Plant Monitoring System without microcontrollers : An Analog Approach

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***Abstract*—This report presents a comprehensive design and implementation of a plant monitoring system that operates without the use of microcontrollers such as Arduino UNO. Instead, the system utilizes analog electronics, including MOSFETs, operational amplifiers (op-amps), potentiometers, and discrete sensors, to create an autonomous plant care system. This document provides detailed explanations of sensor functionality, circuit design, implementation, and the overall benefit to plant health.**

I. Introduction

In recent years, modern gardening and agricultural systems have increasingly adopted automation to enhance productivity, reduce labor, and promote sustainable resource usage. Most of these automated systems rely heavily on digital microcontrollers such as Arduino, Raspberry Pi, or ESP32 to process sensor data and control devices like water pumps, fans, and lights.

This project presents an alternative approach—using a fully analog system for plant monitoring and environmental control. Unlike digital systems, this design eliminates the need for programming or software, relying entirely on analog electronics to perform sensing and actuation.

The system is built around three key types of sensors:

- **Soil Moisture Sensor** — Triggers irrigation when the soil becomes dry.
- **Temperature Sensor** — Activates cooling to prevent heat stress.
- **Light-Dependent Resistor (LDR)** — Controls lighting under low light conditions.

Each sensor directly controls a corresponding output:

- A water pump for irrigation,
- A cooling fan for temperature regulation,
- And LED grow lights for supplemental lighting.

These actions are controlled using analog components, comparators, and transistors. Digital processing is not involved.

The goal of this project is to demonstrate that analog circuits can still provide reliable and efficient automation for plant care. This approach is intended to highlight the effectiveness of analog electronics, which are often overlooked in favor of digital solutions like Raspberry Pi or Arduino.

While digital systems are widely used, analog circuits offer faster response times, inherent simplicity, and can serve as powerful tools for automation—especially in educational and foundational electronics contexts.

II. Benefits of Smart Plant Monitoring

A. Water Pumping

Efficient watering is essential for healthy plant growth, especially during droughts and hot summer months. Water helps maintain plant structure and drives vital processes like photosynthesis and nutrient absorption. When soil moisture is insufficient, plants experience stress, leading to wilting, slowed growth, and reduced yields.

Manual watering is often inconsistent and can result in either under-watering or over-watering. Under-watering stresses plants and limits growth, while over-watering wastes water and can damage roots. This is a significant challenge in dry or high-temperature environments, where soil dries quickly and regular watering is crucial.

An automatic water pump, controlled by a soil moisture sensor, ensures that plants receive water only when needed. When the soil becomes too dry, the analog circuit activates the pump to restore moisture levels, then turns it off once the soil is sufficiently hydrated. This helps maintain consistent hydration, promotes stronger root development, and conserves water.

Using analog electronics for this control offers advantages such as simplicity, low power consumption, and fast response without requiring software or programming. The system provides a reliable and cost-effective solution for maintaining optimal soil moisture, especially in small-scale or resource-limited settings where manual irrigation is impractical.

In summary, automatic water pumping is critical for plant health during dry conditions, and an analog-controlled system provides an effective, low-complexity method to address this need.

B. Artificial Lighting

Artificial lighting plays a crucial role in supporting plant growth, especially when natural sunlight is insufficient or unavailable. Plants rely on light to drive photosynthesis, the process by which they convert light energy into chemical energy for growth and development. In indoor gardening, greenhouses, or during extended cloudy periods, supplemental lighting ensures that plants receive the necessary light spectrum and intensity to maintain their biological rhythms.

LEDs, particularly RGB or white LEDs, are widely used as artificial light sources because they are energy-efficient, long-lasting, and can be tailored to emit specific wavelengths that optimize photosynthesis. By simulating daylight conditions, LEDs help maintain the photosynthetic cycle, promoting healthy leaf development, flowering, and fruiting.

In this project, an analog system uses a Light-Dependent Resistor (LDR) to monitor ambient light levels. When natural light falls below a certain threshold, the circuit activates the LED grow lights to provide supplemental illumination. Once adequate light is detected, the LEDs are turned off automatically. This approach ensures that plants receive consistent lighting without wasting energy.

Using analog control for lighting regulation offers a simple, low-power, and reliable solution that requires no programming. It is particularly suitable for small-scale or off-grid setups where digital systems may be unnecessary or impractical.

In general, artificial lighting controlled through analog circuits helps maintain optimal growing conditions and supports plant health when sunlight is limited.

C. Temperature Control

Temperature regulation is essential for maintaining healthy plant growth. During hot and humid conditions, plants are prone to stress, wilting, and increased susceptibility to diseases caused by fungal and bacterial growth. High temperatures can disrupt key physiological processes such as photosynthesis and respiration, ultimately affecting overall plant health and productivity.

Air circulation plays a vital role in controlling the levels of temperature and humidity around plants. A cooling fan helps dissipate heat, reduce humidity, and promote airflow, creating a more favorable microclimate. This reduces heat stress and the risk of disease by preventing stagnant, moist air that encourages the development of pathogens.

In this system, a temperature sensor continuously monitors the ambient temperature. When the temperature rises above a predefined threshold, the analog control circuit activates the fan to restore optimal conditions. Once the temperature falls back to safe levels, the fan is automatically turned off.

Using analog components for this control ensures a simple, power-efficient, and reliable solution that operates without the need for programming or complex software. This method is especially useful in small-scale or resource-limited environments where maintaining ideal temperature conditions is critical for plant health and growth. This ensures that plants receive optimal care using fully analogous automation without digital processing.

Temperature regulation helps reduce plant stress and supports a healthier growing environment by maintaining optimal airflow and temperature.

The combined use of soil moisture, temperature, and light sensors enables precise, condition-based control of irrigation, cooling, and lighting. This ensures plants receive optimal care using fully analog automation without digital processing.

III. System Overview

This section outlines the components and their integration.

A. List of Sensors and Components

- Soil Moisture Sensor(HW-080)
- Temperature Sensor (LM35)
- LDR (LM393)
- Op-Amps (LM358)
- MOSFETs (IRF540) and BJTs(BC547)
- Potentiometers
- Water Pump, Fan, and LED
- Battery and PCB
- DC to Dc step up booster(XL6009)
- voltage divider(C7805CV)
- Resistors and connecting wires
- Multimeter (DT9205A)

IV. Working Principle of Each Sensor and Its Integration

A. Moisture Sensor

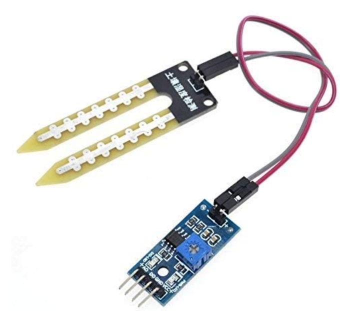

Fig. 1: Soil Moisture Sensor (HW-080)

The soil moisture sensor used in analog systems operates based on the principle of **electrical resistance** between two conductive probes inserted into the soil. This resistance varies depending on the amount of water present, making it a reliable indicator of soil moisture.

1) Conductivity of Soil and Water Content: Soil is composed of minerals, organic matter, and water. When the soil is *wet*, the water content facilitates ion movement, allowing **electric current to flow** more easily between the probes. This results in:

- **Low resistance** between the sensor probes
- **High electrical conductivity**

When the soil is *dry*, the reduced water content limits ion flow, leading to:

- **High resistance** between the probes
- **Low electrical conductivity**

2) Analog Voltage Response: The sensor is typically integrated into a **voltage divider** circuit. As soil resistance changes, so does the voltage drop across it. This produces an **analog output voltage** that varies continuously with the moisture level.

- Wet soil ⇒ Low resistance ⇒ High voltage across the fixed resistor ⇒ **Low sensor output voltage**
- Dry soil ⇒ High resistance ⇒ Low voltage across the fixed resistor ⇒ **High sensor output voltage**

This analog voltage can be interpreted directly by analog circuits without the need for digital conversion.

3) Electrical Characteristics:

- Soil resistance can range from a few **hundred ohms to several megaohms**, depending on the moisture level and soil type.
- The analog output voltage typically ranges from **0V to the supply voltage** (e.g., 0–5V).

4) Design Considerations:

- Use **corrosion-resistant** materials (e.g., stainless steel, copper with plating) for sensor probes.
- Probe **spacing** affects sensitivity—closer probes yield higher responsiveness.
- An **AC excitation signal** can reduce electrolysis and corrosion, though it's uncommon in basic analog systems.

5) Analog Interpretation Without Digital Processing: In this analog system, the sensor's output voltage is **not digitized**. Instead, it is fed to an op-amp comparator and compared to a reference voltage. This enables the circuit to trigger actions based on soil moisture levels using purely analog components, highlighting the simplicity and reliability of analog control systems.

B. Light Dependent Resistor (LDR)

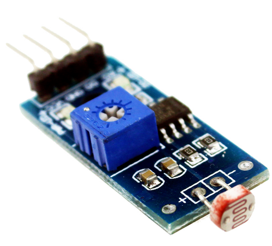

Fig. 2: LDR (LM393)

A Light Dependent Resistor (LDR) is a passive optoelectronic component whose resistance changes based on the intensity of incident light. It is made from a high-resistance semiconductor material, typically cadmium sulfide (CdS).

1) Photoelectric Effect in LDR: The core principle of LDR operation is based on the **photoconductivity effect**, where:

- **In bright light:** Photons strike the semiconductor surface, exciting electrons into the conduction band. This reduces the material's resistance significantly.
- **In darkness or low light:** Fewer photons are available to excite electrons, resulting in much higher resistance.

2) Resistance Range and Analog Behavior: LDRs are highly sensitive to changes in ambient light:

- In bright conditions: Resistance drops to as low as **200–500** Ω.
- In darkness: Resistance can exceed **1–10 M**Ω.

This variation in resistance is continuous and non-linear, making the LDR ideal for analog sensing applications.

3) Analog Voltage Response: LDRs are commonly used in voltage divider circuits to produce an analog output voltage corresponding to light intensity.

- **High light** ⇒ Low LDR resistance ⇒ Higher voltage across series resistor ⇒ **Low LDR output voltage**.
- **Low light** ⇒ High LDR resistance ⇒ Lower voltage across series resistor ⇒ **High LDR output voltage**.

4) Design Considerations:

- Placement of the LDR should avoid direct glare from artificial sources (e.g., LED feedback light).
- A fixed resistor in the voltage divider should be chosen to match the LDR's resistance range for best sensitivity.
- LDRs have slower response times (tens to hundreds of milliseconds) compared to photodiodes, but they are sufficient for daylight applications.

5) Analog Interpretation Without Digital Processing: In analog systems, the continuously varying output of the LDR is directly interpreted by comparator circuits or used to bias transistors. This enables real-time light level detection and automation—such as turning on supplementary lighting—without requiring digital computation or microcontrollers.

C. Temperature Sensor (LM35)

Fig. 3: LM35

The LM35 is a widely used analog temperature sensor that provides a linear voltage output directly proportional to the temperature in degrees Celsius. It is designed for precision temperature measurements and is well-suited for analog automation systems due to its simplicity and accuracy.

1) Working Principle: The LM35 operates based on the principle of temperature-dependent voltage generation. Internally, it uses semiconductor junctions whose voltage characteristics change predictably with temperature.

- The sensor outputs **10 mV per 1**.
- For example, at 25, the output voltage is approximately 250.
- This output increases linearly with temperature, making it ideal for direct analog processing.

2) Analog Voltage Characteristics: Unlike digital sensors, the LM35 provides a continuous analog signal, eliminating the need for analog-to-digital conversion. The characteristics include:

- Output range: Typically from 0 to 1.5, covering temperatures from 0 to 150.
- **High sensitivity**: A small change in temperature results in a noticeable change in output voltage.
- **Linear response**: Simplifies analog circuit design using comparators or operational amplifiers.

3) Advantages in Analog Systems: The LM35's features make it especially advantageous in analog automation circuits:

- No need for calibration, unlike thermistors or RTDs.
- Low self-heating, ensuring accurate ambient readings.
- Requires minimal external components—can be directly interfaced with an op-amp.

4) Design Considerations:

- The sensor should be placed away from heat-generating components to prevent false readings.
- A decoupling capacitor (0.1) may be used between V_{CC} and GND to filter noise.
- Ensure proper thermal contact with the environment if used for surface or air temperature monitoring.

5) Analog Interpretation Without Digital Processing: In a purely analog system, the LM35's output voltage is fed into a comparator (e.g., op-amp) where it is compared against a reference voltage set by a potentiometer. When the temperature exceeds the preset threshold, the comparator's output changes state. This signal can then be used to drive a transistor or MOSFET to control a cooling fan or other thermal management systems—completely independent of any microcontroller or digital processing.

V. Detailed Circuit Design

This section explains the complete analog implementation of the plant monitoring system. The system integrates three analog sensors—soil moisture, temperature (LM35), and light (LDR)—with active components such as operational amplifiers (configured as comparators), MOSFETs, and BJTs to control water pumps, fans, and LEDs respectively.

The output of the sensors are conditioned using voltage dividers and potentiometers to set appropriate threshold levels for each parameter. Comparators then evaluate the sensor signals against these thresholds, generating control signals for the switching devices. MOSFETs and BJTs act as electronic switches, directly driving actuators on the basis of comparator output. Because the entire signal path remains in the analog domain, the system responds continuously and instantaneously to environmental changes without the latency of digital sampling. This approach also demonstrates core analog design principles—voltage division, threshold comparison, and transistor switching.

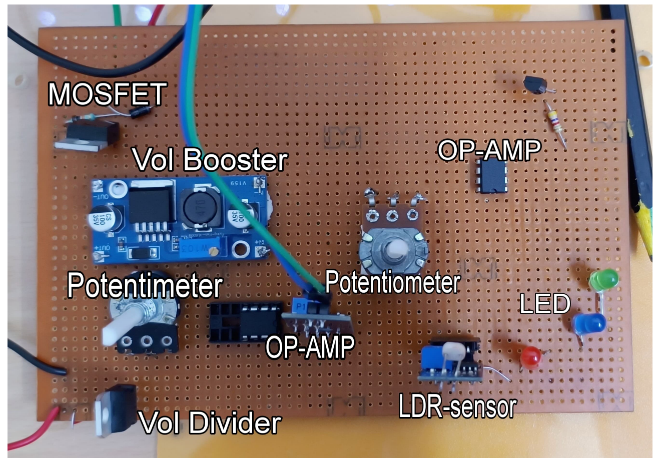

Fig. 4: Circuit design

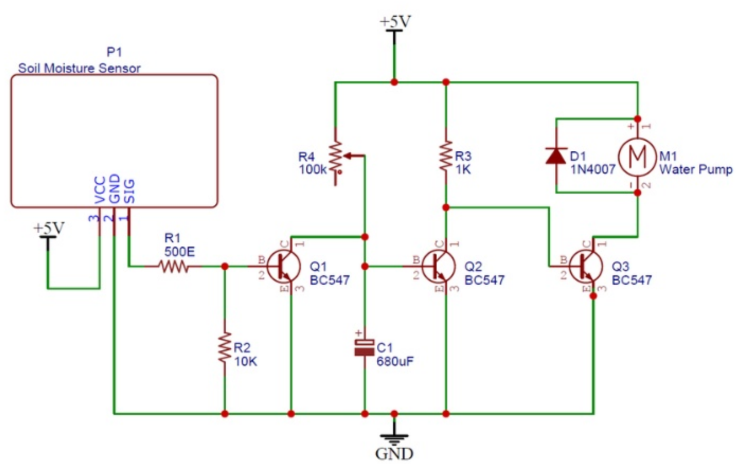

Fig. 5: schematic design

A. Soil Moisture Sensor – Water Pump Activation

1) Working Principle: The soil moisture sensor acts as a variable resistor. Moist soil conducts electricity better (lower resistance), while dry soil resists current (higher resistance). The sensor is placed in a voltage divider configuration with a fixed resistor and the divider outputs a voltage that varies with the resistance of the soil.

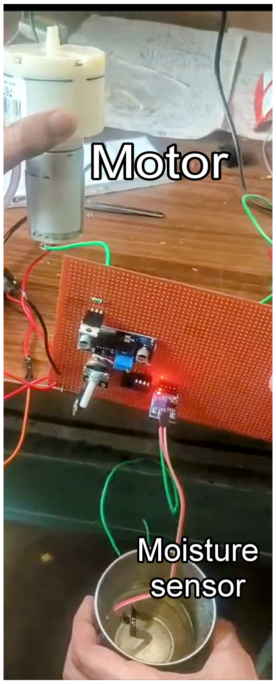

Fig. 6: Working Setup – Moisture Sensor Controlling Pump

2) Circuit Operation:

- The output voltage from the sensor is fed into the **inverting input** of an op-amp configured as a comparator.
- The **non-inverting input** receives a reference voltage from a potentiometer.
- When the soil becomes dry, the sensor's voltage drops below the reference, and the comparator output goes **high**.
- This high signal is passed through a **level booster** to drive a power **MOSFET** (e.g., IRF540), which switches on the **water pump**.
- Once the soil is adequately moist, the voltage increases, the comparator output goes low, and the pump turns off.

3) Design Considerations:

- A **flyback diode** is added across the pump to suppress voltage spikes.
- A potentiometer is used to set the moisture threshold voltage.

B. Temperature Sensor (LM35) – Fan Control

1) Working Principle: The LM35 outputs a linear voltage of 10 mV per °C. For example, at 30 °C, the output is 300 mV.This linearity simplifies interfacing with analog comparators, allowing precise temperature threshold detection. The sensor's analog output can be directly used to trigger control actions, such as activating a cooling fan when the temperature exceeds a set point.

2) Circuit Operation:

- The LM35 output is connected to the **non-inverting input** of an op-amp comparator.
- A reference voltage is applied to the **inverting input** via a potentiometer.
- If the temperature exceeds the threshold, the LM35 output surpasses the reference, and the comparator output goes **high**.
- This output drives a **MOSFET** to switch on the **cooling fan**.
- When temperature drops, the fan switches off automatically.

3) Design Notes:

- A capacitor across the LM35 output can filter noise.
- The system uses a single supply voltage for both the LM35 and the comparator.

C. LDR Sensor – LED Lighting Activation

1) Working Principle: The Light Dependent Resistor (LDR) changes its resistance based on ambient light:

- Bright light: low resistance
- Dim light: high resistance

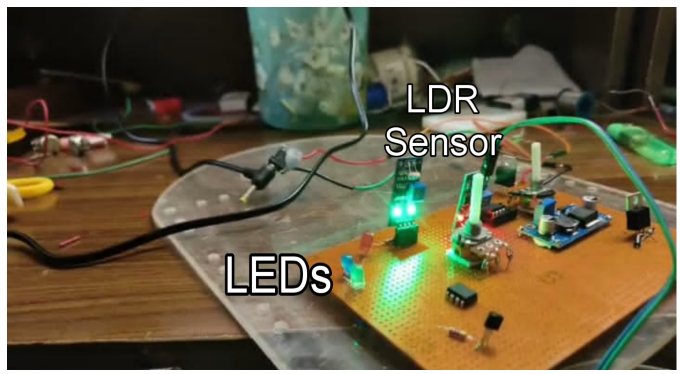

Fig. 7: Working Setup – LDR Controlling LEDs

2) Circuit Operation:

- The LDR is used in a voltage divider with a fixed resistor.
- The divider output is fed to the **non-inverting input** of a comparator.
- A reference voltage is applied to the **inverting input**.
- In low light, the voltage across the LDR increases, surpassing the reference, and the comparator output goes **high**.
- This turns on a **BJT transistor** (e.g., BC547), which powers the **LED grow lights**.

3) Design Notes:

- **Current-limiting resistors** are used in series with the LEDs.
- The use of BJT is suitable due to low current requirement.

Together, these three sensors—soil moisture, temperature, and light—enable the system to automatically provide water, cooling, and light as needed. By working in combination, they help create the ideal environment for healthy plant growth with minimal manual effort

Demonstration Video: Click here to watch the video

D. Power and System Integration

- All components are powered from a regulated **12 V DC supply(using adapter)**, ensuring stable operation across sensors, comparators, and actuators. A common **ground rail** is used to maintain consistent voltage reference throughout the circuit.
- Each sensor input is processed by a dedicated **comparator circuit** that evaluates the sensor's analog voltage against a reference threshold. The reference voltage is adjustable using **precision potentiometers**, allowing fine calibration to match the specific environmental requirements (e.g., optimal soil moisture or temperature).
- **Signal isolation** is maintained between sensor outputs and actuator control using transistors and MOSFETs acting as switches. This ensures that the sensors are not directly loaded by the actuators, preserving signal accuracy.
- The circuit is modular—each comparator and its associated actuator (fan, LED, or water pump) function independently. This modularity enhances fault tolerance and simplifies debugging and calibration.

VI. Power Management

A. Power and Load Management

- All modules are powered by a **12V adapter**,ensuring portable and uninterrupted power supply for field applications.
- The **water pump and cooling fan**, being high-current devices, are connected to the **drain terminals of N-channel MOSFETs**, which act as efficient electronic switches triggered by comparator outputs.
- To prevent thermal damage during prolonged operation, **heatsinks are attached to the MOSFETs**, enabling effective heat dissipation and maintaining safe operating temperatures.

VII. Printed Circuit Board (PCB)

All components are mounted on a custom-fabricated PCB, which enhances system compactness, minimizes wiring complexity, and improves overall reliability and serviceability.

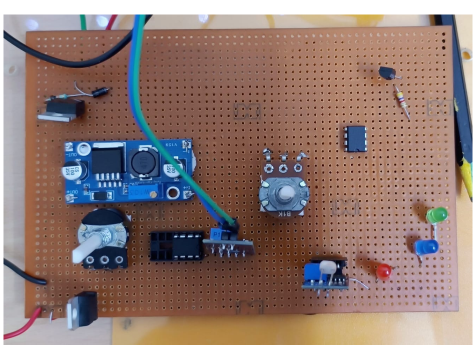

Fig. 8: PCB(front view)

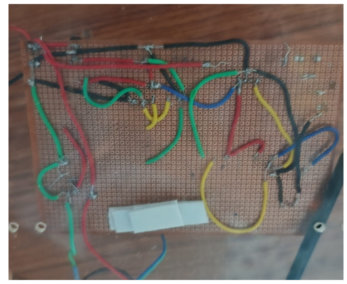

Fig. 9: PCB(rear view)

VIII. System Functionality Summary

- **Dry Soil Triggers Water Pump:** When the soil moisture level drops below the preset threshold, the moisture sensor output falls below the reference voltage. This causes the comparator to activate the MOSFET, powering the water pump to irrigate the soil.
- **High Temperature Activates Fan:** The LM35 temperature sensor outputs a voltage proportional to ambient temperature. When this exceeds the comparator's threshold, the resulting high output drives the MOSFET, turning on the cooling fan to reduce thermal stress on the plants.
- **Low Light Switches on LEDs:** The LDR detects ambient light levels. In low-light conditions, its resistance increases, raising the voltage across a reference resistor. Once this crosses the threshold, the comparator output drives a BJT, turning on the supplemental LED grow lights.

Each action is triggered automatically without manual intervention or digital controllers.

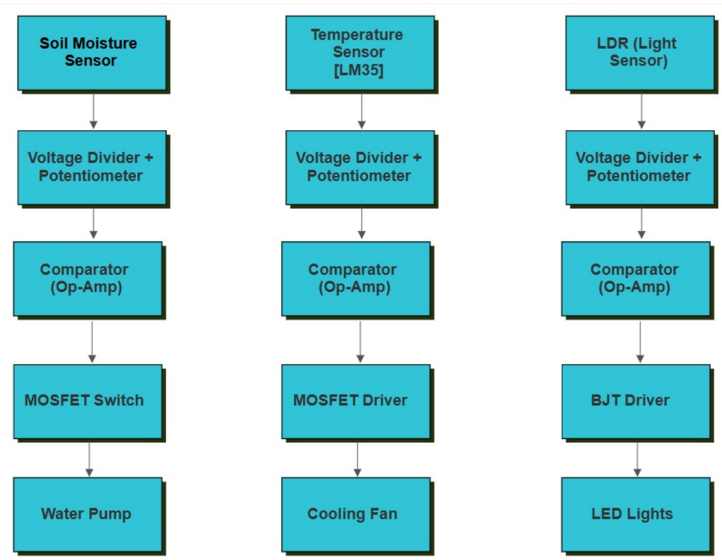

Fig. 10: Block diagram

IX. Results and Observations

The system successfully automates three essential plant care operations—soil irrigation, ambient temperature regulation, and artificial lighting—through a fully analog control architecture. Testing and observation of the prototype yielded the following key insights:

- **Minimal Response Delay:** Since the entire system operates in the analog domain, sensor inputs are processed continuously and instantaneously. The absence of analog-to-digital conversion or microcontroller-based polling eliminates latency, resulting in immediate actuator response to environmental changes.
- **Efficient Power Consumption:** By activating actuators only when their corresponding sensor thresholds are crossed, the system avoids unnecessary energy usage. For example, the pump remains off unless soil dryness is detected, and the LEDs engage only under low ambient light, ensuring energy is used precisely when and where needed.
- **Reliable and Adaptive Performance:** The system maintained consistent output across diverse test scenarios—ranging from indoor low-light conditions to high ambient temperatures and varied soil moisture levels. The analog threshold-based design proved stable and reproducible, with minimal need for recalibration once the potentiometers were tuned.
- **Practical Analog Education Value:** The design serves as a functional demonstration of core analog principles like voltage division, comparator-based decision making, and transistor-level switching, offering significant educational value in addition to its practical utility.

X. Conclusion

The analog plant monitoring system developed in this project validates the feasibility of automating essential horticultural tasks without relying on microcontrollers or software-based control. By integrating fundamental analog components—such as operational amplifiers, BJTs, MOSFETs, voltage dividers, and sensors—the system continuously monitors key environmental parameters (soil moisture, temperature, and light intensity) and responds in real time through appropriate actuation.

The core design utilizes sensor signals compared against user-defined reference levels set via potentiometers. These signals are processed by comparators, which in turn control the switching of outputs like water pumps, cooling fans, and LED grow lights. The use of analog signal processing ensures minimal response latency and removes dependencies on firmware, coding errors, or digital logic.

This analog-first architecture presents several key advantages:

- **Real-time operation:** Continuous monitoring and response without sampling delay or computational lag.
- **Power efficiency:** Devices are activated only when necessary, conserving energy in low-resource settings.
- **Simplicity and robustness:** Eliminates the need for programming, reducing system complexity and potential points of failure.
- **Educational value:** Offers an intuitive platform for understanding electronics fundamentals and sensor-based automation.

The project not only highlights the practical applications of analog electronics in modern contexts but also challenges the prevailing notion that effective automation must be digital. It serves as a testament to the enduring utility and relevance of analog circuits—particularly in small-scale or learning-focused environments.

Future Scope

- **Analog Audio/Visual Alerts:** Adding analog buzzer circuits or indicator lights can provide immediate local alerts for critical conditions (such as extreme dryness or high temperature), ensuring that users are notified without the need for digital communication modules.
- **Scalability and Sensor Expansion:** The system can be expanded to support multiple analog sensors (soil moisture, light, or temperature) across different zones using additional comparators and switching circuits. Each channel can be independently calibrated using potentiometers, allowing for granular monitoring and control in larger gardens or greenhouses.
- **Adjustable Timing and Hysteresis:** Incorporating analog timing circuits (such as RC delay networks or 555 timers) can introduce features like delayed actuation or hysteresis, reducing actuator wear and preventing rapid switching in fluctuating conditions.

Acknowledgments

We thank our faculty mentors and lab assistants for their support in developing, testing, and verifying this project.

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