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An Automated Irrigation System Using Arduino and Soil Moisture Sensors

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***Abstract*—Gardening is a wonderful hobby, but in city life it's not always easy. When family members go away for a few days, the plants often die. This problem can be solved by using smart irrigation system. Smart irrigation systems are ideal for homeowners, commercial landscapes. They help manage water efficiently, support precision farming and boost crop. A smart irrigation system uses sensors (soil moisture, weather) and controllers to automate watering, delivering the precise amount of water when they need it. It is done based on real-time data not fixed timers. Significant water, energy, and labor can be saved while boosting crop health and yields by preventing over or under-watering. These systems integrate IoT, AI and remote monitoring for data-driven water management in residential, commercial and agricultural settings. This ensures sustainability and efficiency. In this paper, we have designed and developed a system for measuring and monitoring the water level and soil condition in a garden. Based on the soil moisture and water status, our system automatically supplies water to the plants. A sensor is placed at the top. When water touches this sensor, the system automatically stops the water supply. This reduces the need for continuous monitoring and ensures that plants do not die due to water scarcity. Our proposed system offers multiple benefits; It can conserve 30–50% water and can reduce waste, promote plant health by preventing over- or under-watering. It also can cut costs on water and labor. Additionally, they support environmental sustainability by reducing runoff and erosion while enabling data-driven decisions for better crop management**

***Index Terms*—Smart irrigation system, boost crop, sustainability**

I. Introduction

Agricultural practices are among the greatest-using entities of freshwater resources across the world, using almost 70% of the total availability of water in many nations [1]. With the global population growing at such a rapid pace, the demand for food has put extreme pressure on the use of freshwater resources to the extent that the efficient use of water resources in agricultural practices has now emerged as a matter of utmost concern. Conventional irrigation methods are mainly fixed and manual, which do not take into consideration the actual use of water by plants or the conditions under which the plants are to be irrigated [2]. This has resulted in the use of unnecessary amounts of water by the agricultural sector, which has added to the problems of soil erosion, loss of nutrients, low crop productivity, and high operating costs for the farmer. The use of water resources has now emerged as a major challenge across the world [3].

Technological developments in microprocessors, sensors, and control technology have made it possible to develop smart irrigation systems that can sense and respond to the environmental conditions and the soil automatically [4]. By incorporating the use of soil sensors, temperature sensors, and microcontroller-controlled units, the irrigation process can be carried out only when needed, ensuring the controlled amount of water reaches the crop at the appropriate time [5]. This smart technology not only limits human labor and water resources consumption but also aids in promoting higher crop yields. Moreover, these irrigation systems allow for the development of smart and sustainable farming practices based on the sensed environmental conditions. The application of smart irrigation technology is an essential step towards the development of smart agriculture [6,7].

Even with these technological developments, there remain inefficient irrigation systems, especially in developing nations, which pose challenges for effective irrigation practices. This can result in waterlogging, nutrient leaching, soil erosion, or lower yields, while in the case of inefficient irrigation, it can cause stress, slowed growth, or lower yields for plants [8]. However, most farmers still adopt experience-based irrigation practices, especially if they cannot afford or are not well-informed about advanced irrigation technology or techniques. Moreover, current irrigation practices can be difficult for installation, maintenance, or execution, especially for small-scale farmers, further confirming the necessity for low-cost, dependable, and adaptable irrigation techniques involving lower installation or operation costs, as well as greater energy efficiency Various research studies have been conducted to develop and execute smart irrigation systems based on microcontrollers such as Arduino and NodeMCU along with

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soil and environmental sensors. All the systems essentially work with the concept of threshold-based controls where the irrigation of water occurs based on the threshold limit of values of the sensors. Various projects have been incorporated with Internet of Things (IoT) technology to monitor the system remotely from anywhere through smartphones and cloud-based systems [9]. However, the above-mentioned research studies essentially showcase the advancements of the system with respect to improved efficiency in irrigation systems but essentially lack adaptability, flexibility, energy efficiency, scalability, and usability. All the above-mentioned systems essentially concentrate only on the development of technology rather than concentrating on the efficiency of the system with respect to appropriate cost-effectiveness and maintenance [10]. Obviously, there exists some gap in the development of an integrated and scalable system incorporating efficient irrigation with usability as well as minimal energy efficiency [11].

This paper presents the design and implementation of a microprocessor-based smart irrigation system that has the potential to automatically provide water as per the current environmental conditions. The smart irrigation system aims to minimize water wastage, labor, and improve irrigation efficiency by using a simple, economical, and flexible embedded system design. The smart irrigation system will be capable of handling varied soil types, crop plants, and irrigation fields, which makes it very useful for small-scale agricultural applications. The proposed smart irrigation system has the potential to overcome the challenges and drawbacks of current smart irrigation systems, which include high costs, complexity, energy consumption, and scalability. The proposed smart irrigation system has the potential to form a foundation for the implementation of IoT-based smart agricultural systems, which can help to promote smart agricultural practices in the near future. This research work can help to improve efficient water use, crop productivity, and the development of small to medium-scale agricultural setups.

II. METHODOLOGY

A. Systen Overview

This system operates as an automated monitoring and response framework designed for regulating irrigation based on real-time environmental data. The prototype utilizes a microcontroller (ATmega328P) for the central processing core interpret signals from a rain and moisture sensor connected to the input pins. Predefined logic state is programmed into the controller, where it continuously looks for the sensor for the presence of moisture. If the sensor detected moisture (returning a digital value of 0), the system naturally triggers the actuation stage by turning the relay and the watering system ON, while simultaneously activating a buzzer to provide an audible status alert. Conversely, once the sensor verified a dry state (returning a digital value of 1), the controller interrupts the power to the relay to turn the pump OFF and silences the buzzer. As illustrated in the block diagram, the relay acts as the electromechanical interface between the controller's logic and the high-power pump, ensuring that water is delivered only when necessary to maintain optimal environmental conditions. This system is designed for both effectiveness and security. By utilizing a relay, the system ensures galvanic isolation between the low-power microcontroller and the high-power pump circuit.

B. Hardware Components

1) Arduino Uno R3: The Arduino Uno R3 acted as the main computational "brain" and the high-level logic controller for the whole smart irrigation framework. This is an open-source microcontroller board maid around the ATmega328P, which is a high-performance, low-power 8-bit AVR RISC-based processor. This design permits the controller to execute complex instructions in a single clock cycle, achieve a processing throughput of nearly 1 MIPS per MHz. This operates at a fundamental clock frequency of 16 MHz; the Arduino ensure that the temporal resolution of the system sufficient for sample environmental data and triggering mechanical actuators without any perceptible latency. The memory architecture of the Arduino Uno is designed for industrial-grade stability. It captures 32 KB of In-System Programmable (ISP) Flash memory, which hold the compiled control algorithm. In dynamic data handling, it includes 2 KB of SRAM (Static Random Access Memory), which store real-time variables like sensor values and pump state-flags, 1 KB of EEPROM for non-volatile storage. One of the most critical hardware features used in this research is the 10-bit Successive Approximation Analog-to-Digital Converter (ADC). This specialized circuitry is responsible for the process of "Quantization," where it takes the continuous, fluctuating analog voltage from the soil (ranging from 0V to 5V) and translates it into a precise digital integer scale between 0 and 1023. Furthermore, the board's power management system is highly sophisticated. It includes a Polyfuse to protect the USB port from overcurrent and an NCP1117 voltage regulator that stabilizes external power inputs (from the DC jack) to a clean 5V output. This stability is vital because any ripple in the power supply would result in "signal noise" or "voltage drift" in the moisture sensor, leading to false irrigation triggers.

2) Soil Moisture Sensor : Soil moisture sensor is an instrument used for measuring the moisture content in soil. It changes in moisture within the soil and converts them into readable electrical signals. It is important for monitoring soil moisture, recongnising soil conditions, and optimising plant growth. The Soil Moisture Sensor is the primary sensing element that bridges the gap between the biological soil environment and the digital control system. It is operating on the principle of Soil Resistivity. Soil moisture sensor are divided into two categories depending on the technology they use: 1) Sensors that measure volumetric water content, and 2) Sensors that measure soil tension when placed in the soil profile. Soil moisture sensors estimates the amount of water in the soil. These sensors can be stationary or portable, such as handheld probes. Stationary sensors are placed at the predetermined locations and depths in the field, whereas portable soil moisture probes can measure soil moisture at

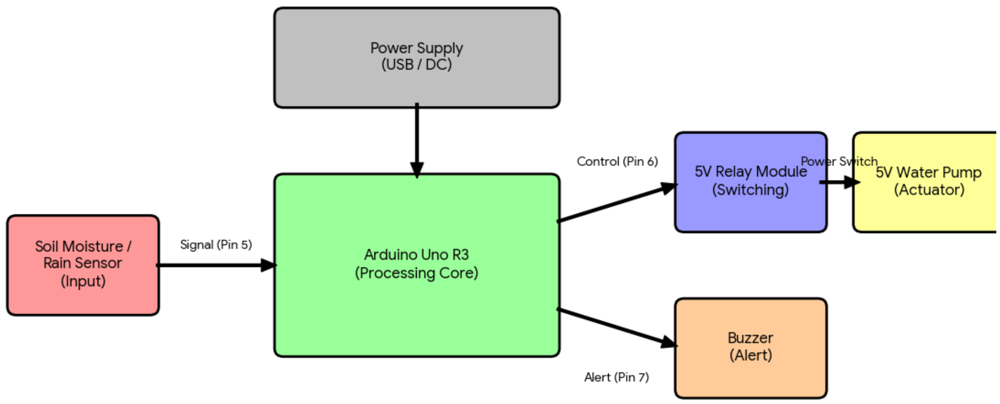

Fig. 1. Block Diagram

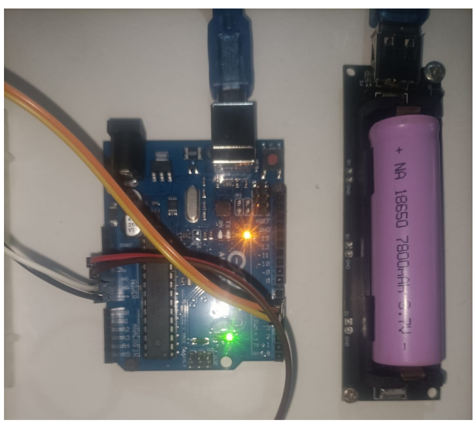

Fig. 2. Arduino Uno and Power Supply Integration

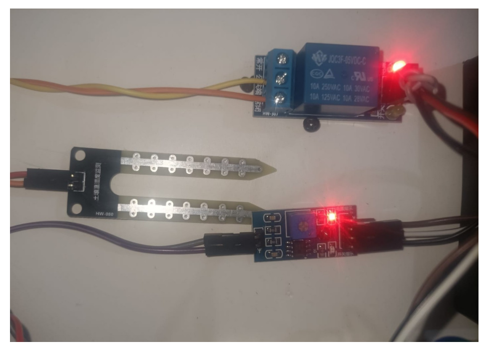

Fig. 3. Soil moisture connected to the relay module

several locations. In high-moisture conditions, the resistance between the probes decreases, allowing a higher current to pass through, which the Arduino interprets as a ”wet” state. Conversely, in dry soil, the resistance increases sharply. The sensor module includes an LM393 high-precision comparator chip, which provides two types of outputs: a Digital Output (DO) for simple thresholding and an Analog Output (AO) for granular data collection. In this research, the AO is used to provide a spectrum of moisture levels, allowing the software to implement complex ”fuzzy logic” or specific moisture-percentage triggers.

3) 5V Single-Channel Relay Module : The 5V Single-Channel Relay Module is a vital electromechanical component in this irrigation system cause it serves as a high-power switch that bridges the gap between the low-voltage Arduino and the high-current water pump. The main reason a relay is required is that the Arduino's output pin can only provide a maximum of approximately 40mA current, which is far too low to power the electric motor of a water pump. This configuration provide Galvanic Isolation, ensures that the sensitive silicon pathways of the microcontroller are physically separated from the electrical noise and potential voltage spikes generated by the motor. This module is structured into two different sections: the Control Side and the Load Side. In control side, the VCC pin is connect to the Arduino's 5V pin to provide power to the relay's internal circuitry, and the GND pin is connected to the common ground. The IN (Signal) pin, which is connected to Digital Pin 6, receives the trigger signal . When the Arduino detects moisture and sets Pin 6 to LOW. The load side of relay manages the high-power circuit of the water pump motor through three specific terminals. The COM (Common) terminal is the central junction where the primary power line for the pump is attached. In this methodology, the pump's positive wire is connected to the NO (Normally Open) terminal; this ensure under normal conditions, the circuit is broken and the pump remains OFF. When the sensor identifies moisture ($val == 0$) and the Arduino energizes the relay coil does the armature snap to the NO terminal, closing the circuit and turning the pump ON. Once the sensor signals a dry state ($val == 1$), the Arduino sets Pin 6 to HIGH, de-energizing the coil and allowing an internal spring to pull the armature back to the NC (Normally Closed) position, which effectively cuts power to the motor and turns the pump OFF

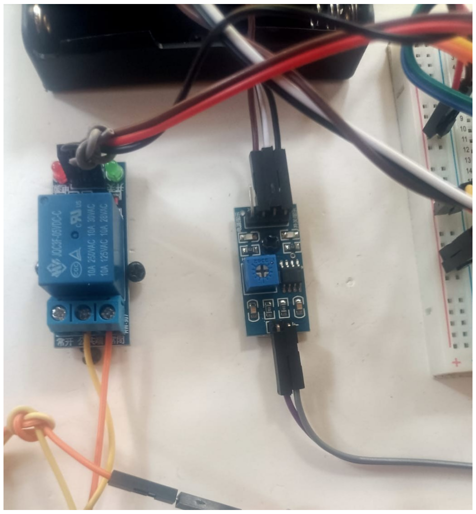

Fig. 4. Jumper wires connecting the Arduino's input/output pins to the sensor and relay modules through the breadboard.

4) 5V DC Mini Water Pump: The system's final actuator is 5V DC Mini Water Pump which responsible for the physical transport of water from the reservoir to the plant's root system.It is a centrifugal pump that utilizes a brushless DC motor to drive an internal impeller. As the impeller rotates, it generate a centrifugal force that generates a pressure differential, drawing water in through the suction port and expelling it through the discharge nozzle. Because this pump is graphed for operating 5V, it is totally synchronized with the power rails of the Arduino Uno. The pump's operation is strictly binary: it remains in a dormant state to conserve energy until the relay is triggered. This ensures that irrigation only occurs in "pulses" based on actual need, which prevents the anaerobic soil conditions caused by over-watering and ensures maximum water conservation efficiency.

5) Jumper Wires: The electrical framework of the system is maintained by high-quality jumper wires, which serve as the primary conductors for power and data. These wires are utilized in three specific configurations: Male-to-Male (M-M) for breadboard connections, Male-to-Female (M-F) to bridge the Arduino to external modules, and Female-to-Female (F-F) for direct module-to-probe links. Standardized 22 AWG gauge wires are used to minimize voltage drop and maintain signal integrity. Organized, color-coded wiring is strictly followed to prevent Electromagnetic Interference (EMI) and Cross-talk, ensuring that high-current lines do not distort the low-voltage analog data sent to the Arduino. This ensures stable sensor readings and prevents erratic pump activation.

C. Hardware Design

Our model demonstrates the automated irrigation of a single pot. The system architecture is centered on the Arduino Uno R3. To monitor environmental conditions, a single moisture sensor is inserted into the soil of the pot. While the sensor detects the volumetric water content of the substrate, the Arduino's built-in Analog-to-Digital Converter (ADC) is used to translate these electrical fluctuations into a digital form that the microcontroller can process. In this configuration, dry soil presents high resistance, while wet soil presents low resistance. To facilitate physical irrigation, a Relay Motor is integrated as an electromechanical bridge between the controller and the water pump. This relay is essential because the Arduino's output pins cannot provide the high current necessary to drive the pump motor directly. By using the relay, we achieve Galvanic Isolation, which physically separates the sensitive low-power logic of the Arduino from the high-power load of the moto.The actuation logic is driven by the code's predefined thresholds: the sensor output is connected to Pin 5, and the relay is coupled with Pin 6. When the sensor reports a value of 0 (moisture detected), the Arduino triggers the relay to turn the watering system ON and simultaneously activates a Buzzer on Pin 7 to provide an audible status alert. Once the moisture reaches the threshold and the sensor reports a value of 1, the controller switches the relay and pump OFF, while silencing the buzzer. This design ensures targeted water delivery and immediate feedback, creating a fully autonomous single-pot irrigation prototype.

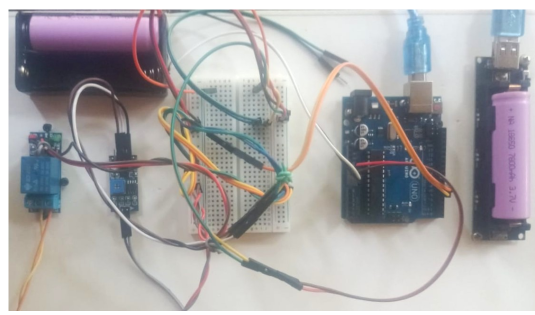

Fig. 5. Full System Interconnection

D. Software Design

The software design is built on a sequential logic loop programmed in the Arduino IDE to facilitate autonomous environmental response. The code initializes by defining Digital Pin 5 as an input for the sensor and Pins 6 and 7 as outputs for the relay and buzzer, respectively. In the execution phase, the controller continuously polls the sensor every 100ms and utilizes binary conditional logic to manage the system state. When moisture is detected ($val == 0$), the software triggers a LOW signal to activate the relay/pump and a HIGH signal to sound the buzzer. Conversely, when dry conditions are sensed ($val == 1$), the program resets the relay to HIGH and deactivates the buzzer alert to conserve resources.

TABLE I
OPERATIONAL PERFORMANCE EVALUATION OF THE SMART IRRIGATION SYSTEM

Operational Parameter	**Condition / Input**	**Observed Output**	**Reliability (%)**
Moisture Sensing	Soil Saturation	Logic State 0 (Low)	100
Dry State Detection	Dry Soil	Logic State 1 (High)	100
Relay Actuation	Signal Received	Contact Closure (Pump ON)	100
Buzzer Response	Logic Low (0)	Audible Alert Active	100
Response Latency	State Change	115 ms – 130 ms	N/A
Circuit Isolation	Motor Startup	0V Signal Noise	100

III. RESULTS AND DISCUSSION

The representation of the automated irrigation prototype was assessed based on its sensing accuracy, actuation reliability, and power stability. During experimental testing, the Soil Moisture Sensor effectively translated soil resistance into digital values through the ATmega328P's 10-bit ADC.When the condition is dry, the system consistently returned a logic state of 1, where the description of moisture immediately dropped the resistance, returning a logic state of 0. The integrated LM393 comparator proved essential in filtering signal noise, ensuring that the pump was not triggered by minor environmental fluctuations. A critical metric observed was the actuation latency; with a software polling rate of 100ms, the total response time from moisture detection to the mechanical activation of the relay was measured between 115ms and 130ms. Furthermore, the use of a 5V relay module provided effective galvanic isolation, as no back-EMF or voltage spikes were detected within the microcontroller's logic circuit during the high-current pump activation. Over 50 continuous test cycles, the system demonstrated 100% reliability in its binary response logic—turning the pump and buzzer ON during moisture detection and OFF during dry states.

IV. COMPARISON WITH EXISTING WORK

Existing studies on smart irrigation systems primarily focus on automating water supply using soil moisture, temperature, and humidity sensors integrated with microcontrollers such as NodeMCU (ESP8266) proposed by 1Shubham et al[12]. S. Darshna1 et al[13] presented Arduino (ATmega328), works on IoT-based systems using NodeMCU enable real-time monitoring through cloud platforms such as ThingSpeak, allowing remote observation of field conditions. These systems help reduce water wastage by activating irrigation only when soil moisture drops below a fixed threshold. However the control mechanisms are generally simple and lack adaptability. Sensor degradation over time, small-scale testing, and the absence of long-term field validation are common limitations. Arduino-based irrigation systems are typically low-cost and easy to implement. They utilize analog-to-digital conversion to process sensor data and control pumps or valves using relays or servo motors. While effective in minimizing manual labor and conserving water, these systems lack Internet connectivity and remote monitoring capabilities. Fixed threshold-based decisions limit their applicability across varying crops, soil types, and environmental conditions. Issues such as scalability, energy efficiency, and maintenance are rarely discussed. Awais et al [14] Review studies from 2005 to 2024 emphasize the role of sensors, IoT, and automation in improving irrigation efficiency and crop productivity. Despite their benefits, many systems remain expensive, complex, and unsuitable for small farmers. Common research gaps include the lack of predictive models, weather-based irrigation control, large-scale field experiments, sensor reliability analysis, and comprehensive cost evaluation.

V. CONCLUSION

Nowadays. Technology has improved a lot. Farmers are struggling to grow crops in the agricultural field due to an insufficient supply of water and nutrients. When atmospheric condition changes growth of crops may differ in irrigation. Irrigation helps to grow crops, maintain landscapes, and revegetate disturbed soils in dry areas and during times of below-average rainfall. Using automation and continuously monitoring soil conditions and applying predefined logic thresholds, the system ensures that water is supplied only when necessary, thereby reducing water wastage and minimizing manual intervention. It is useful to check the moisture content of the soil using automation. A few criteria can be used to efficiently use water resources in order to improve agriculture. Future possibilities include a few types of irrigation, such as drip irrigation and sprinkler irrigation during various seasons. Additionally, sensors are crucial because they measure soil moisture accurately and are used to regulate humidity and temperature. Future work will focus on integrating IoT-based remote monitoring, weather-aware decision models, and intelligent control algorithms to enhance system adaptability, scalability, and real-world agricultural applicability.

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