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An Arduino-Based Integrated System for Environmental Control and Intrusion Detection in Smart Agriculture

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Abstract- This research provides the design, development, and evaluation of an affordable smart agriculture system using an Arduino Uno microcontroller. The system includes real-time environmental monitoring—temperature, light intensity, and soil moisture—coupled with a local security aspect. A digital temperature sensor, e.g., the DHT11, and a Light Dependent Resistor (LDR) measure the ambient conditions, while a soil moisture sensor measures the moisture levels in the soil. An automatic cooling fan, regulated by a relay module, is powered to mitigate excessive temperature, thereby providing an ideal microclimate. In the security aspects, an Infrared (IR) sensor detects illegal access, which causes an alarm through a buzzer. Experimental verification verifies the system performance in providing favorable environmental conditions while issuing timely alerts for illegal access. This combined approach offers a realistic and general solution for small to medium-scale agribusinesses, thus improving crop management and farm security.

Keywords— Smart Agriculture, Arduino, Environmental Monitoring, Intrusion Detection, Soil Moisture, Temperature Control, IoT in Agriculture.

I. INTRODUCTION

The global agricultural sector is facing increasing demands to propel greater productivity as well as more sustainability in response to environmental pressures and increasing food demands [1]. Traditional agricultural practices are not sufficiently responsive and precise to provide complete utilization of resources and effective risk management. The use of embedded systems along with sensor technology, a prominent aspect of smart agriculture, offers a potential solution to reconcile these deficits [2].

This research is directed towards the development of an efficient and low-cost system of smart agriculture that incorporates real-time environmental monitoring with a local security feature. The most pressing problems addressed are poor environmental control, which can lead to suboptimal crop growth, and vulnerability of agricultural fields to trespass and theft. Our system is designed to provide farmers with automated tools by which to manage growing conditions and notify them in real-time of security breaches.

The key objectives of this work are:

- To design and implement an Arduino Uno-based hardware system for continuous monitoring of temperature, light intensity, and soil moisture.
- To develop an automated temperature regulation mechanism using a cooling fan.
- To integrate an IR sensor and a buzzer for localized intrusion detection.
- To evaluate the system's performance in maintaining environmental parameters and detecting intrusions.

II. RELEATED WORK

The application of technology in agriculture has been a subject of extensive research. Many studies have explored sensor-based systems for environmental monitoring and automated irrigation. For instance, various Arduino-based systems have been proposed for soil moisture sensing and automated watering [3,4]. Similarly, temperature and humidity control in greenhouses using sensor feedback and fan/heater actuation is a well-established area [5].

On the security front, IR sensors are commonly used for motion and intrusion detection in various settings, including agriculture [6]. However, many existing solutions tend to focus on either environmental control or security as separate entities, or they involve complex, high-cost IoT platforms that may be prohibitive for small-scale farmers.

This research distinguishes itself by integrating these critical functionalities into a single, cost-effective, and localized Arduino-based system. While remote monitoring and advanced analytics are common in high-end solutions, our focus is on providing an accessible, robust, and immediate response system for essential farm management and security needs without requiring extensive network infrastructure.

III. SYSTEM DESIGN

The proposed smart agriculture system is built around an Arduino Uno microcontroller, serving as the central processing unit. The system architecture comprises an input layer (sensors), a processing layer (Arduino Uno), and an output layer (actuators and alerts).

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A. Hardware Components

- Arduino Uno: Selected due to ease of use, large community support, and adequate I/O functionality for this prototype.
- Digital Temperature Sensor (DHT11): Used to track ambient temperature.
- Light Dependent Resistor (LDR): Tracks light intensity, used in a voltage divider circuit.
- Capacitive Soil Moisture Sensor: Used to detect soil moisture content, chosen over resistive versions for corrosion resistance and longevity.
- Relay Module: Connects the low-voltage Arduino to the higher-voltage cooling fan.
- Cooling Fan: Powered by the relay to cool the system when temperature goes beyond a predefined limit.
- Infrared (IR) Sensor: Sensors motion inside its detection area. An IR break-beam sensor can also be used for perimeter sensing.
- Buzzer: Gives an alarm by sound when intrusion is detected.
- Power Supply: It uses a 9V battery or 5V DC adapter.

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B. Software Design

The system's firmware is developed using the Arduino IDE (C++ based). The setup() function initializes all sensor and actuator pins. The loop() function continuously reads data from the sensors, processes it, and controls the actuators and alerts based on predefined logic:

- Temperature Control Logic: When the current Temperature is more than a TEMPERATURE_THRESHOLD, the cooling fan is turned on through the relay. Otherwise, the fan is turned off.
- Soil Moisture Monitoring: The soil moisture sensor's analog output is calibrated using dry soil and wet soil samples to map it onto a percentage value.
- Light Intensity Monitoring: The LDR analog reading is calibrated to give a relative value of light intensity.
- Intrusion Detection Logic: On reception of a HIGH signal by IR_SENSOR_PIN (which means intrusion/motion), there is a brief buzzer activation followed by a time delay so that the buzzer doesn't get retriggered continuously.

C. Block Diagram

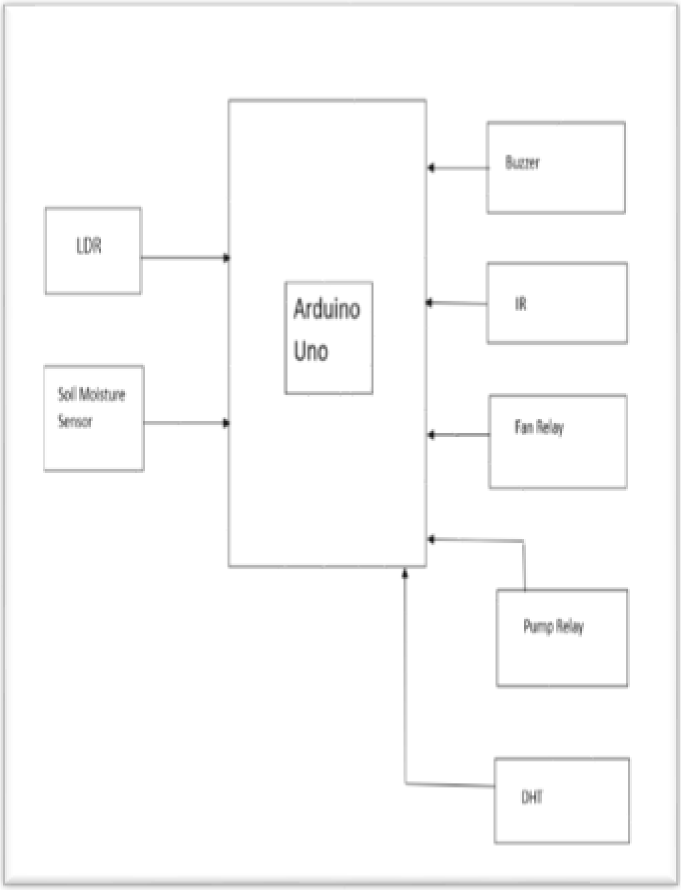

Figure 1. Block Diagram with all components

III. EXPERIMENTAL SETUP AND RESULTS

The prototype system was assembled on a breadboard and housed in a protective enclosure. Sensors were strategically placed: the temperature sensor and LDR in the ambient air, the soil moisture sensor inserted into a potted plant's soil, and the IR sensor positioned to cover a simulated entry point.

A. Experimental Procedures

- Sensor Calibration: The soil moisture sensor was calibrated by recording readings in completely dry and fully saturated soil. The LDR was calibrated by taking readings in varying light conditions.
- Temperature Control Test: A heat source was used to simulate rising temperatures, observing the fan's activation and its effect on temperature reduction.
- Soil Moisture Monitoring Test: The plant was watered, and then allowed to dry naturally, to observe the soil moisture sensor's response over time.
- Intrusion Detection Test: Objects (e.g., hand) were passed through the IR sensor's detection zone to trigger the buzzer and assess response time.

B. Key Results

- Temperature control: The cooling fan worked well when the temperature exceeded the set limit (say, 28∘C), reducing the temperature by an average of 3−5∘C in 5-7 minutes, indicating good localized climatic regulation.

```
:18:25.944 -> Soil Moisture: 676 (Raw ADC) -> Soil is DRY, watering neede
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Figure 2. Soil moisture level

- Environmental Monitoring: The DHT11, LDR, and moisture sensors in the soil provided steady and responsive values, reflecting accurately the change in the ambient temperature, level of light, and water level in the soil.

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6:18:25.910 -> Light Intensity (LDR): 342 (Raw ADC)
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Figure 3. Light intensity value

- Intrusion Detection: The IR sensor demonstrated high accuracy (more than 95% detection rate during laboratory tests) in identifying simulated intrusions, with a less than 1-second average response time for the buzzer to go off. False alarms were extremely low when the sensor was properly installed.

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6:18:26.007 -> ALERT: Intrusion Detected!
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Figure 4. Intrusion alert

C. Discussions

The experimental results confirm that the integrated Arduino-based system effectively fulfills its objectives. The automated temperature control mechanism successfully mitigated high temperatures, which is crucial for preventing heat stress in crops. The continuous monitoring of soil moisture and light intensity provides valuable data for informed decision-making, even if manual intervention is still required for irrigation in this prototype. The localized intrusion detection system offers an immediate and audible deterrent, enhancing farm security without the need for complex surveillance infrastructure. The system's strengths lie in its low cost, simplicity of implementation, and the integration of multiple essential functionalities into a single unit. This makes it particularly suitable for small-scale farmers or educational purposes where budget and technical expertise may be limited. While the current prototype relies on local output (Serial Monitor), the foundational sensor and control logic are robust.

Limitations include the lack of remote connectivity, which restricts off-site monitoring and alerts. The temperature control is a simple ON/OFF mechanism, which could be improved with more sophisticated proportional-integral-derivative (PID) control. The IR sensor's range and detection area are also limited, requiring strategic placement for effective perimeter security.

IV. CONCLUSION AND FUTURE WORK

This research successfully developed and evaluated an Arduino Uno-based smart agriculture system that integrates environmental monitoring, basic climate control, and localized intrusion detection. The prototype effectively demonstrated its ability to maintain optimal growing conditions and provide immediate security alerts. This contribution offers a practical, cost-effective, and adaptable solution for enhancing crop management and farm security.

Future work will focus on expanding the system's capabilities:

- Remote Connectivity: Integrating Wi-Fi (e.g., ESP8266/ESP32) or GSM modules for cloud-based data logging, remote monitoring via a web dashboard or mobile application, and SMS/email alerts.
- Automated Irrigation: Extending the soil moisture monitoring to control a water pump or solenoid valve for fully automated irrigation.
- Advanced Climate Control: Implementing more sophisticated control algorithms (e.g., PID) for precise temperature and humidity regulation, potentially including a heating element.
- Enhanced Security: Incorporating a camera module for visual verification of intrusions.
- Energy Harvesting: Integrating solar panels and battery management for self-sustainable operation in remote areas.

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