be expressed as a percentage.

$$GWC = \frac{(wet\ weight - dry\ weight)}{wet\ weight} x100\% \quad (1)$$

We implement the two set points (the upper and lower limit points) with an ON/OFF control system for each setting point. The lower limit is the desired point, while the upper limit is the lower limit plus 2. The set points are adjustable and stored in the Arduino's internal memory. The soil moisture value is compared with the set points to activate or deactivate the pump so that the soil moisture is kept between the wilting point and the field capacity of sand soil. Sensor outputs, set points, timer, and pump status are stored on the microSD card. The data file is automatically created every day.

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C. Results And Discussion

1. The Automatic Irrigation System

We optimally configured the Arduino Mega2560 by using almost all pins to automatically apply watering based on soil moisture to activate the irrigation equipment for keeping the soil moisture at the desired set points. The picture of the built system and the algorithm of the system put into the minimum system are shown in Figure 3 and Figure 4, respectively.

Figure 3. Automatic irrigation control

The principle works of the two set points ON/OFF control system is as follows:

a. The system takes actual day, date, and hour data from the RTC and displays it on the display.
b. The system reads the three probes of soil moisture and displays them.
c. The system compares the soil moisture to set points (the lower set point is 12%, and the upper set point is 18%).
d. If the three soil moisture (S1 to S3) is below the lower set point, then the status is "being ON" then:
   If the three soil moisture (S1 to S3) <= upper set point, then the pump is "ON" until the three soil moisture is above the upper set point.
e. If the three soil moisture (S1 to S3) is above the upper set point, then the status is "being OFF" then:
   If the three soil moisture (S1 to S3) >= lower set point, then the pump is "OFF" until the three soil moisture is below the lower set point.

Automatic irrigation systems based on soil moisture status provide more precise and efficient water management. The systems ensure that irrigation is given only when the soil moisture drops below a specified/predetermined threshold. This system allows them to adapt to real-time conditions, giving plants the needed water. Integrating a soil moisture sensor with an Arduino microcontroller can automate the watering process, turning on the irrigation device when the soil is dry and off when it reaches adequate moisture[15,16].

The Arduino Mega2560 is the heart of the automation system, managing the sensors (such as soil moisture sensors), timing mechanisms, and actuators (valves, pumps, etc.) to automate irrigate crops based on real-time data automatically and allows them to adjust irrigation schedules, soil moisture thresholds, and watering times according to the specific needs of their crops and local conditions. Moreover, an Arduino-based system is affordable (low cost) compared to more complex and expensive agricultural automation systems, especially for small-scale farmers in developing regions[17].

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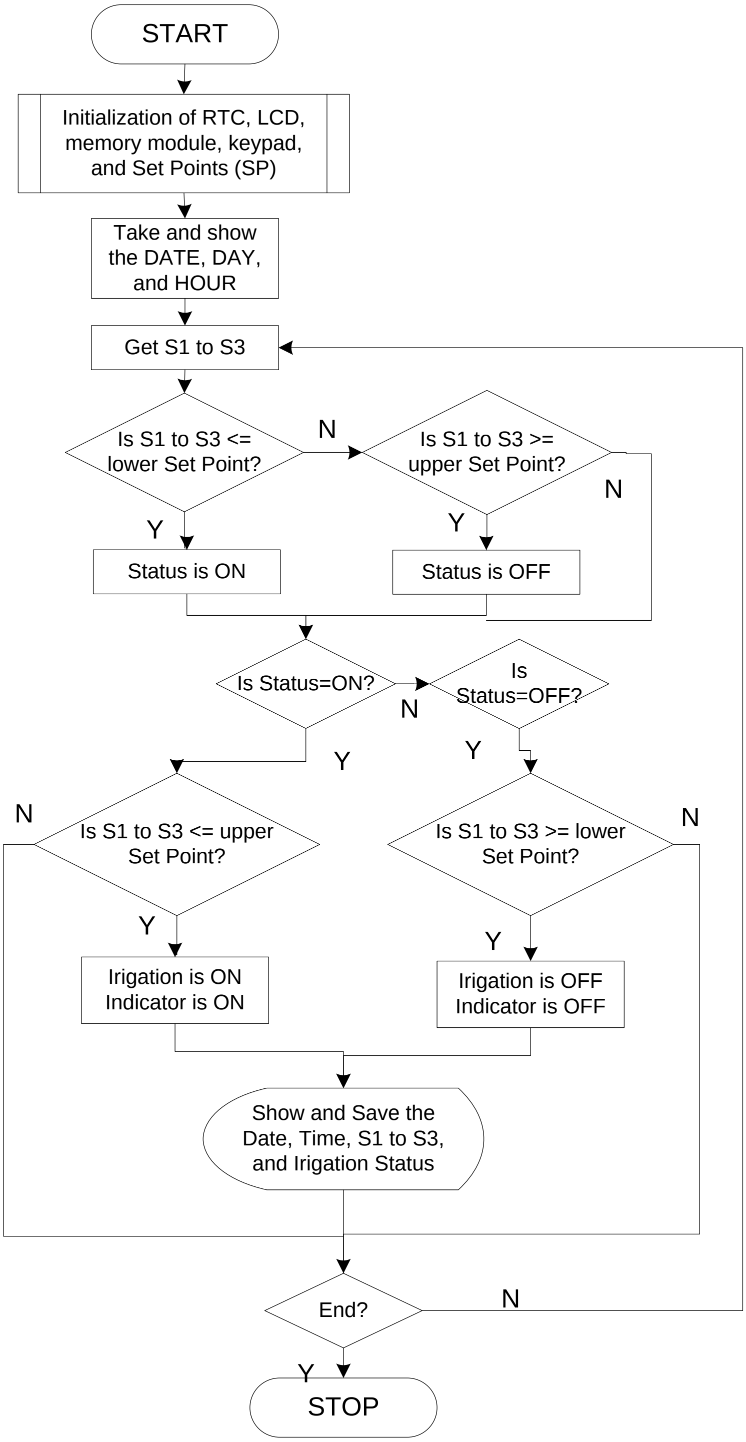

Figure 4. Algorithm of soil moisture-based irrigation control

2. The Model of Capacitive Soil Moisture Sensors

We applied our calibration result using the gravimetric water content (wet-based) method to obtain the most fitted model for capacitive moisture sensors [18]. The wet-based gravimetric method is the ratio of the mass of water to the volume of soil in a sample.

Figure 5 shows the graphical response between the voltage reading from the capacitive sensor and soil moisture derived by gravimetric methods. We obtained the fit equation of the polynomial model (equation 1) with the highest R2 value by observing some models using the Excel spreadsheet application, as shown in Table 1. Then, we calculated the RMSE and MAPE

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between the measured water content and the calculated water content. We obtained the MAPE of 10.09%, indicating that the volumetric water content of the soil utilized in this investigation can be approximately within 0.08% of a given reading. This inaccuracy is also near similar devices that have been extensively calibrated [19].

$$\theta_w = 34.23 \, x \, V^2 - 182.84 \, x \, V + 249.45 \quad (2)$$

Where,
θw = soil moisture, wet based (%)
V = sensor voltage (volt)

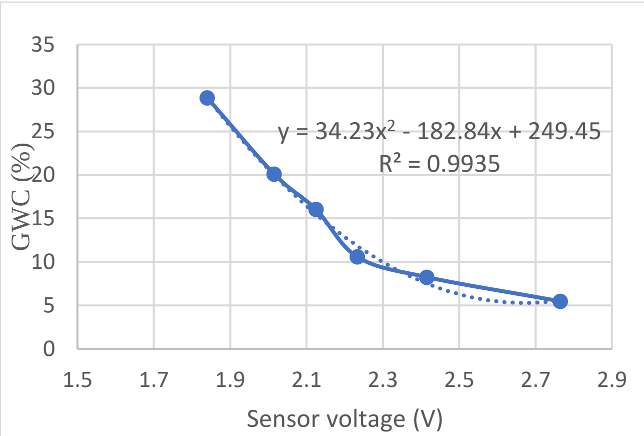

Figure 5. Gravimetric calibration to the output of capacitive soil humidity sensor

D. Conclusion

We built a low-cost adjustable automatic irrigation system based on soil moisture and watering time, which can be applied to dry land cultivation. 9 capacitive soil sensors and RTC1302 were used. The single Arduino Mega2560 is employed as the heart of the control system. The desired points of both soil moisture and watering time can be adjusted from a keypad. We obtained the equation model of capacitive soil moisture as $\theta_w = 34.23 \text{ x } V^2$ -182.84 x V + 249.45 where θ_w = soil moisture, wet based (%), and V = sensor voltage (volt). The range of desired points of soil moisture and watering time could be set and adjusted using the keypad. There are three default set points of both soil moisture (i.e., 40% to 42%, 60% to 62%, and 80 to 82%) and watering time (08:00, 12:00, and 17:00)

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