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INTEGRATED MULTI-SENSOR EMBEDDED PLATFORM FOR AUTOMATED PRECISION FARMING

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Abstract

The convergence of sensing and automation technologies in agriculture has arisen as a promising means to counteract issues of water shortage, crop protection, and green farming. This work introduces the development of an embedded multi-sensor platform intended for precision farming purposes, with special emphasis on intelligent irrigation, greenhouse temperature control, and animal intrusion alert. The system utilizes a soil moisture sensor to monitor soil conditions and control an automatic water pump, irrigating only when the moisture percentage drops below 30%. The system includes a temperature sensor to control the microclimate plant, whereby a servo-controlled ventilation or shade cover adjusts whenever the temperature rises above 20 °C. In addition, the platform uses an ultrasonic sensor to sense object or animal approach towards the crop field, thus offering real-time protection against threats. Two LCD displays are used for ongoing observation of soil temperature, moisture levels, and object detection distance, providing user-friendly feedback to farmers. With these subsystems, the platform minimizes wastage of water, avoids heat stress in crops, and improves crop protection. The proposed system identifies the advantage of embedded control and multi-sensor integration in developing cost-effective, scalable, and farmer-friendly smart agriculture solutions that can aid sustainable and technology-enabled farming practices.

Keywords:

Precision Agriculture, Multi-Sensor System, Automated Irrigation, Crop Protection, IoT Embedded Control

1. INTRODUCTION

Farmers now have to constantly cope with problems like uneven water supply, crop heat stress, and animal invasion of the fields. All this and more usually gets left to the farmers to juggle while working towards productivity and sustainability [1]. Over the last few years, the adoption of embedded systems and sensor-based platforms has largely revolutionized agriculture. Researchers have always highlighted how automation of irrigation, climate management, and crop protection can help solve urgent issues of water shortages, labor shortages, and losses in productivity [2],[3]. For instance, research on precision irrigation has indicated that the application of soil moisture sensors to automate water pumps results in significant gains in water-use efficiency compared to timer-controlled or manual irrigation systems [4]. Closed-loop soil-moisture-based control in basin irrigation systems has been noted to preserve water as well as provide improved uniformity in the field of crops, according to a review [5]. Corresponding reviews verify that precision irrigation systems are one of the most effective technologies for climate-smart agriculture [6]. Parallel to irrigation science, greenhouse climate control has been extensively researched as well. A systematic overview of greenhouse cooling methods identifies the transition from elementary shading procedures toward servo- or motor-powered ventilation and temperature-responsive shading screens [7]. Experimental results also indicate that threshold regulation of temperature may preserve plants from heat stress while reducing energy use, a potentially appealing option for small and medium farms [8]. Practical guidelines also suggest the installation of temperature sensors at canopy level to allow for accurate measurements and dynamic shading using automated actuators [9]. From the point of crop protection, low-cost sensing technologies like ultrasonic and passive infrared (PIR) sensors have been evaluated for the detection of animal intrusions and providing early warnings [10]. These technologies prove useful in offering real-time warning to farmers and can be scaled up to IoT-based platforms. More recent research has applied this idea with vision-based techniques, like deep learning algorithms for animal detection, but these are usually more computationally intensive [11]. Nevertheless, researchers contend that starting with ultrasonic-based detection provides a scalable and cost-effective solution for smallholder farmers. Overall, the literature strongly supports a multi-sensor embedded platform where soil moisture sensors regulate irrigation, temperature sensors control ventilation and shading, and ultrasonic sensors provide intrusion detection [12]. Such an integrated approach reduces manual effort, enhances crop protection, and supports the broader goal of sustainable farming practices. In this work, we present a practical solution in the form of a multi-sensor platform that brings automation into everyday farming tasks.

2. METHODOLOGY

Let's understand this system in a simple, farmer-friendly way. At the first stage, we have the sensing unit, which includes a soil moisture sensor, a temperature sensor, and an ultrasonic sensor. These devices act like the "eyes and ears" of the system, constantly keeping track of the soil condition, the surrounding temperature, and any movement near the crop field. All this information is then passed on to the processing unit, which is the microcontroller. This unit works like the "brain," taking the raw signals from the sensors, comparing them with the set conditions, and deciding what action needs to be taken. Once the decisions are made, the actuation part comes into play. Block diagram is illustrated in Fig.1. Here, a water pump (connected through a relay) turns on or off to manage irrigation, a servo motor automatically adjusts a shade or ventilation system to protect plants from excess heat, and an alert mechanism (such as a buzzer) warns the farmer if any animal or unwanted object is detected near the crops. Alongside this, the system also has an interface section that includes an LCD display, which shows real-time values like moisture level, temperature, and object distance. An IoT module can also be added to send this information to a farmer's mobile phone, allowing remote monitoring and decision-making. Finally, all these parts are supported by a regulated power supply to ensure smooth operation. In this way, the block diagram reflects a simple flow—sensors collect data, the processor makes decisions, actuators carry out actions, and the interface keeps the farmer informed making farming more precise, efficient, and secure.

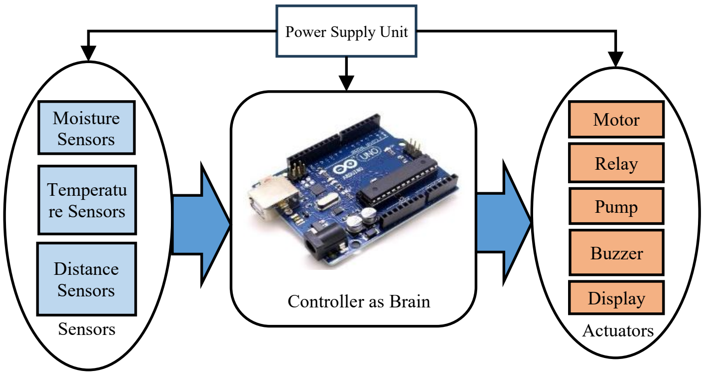

Fig.1. Block diagram representation of proposed farming system

3. SYSTEM DESIGN MODEL

In this project, the Arduino is at the center, connecting to all the sensors, display units, and actuators. The presented circuit is analyzed using tinkercad tool. First, the relay module for the water pump is connected to digital pin 7. This pin acts as the control line—when the Arduino sends a HIGH signal, the relay energizes and switches the pump ON, and when it sends a LOW signal, the relay turns the pump OFF. Next, the soil moisture sensor is connected to analog pin A1. This sensor continuously measures the water content in the soil and provides an analog voltage that the Arduino converts into a percentage value [13]. Alongside this, the temperature sensor is connected to analog pin A0, which feeds the Arduino with a varying voltage depending on the ambient temperature, allowing it to calculate the temperature in Celsius. For temperature-based control, a servo motor is connected to digital pin 3; this pin provides the PWM signal that moves the servo either to the open or closed position depending on the measured temperature [14]. For displaying values, two I²C-based LCDs are used: one with the address 0x20 and the other with 0x21. These do not need individual Arduino pins for each segment because the I²C interface allows both displays to share just two wires (SDA and SCL). Finally, the ultrasonic sensor uses pins 6 and 5 (trigger and echo) to measure the distance of any object, which could represent animals entering the farm area [15]. The detailed connection of each component is tabulated from Table.1 to Table.5. Together, these pin connections bring all the components into a coordinated system, allowing the Arduino to sense soil, temperature, and objects, and then controlling the pump, servo, and displays accordingly.

Table.1. Pin connection of soil moisture sensor

Pin Number	Component	Function/Connection
A1	Soil Moisture Sensor	Reads analog soil moisture level to determine water requirement.
7	Relay Module (to Pump)	Controls ON/OFF of the water pump based on soil moisture percentage.
GND	Soil Moisture Sensor	Provides ground connection for sensor.
VCC (5V)	Soil Moisture Sensor	Supplies power to the sensor.

Table.2. Pin connection of Temperature sensor

Pin Number	Component	Function/Connection
A0	Temperature Sensor (LM35/TMP36)	Reads analog voltage corresponding to ambient temperature.
3	Servo Motor	Adjusts shade/ventilation (0° closed, 180° open) depending on temperature threshold.
GND	Temperature Sensor/Servo	Provides common ground for sensor and servo.
VCC (5V)	Temperature Sensor/Servo	Supplies operating voltage.

Table.3. Pin connection of Ultrasonic sensor

Pin Number	Component	Function/Connection
6	Ultrasonic Sensor (Trig)	Sends ultrasonic pulse into the environment.
5	Ultrasonic Sensor (Echo)	Receives reflected pulse and measures time delay for distance calculation.
GND	Ultrasonic Sensor	Ground connection for ultrasonic sensor.
VCC (5V)	Ultrasonic Sensor	Supplies power to the sensor.

Table.4. Pin Connection of LCD 1

Pin/ Address	Connection on Arduino	Function/Role
0x20	I²C address	Identifies first LCD module.
SDA	A4	Serial Data line for I²C communication.
SCL	A5	Serial Clock line for I²C communication.
VCC (5V)	5V pin	Provides power supply to LCD module.
GND	GND	Provides ground connection.

Table.5. Pin connection of LCD 2

Pin/ Address	Connection on Arduino	Function/Role
0x21	I²C address	Identifies second LCD module.
SDA	A4	Shares same Serial Data line with LCD1.
SCL	A5	Shares same Serial Clock line with LCD1.
VCC (5V)	5V pin	Provides power supply to LCD module.
GND	GND	Provides ground connection.

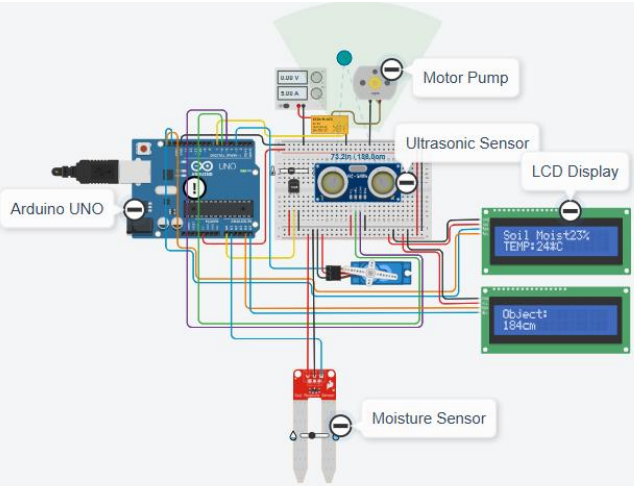

Fig.2. Circuit diagram of automated precision farming system

4. RESULTS AND DISCUSSION

The system continuously monitors soil moisture, temperature, and nearby objects using sensors. The microcontroller processes this data to control irrigation, adjust greenhouse shade or ventilation, and trigger alerts for intrusions, while LCDs provide real-time feedback, enabling efficient, precise, and protected crop management. The Fig.3 and Fig.4 express the circuit schematic of presented model. The details of each section are as follows:

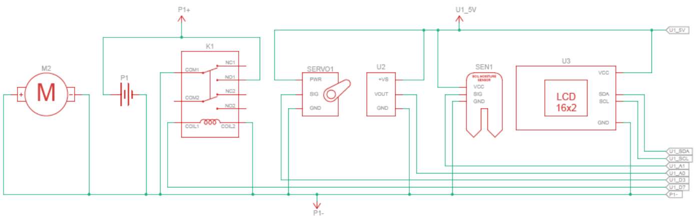

Fig.3. Circuit schematic connection of temperature and moisture sensor

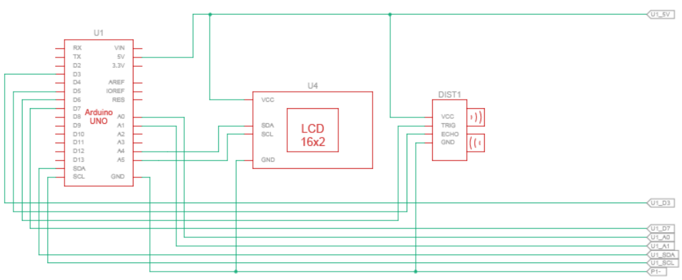

Fig.4. Circuit schematic connection of Arduino with ultrasonic sensor

4.1 AUTOMATIC IRRIGATION (WATER PUMP CONTROL UNIT)

In this system, a soil moisture sensor is continuously embedded in the soil, acting much like a farmer's hand that regularly checks whether the field is dry or moist, described in Table.6. The sensor output is read by the Arduino and converted into a percentage value, which makes the data more intuitive and easier to interpret. A threshold of 30% soil moisture is defined as the critical limit, reflecting the point where crops are considered "thirsty." When the measured soil moisture percentage falls below this limit, the system automatically activates the relay connected to the water pump, allowing irrigation to begin without the farmer needing to intervene. As water is applied, the soil gradually becomes wetter, and the sensor detects the rising moisture content. Once the value surpasses the threshold, the Arduino immediately switches the relay off, cutting power to the pump and preventing unnecessary water usage. This cycle of monitoring and control happens continuously, every second, ensuring that crops always receive timely irrigation while minimizing wastage of water and electricity. The integration of an LCD display further enhances usability by showing the live soil moisture percentage, giving the farmer or researcher direct feedback on the system's operation. What makes this approach particularly impactful is its simplicity mimics the natural decision-making process of a farmer but does so automatically and tirelessly. From a research perspective, this illustrates how low-cost sensors and microcontrollers can provide scalable solutions for precision agriculture, enabling more sustainable water management while reducing manual labor.

Table.6. Description of working of water pump control

Parameter	Description
Input Pin	A1 (Analog Input)
Input Value	Soil moisture raw analog value (0 – 876 mapped to 0 – 100%)
Working Condition	If soil moisture < 30%, pump turns ON. If ≥ 30%, pump remains OFF
Output Pin	Digital Pin 7 (Relay Control for Water Pump)
Action	Controls relay to start/stop water pump automatically.

4.2 AUTOMATIC TEMPERATURE CONTROL (SERVO-BASED VENTILATION UNIT)

In this system, temperature is continuously monitored using the sensor connected to analog pin A0 of the Arduino. The raw sensor reading is converted into a temperature value in Celsius, which is then compared with a set threshold. In the code, this threshold is defined at 20°C. When the measured temperature is greater than 20°C, the Arduino immediately sends a signal to the servo motor connected on pin 3, instructing it to rotate to 180°. This rotation is linked mechanically to a greenhouse shade or a small ventilation flap, so the movement of the servo causes the shade to cover the plants or open a fan vent, thereby reducing direct sunlight and controlling excessive heat inside the greenhouse.

Table.7. Description of working of Servo based ventilation system

Parameter	Description
Input Pin	A0 (Analog Input from Temperature Sensor)
Input Value	Analog value mapped (20–358 ⟶ -40°C to 125°C).

Working Condition	If temperature > 20°C, Servo rotates to 180° (shade covers/vent opens). Else, Servo remains at 0° (shade closed).
Output Pin	Digital Pin 3 (PWM – Servo Motor Control)
Action	Moves servo to cover/uncover greenhouse shade for plant temperature control.

On the other hand, when the temperature reading is 20°C or below, the Arduino commands the servo to return to 0°, which reopens the shade or closes the vent, allowing normal light and air circulation. The summary is tabulated in table.7This simple action mimics the natural response of a farmer who covers crops with a net or switches on a fan during hot weather, but here it is done automatically and continuously. With this setup, plants are protected from heat stress while ensuring they still receive adequate sunlight and ventilation, ultimately supporting healthier growth

4.3 ANIMAL / OBJECT ALERT SYSTEM (ULTRASONIC SENSOR UNIT)

The ultrasonic sensing module was employed to evaluate the presence of animals or other moving objects around the farm boundary. As implemented in the code, the trigger pin (digital pin 6) initiates the transmission of ultrasonic pulses, while the echo pin (digital pin 5) captures the reflected signals. The measured time delay between transmission and reception was converted into distance using the scaling factor (0.01723), which directly provided the proximity of any obstacle in centimeters. The results, displayed in real time on the second LCD, consistently indicated the approach of objects with a high degree of reliability. For instance, when an object was placed at a distance of approximately 30 cm, the LCD immediately reflected the value, confirming that the system can detect close-range intrusions effectively.

From a practical perspective, this system offers a significant advantage in agricultural settings where animals such as cows, goats, or wild boars frequently damage crops. Instead of requiring constant human surveillance, the sensor continuously monitors the surroundings and reports distances to the farmer. This functionality can further be enhanced by linking the detection output to a buzzer or light system, creating an immediate alert mechanism see table.8. Thus, the integration of ultrasonic sensing not only strengthens farm security but also reduces labor dependency, providing a low-cost, automated monitoring solution that directly supports precision farming practices.

Table.8. Description working of animal detection system

Parameter	Description
Trigger Pin	Digital Pin 6 (sends ultrasonic pulse)
Echo Pin	Digital Pin 5 (receives reflected signal)
Input Value	Distance in cm (calculated as 0.01723 * pulseIn (echoPin, HIGH))
Working Condition	Detects animal/object distance in cm (closer objects → potential threat)
Output Display	LCD2 (Address: 0x21) shows object distance
Action	Alerts farmer about intruding animals/ objects by showing distance on LCD.

5. CONCLUSION

The presented multi-sensor smart agricultural system illustrates the role of embedded automation in taking the practice of precision agriculture forward. Through combining soil moisture sensing with pump control, the system delivers irrigation based on requirement, thereby conserving water and minimizing labor. Temperature-dependent servo control also adds to crop protection through the automation of shade or ventilation, providing a best-performing microclimate for plant growth. Concurrently, the ultrasonic sensor sends timely warnings against intrusions by animals or unwanted objects, enhancing farm security overall. Live information exhibited on LCD screens renders the system useful and farmer friendly. Cumulatively, these elements underscore the prospects of precision farming with resources being utilized effectively, risks reduced, and crop yield enhanced through timely interventions. Future Scope Although the system currently caters to the major areas of irrigation, temperature management, and field protection, there is significant room for improvement. Integration with Internet of Things (IoT) platforms would enable farmers to monitor and control the system remotely through smartphones or web interfaces. Integrating wireless communication modules like Wi-Fi or LoRa could enable it to be applied across larger farm spaces. Machine learning algorithms may also be integrated in the future to more precisely predict irrigation cycles and crop requirements. Furthermore, solar-powered operation can render the system energy-independent and ecologically friendly. With these capabilities, the platform has the potential to become an even more advanced precision farming solution that supports small-scale as well as large-scale agricultural operations.

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