© May 2026 | IJIRT | Volume 12 Issue 12 | ISSN: 2349-6002

Smart Irrigation and Farm Protection System Using Sensor-Based Automation and Solar Power

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***Abstract*—Efficient irrigation and farm protection are two important requirements in small agricultural fields, nurseries and home-garden applications. Manual irrigation can waste water, while unmonitored farms remain vulnerable to crop damage caused by animals or intruders. This paper presents a low-cost smart irrigation and farm protection prototype based on an Arduino UNO, a soil moisture sensor, a passive infrared (PIR) motion sensor, a relay-driven water pump, LED/buzzer alarms, a servo scanning mechanism and a solar-assisted power supply. The system measures soil moisture and compares it with a preset threshold to switch the pump ON or OFF automatically. In parallel, the PIR sensor detects motion and triggers an audible and visual alert for farm protection. Functional testing showed that the pump control responded correctly to dry and wet soil conditions, while the PIR section activated the alert output during motion detection. The design demonstrates a practical, affordable and expandable approach for sustainable agriculture and can be extended with IoT connectivity for remote monitoring.**

***Index Terms*—Arduino UNO, farm protection, PIR sensor, relay module, smart irrigation, soil moisture sensor, solar power.**

I. INTRODUCTION

Agriculture depends strongly on timely water availability, but conventional irrigation often uses more water than the crop actually needs. FAO notes that irrigation water withdrawal can far exceed the net irrigation requirement because of distribution and application losses [1]. At the same time, agriculture remains the dominant water-use sector in many regions, so practical water-saving control methods are important for farms of every scale [2].

A sensor-based irrigation controller can reduce over-irrigation by applying water only when the soil condition crosses a dryness threshold. Soil moisture monitoring supports irrigation scheduling by measuring the water stored in the crop root zone and by helping farmers make timely irrigation decisions [8], [9]. Soil-moisture-based irrigation controllers have also been promoted as a way to reduce unnecessary water use in automatic irrigation systems [10].

Farm protection is a second challenge. Farms located near open land or forest boundaries are vulnerable to animal movement and unauthorized entry. The proposed prototype addresses both requirements using a simple embedded system: the soil sensor controls irrigation, the PIR sensor detects movement, and the Arduino UNO coordinates the relay, pump, buzzer, LED and servo actions. Solar power is included as a future-ready supply path because solar-powered irrigation systems can provide reliable energy in rural locations where grid supply may be unavailable or costly [3].

II. RELATED WORK

IoT-based smart irrigation research has shown that combining sensors, embedded controllers and communication modules can improve irrigation scheduling and field monitoring [4], [5]. Reviews of precision irrigation systems emphasize real-time monitoring, automated control and decision support as important strategies for improving water-use efficiency under changing climate conditions [6], [7].

For student-level and small-farm deployments, Arduino-based designs remain attractive because they are inexpensive, easy to program and compatible with many analog and digital sensors. The Arduino UNO R3 is based on the ATmega328P and provides 14 digital input/output pins and 6 analog inputs, which is sufficient for the proposed prototype [11]. The ATmega328P supports low-power embedded operation and programmable I/O lines, making it suitable for sensor-actuator control tasks [12].

III. PROPOSED SYSTEM

The proposed system integrates two functional modules: an irrigation automation module and a farm protection module. In the irrigation module, a soil moisture sensor is inserted into the soil and connected to the analog input of the Arduino. When the analog moisture value indicates dry soil, the Arduino energizes the relay, allowing the water pump to supply water. When the soil becomes sufficiently wet, the relay is switched OFF to stop the pump.

In the farm protection module, the PIR sensor monitors changes in infrared radiation produced by moving humans or animals. When motion is detected, the Arduino activates the buzzer and LED indicators. The servo can be used as a scanning or directional mechanism; in the prototype logic, the servo scans when no motion is detected and stops at the current angle during an alert. The HC-SR501 PIR module is suitable for this task because it provides a digital output and operates over a wide low-voltage range [13].

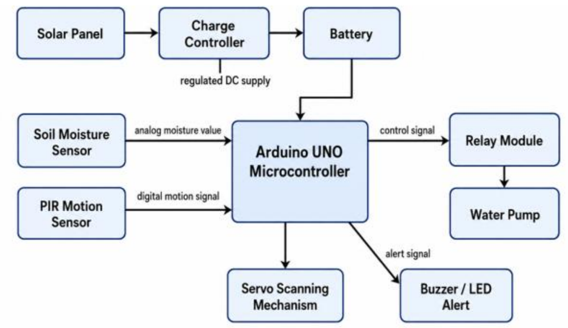

Fig. 1. Proposed system architecture showing irrigation, protection and solar power blocks.

IV. HARDWARE AND SOFTWARE DESIGN

A. Component Selection

Table I summarizes the main components used in the prototype. The soil moisture sensor provides an analog value proportional to soil condition. Capacitive moisture sensors are preferred for longer service life because they avoid exposed conductive probes and are compatible with 3.3-5.5 V microcontroller systems [14]. The relay provides electrical isolation between the low-power Arduino signal and the pump circuit, while the buzzer and LED provide immediate local alerts.

TABLE I
MAJOR COMPONENTS USED IN THE PROTOTYPE

Component	Specification	Function
Arduino UNO R3	ATmega328P, 5 V, 14 digital I/O, 6 analog inputs	Main control unit
Soil moisture sensor	Analog output, 3.3-5.5 V compatible	Detects soil dryness/wetness
PIR sensor	Digital HIGH/LOW output, motion detection	Detects animals or humans
Relay module	5 V control input	Switches water pump
Water pump	5-12 V DC prototype pump	Supplies irrigation water
LED/Buzzer	5 V alert output	Visual and audible warning
Servo motor	PWM controlled, about 180 degrees	Scanning/positioning mechanism
Solar panel and battery	6-12 V small-scale supply	Renewable power support

B. Control Logic

The program repeatedly reads the moisture and PIR sensor inputs. A dryness threshold is stored in the Arduino code. If the soil value is above the threshold selected for the prototype, the relay output is set HIGH and the pump turns ON. Otherwise, the relay remains LOW. When PIR output is HIGH, the buzzer and LED are switched ON; otherwise, the alert outputs remain OFF and the servo continues scanning.

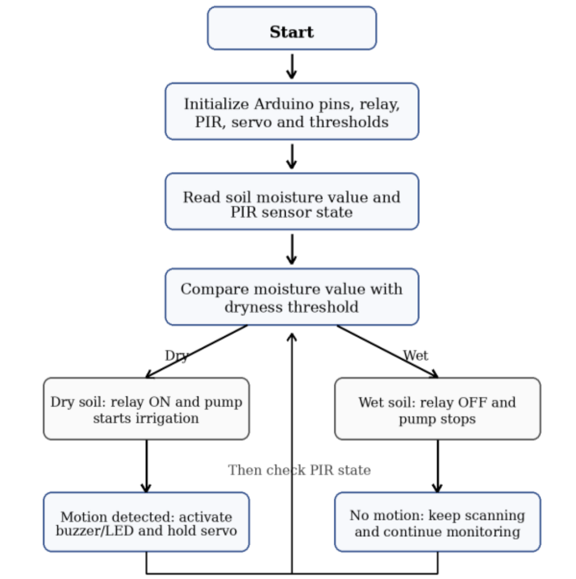

Fig. 2. Control flow used for irrigation and protection decisions.

TABLE II
PIN MAPPING USED IN THE ARDUINO PROTOTYPE

Module Signal	Arduino Pin
Soil moisture sensor output	A0
PIR sensor OUT	D2
Buzzer	D3
LED	D4
Servo signal	D6
Relay IN	D8
Common ground	GND

V. SIMULATION AND PROTOTYPE

The circuit was first represented in TinkerCAD to verify sensor connections, Arduino pin assignment, relay switching and alert behavior. The simulation helped confirm that the software structure matched the intended hardware connections before assembling the physical prototype.

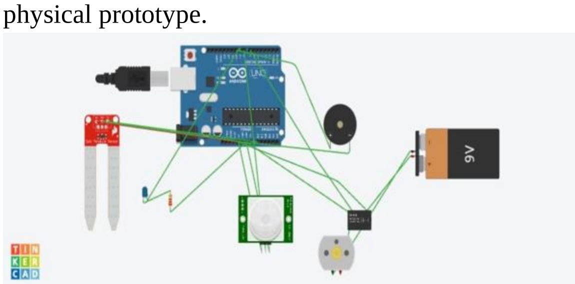

Fig. 3. TinkerCAD circuit design used for simulation and connection planning.

The physical prototype was assembled on a base board using a small water reservoir, pump tubing, a solar panel, Arduino-based control circuit, relay module, PIR sensor, buzzer, LED indicator, servo and rechargeable battery. The prototype layout is shown in Fig. 4.

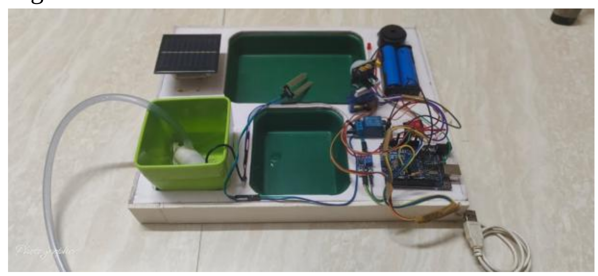

Fig. 4. Implemented smart irrigation and farm protection prototype.

VI. RESULTS AND DISCUSSION

The prototype was tested in function modes that were equivalent to dry soil, wet soil, motion detected and no motion detected. Tests in dry soil showed the relay to turn on a pump so that water could flow to the irrigation area.
When the soil condition reached the wet threshold, the pump was automatically switched OFF.

This behaviour is consistent with the objective of reducing water wastage and avoiding both over- and under-irrigation.
As we expected, the farm protection section responded.
When the PIR sensor sensed motion, the buzzer and LED were turned on. If there was no motion detected the alert was kept OFF and the operation of the servo scanning continued.
These results show that a single microcontroller can coordinate irrigation and security tasks in real time for a small prototype.

TABLE III
FUNCTIONAL TEST OBSERVATIONS

Test Condition	Expected Output	Observed Result
Dry soil condition	Relay ON, pump ON	Pump activated
Wet soil condition	Relay OFF, pump OFF	Pump stopped
PIR motion detected	Buzzer/LED ON	Alert activated
No motion detected	Alert OFF, servo scanning	Normal monitoring

VII. APPLICATIONS AND FUTURE SCOPE

The system can be used in nurseries, greenhouses, home gardens, small agricultural plots and smart farming demonstrations. Its main benefits are less manual labour, automatic pump switching, local intrusion alarm and compatibility with renewable energy.

Future work can be integration of ESP8266/ESP32 or GSM module for IoT based remote monitoring, mobile notifications and cloud data logging.

Other sensors such as temperature, humidity, rain and pH sensors can be added to enhance the irrigation decisions.

Multi-zone irrigation can be accomplished with additional relay channels and moisture sensors.

For real farm deployment a weatherproof enclosure, larger solar panel, charge controller and field-grade pump would be needed.

VIII. CONCLUSION

The project is integrated with Arduino UNO, soil moisture sensor, PIR sensor, relay, pump, buzzer, LED and servo with a solar assisted power supply to automate the irrigation and to provide local security alerts.

Functional testing showed the pump turning on when the soil was dry, turning off when the soil was wet, and turning on the alert when motion was detected.

The prototype is simple, low cost and suitable for educational demonstration, while the architecture can be expanded towards IoT enabled precision agriculture.

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