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DESIGN OF A LIGHT – DEPENDENT TRACKING SYSTEM USING ARDUINO AND ADDITEVLY MANUFACTURED COMPONENTS

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Abstract: This paper presents the design and implementation of a light-sensing tracking system based on an Arduino microcontroller and 3D printed mechanical components for solar alignment applications. The system consists of an Arduino Uno board, light-dependent resistors (LDRs) arranged in voltage divider circuits, a servo motor for angular positioning, and a regulated 5 V power supply. Sensor signals are processed using the built-in 10-bit analog-to-digital converter, while a comparison-based control algorithm generates pulse-width modulation (PWM) signals to adjust the servo position toward the highest detected light intensity. The study focuses on component selection, electrical connections, and system integration. The mechanical structure is fabricated using additive manufacturing, enabling rapid prototyping and cost-effective production. Experimental results confirm stable operation, accurate tracking behavior, and low power consumption, demonstrating the feasibility of the proposed system for educational and small-scale renewable energy applications.
Keywords: Arduino microcontroller, light-dependent resistor (LDR), solar tracking system, pulse-width modulation (PWM), analog-to-digital conversion (ADC), embedded systems, 3D printing, additive manufacturing, mechatronic systems, renewable energy applications.

INTRODUCTION

The increasing demand for renewable energy systems has intensified the development of efficient solar energy harvesting technologies. Conventional fixed photovoltaic systems suffer from reduced energy efficiency due to the continuous change in the sun's position throughout the day. Solar tracking systems represent an effective solution by dynamically aligning photovoltaic panels toward the direction of maximum light intensity.

This paper presents the design and implementation of a low-cost light-sensing tracking system based on an Arduino microcontroller and additively manufactured mechanical components. Unlike complex industrial tracking systems, the proposed solution focuses on simplicity, modularity, and educational applicability while maintaining reliable tracking performance.

The primary objective of this research is to analyze component selection, electrical circuit design, signal processing, and system integration. Special emphasis is placed on sensor interfacing, microcontroller-based control logic, power management, and mechanical structure fabrication using 3D printing technology.

SYSTEM ARCHITECTURE

The developed system is a single-axis light-tracking platform designed to rotate along one horizontal axis. The architecture consists of four main subsystems:

- Light sensing subsystem.
- Control unit.
- Actuation mechanism.
- Mechanical support structure.

The light sensing subsystem includes two light-dependent resistors (LDRs) positioned with a physical divider between them to detect differential light intensity. The control unit is based on an Arduino Uno microcontroller board, which processes analog signals from the sensors. The actuation mechanism consists of a servo motor that adjusts the angular position of the platform. The mechanical structure is fabricated using additive manufacturing techniques to ensure lightweight construction and structural stability.

The signal flow within the system can be described as follows:

Light intensity → LDR resistance variation → Voltage divider output → Analog input (Arduino) → Control algorithm → PWM output → Servo rotation

The system operates on a closed-loop principle, where the difference between left and right sensor signals determines the direction of rotation until equilibrium is reached.

HARDWARE COMPONENTS AND ELECTRICAL DESIGN

Arduino microcontroller

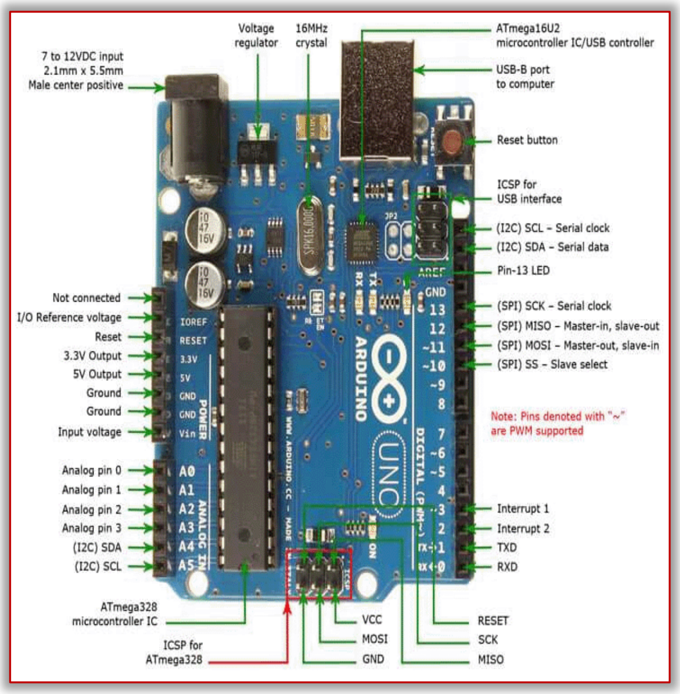
The control system is based on the Arduino Uno development board, which incorporates the ATmega328P microcontroller operating at 16 MHz. The board provides six analog input channels (A0-A5) and multiple PWM-enabled digital outputs.

Key electrical characteristics:

- Operating voltage: 5 V.

— Analog resolution: 10-bit (1024 discrete levels).
— ADC reference voltage: 5 V.

The analog resolution is calculated as:
Resolution = 5V / 1024 = 4.88 mV



Picture 1 – Arduino UNO microcontroller

This resolution allows precise detection of voltage variations produced by the LDR voltage divider network.

The microcontroller reads analog values from the sensors and processes them using a comparison-based control algorithm to generate PWM signals for servo positioning.

Light-Dependent Resistors (LDRs) and signal conditioning

The light detection subsystem uses two LDRs configured in voltage divider circuits. The resistance of an LDR decreases as light intensity increases, following a nonlinear photoconductive characteristic.

Each LDR is connected in series with a fixed resistor. The output voltage of the divider is given by:

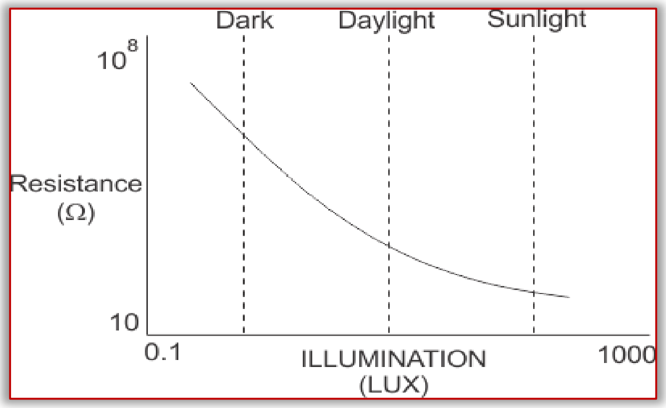
$$V\_out = V\_cc \times (R\_fixed / (R\_LDR + R\_fixed))$$

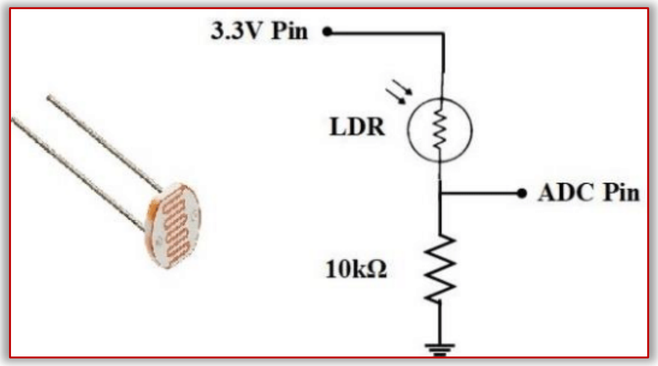
where:

≡ V_cc = 5 V supply voltage
≡ R_LDR = light-dependent resistance
≡ R_fixed = selected fixed resistor value

The divider output is connected to analog inputs A0 and A1 of the Arduino board. A common ground reference is maintained across all components to ensure stable signal acquisition.

To minimize oscillation due to small light variations, a threshold (dead-band region) is implemented in the control algorithm.





Picture 2 – Light-dependent resistor and a voltage divider to sense light intensity

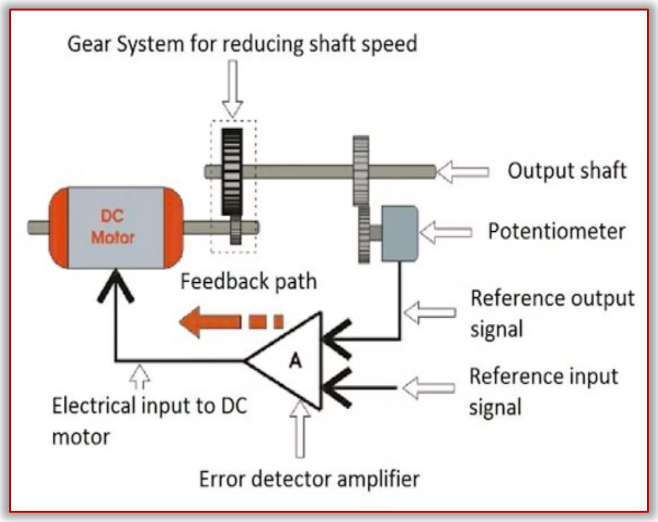
Servo motor and actuation mechanism

The positioning system utilizes a standard hobby servo motor with a rotation range of 0–180°. The servo contains an internal DC motor, gear reduction mechanism, position feedback potentiometer, and control circuitry.

The servo is controlled via pulse-width modulation (PWM). The control signal characteristics are:

— Frequency: approximately 50 Hz
— Pulse width range: 1 ms (0°) to 2 ms (180°)

The angular displacement of the shaft is proportional to the pulse width duration.



Picture 3 – The principle of operating for DC servo motor

The torque requirement depends on the weight of the mounted structure and its distance from the rotation axis. The required moment can be estimated as:

$$M = F \times r,$$

- where:
  F = gravitational force acting on the load.
- r = distance from axis of rotation.

Proper torque selection ensures stable positioning without mechanical overload.

Power supply design

The entire system operates at 5 V DC. However, the servo motor can draw significantly higher current compared to the Arduino board.

Total current consumption can be approximated as:

$$I\_total = I\_Arduino + I\_Servo$$

Typical values:

- Arduino Uno: ~50 mA
- Servo motor (under load): up to 500–700 mA

For this reason, it is recommended to use an external regulated 5 V power supply capable of delivering sufficient current, with a common ground shared between the Arduino and the servo motor.

Proper decoupling capacitors can be added to reduce voltage fluctuations during servo actuation.

Electrical interconnections

The electrical connections are defined as follows:

- LDR left → Analog pin A0
- LDR right → Analog pin A1
- Servo signal wire → PWM digital pin (e.g., D9)
- 5 V and GND distributed to all components
- Common ground reference required

Careful wiring layout is essential to minimize noise and ensure stable analog readings.

CONTROL ALGORITH AND SYSTEM ANALYSIS

The tracking system operates using a differential light intensity comparison algorithm. Two LDR sensors are positioned symmetrically with a physical divider between them, allowing the system to detect the direction of higher light intensity.

Let:

- V_L= voltage from left LDR
- V_R= voltage from right LDR
- $\Delta V = V_L - V_R$

The control logic is based on the following condition:

- If $\Delta V > \delta \rightarrow$ rotate servo left
- If $\Delta V < -\delta \rightarrow$ rotate servo right
- If $|\Delta V| \leq \delta \rightarrow$ hold position

Where δrepresents the dead-band threshold introduced to prevent oscillations due to minor light fluctuations or ADC noise.

Since the Arduino ADC resolution is 4.88 mV per step, the minimum detectable difference is limited by quantization error. The digital value read from the ADC is:

$$ADC = \frac{V_{in}}{5V} \times 1023$$

The control output is generated via PWM signal. The servo angle $\theta$is mapped linearly from PWM pulse width:

$$\theta = k \cdot t_{pulse}$$

Where t_{pulse}varies between 1 ms and 2 ms.

To avoid abrupt movement, incremental angle adjustment is applied:

$$\theta_{new} = \theta_{current} \pm \Delta\theta$$

This ensures smoother motion and reduces mechanical stress.

MECHANICAL DESIGN ANALYSIS

The mechanical structure is fabricated using fused deposition modeling (FDM) 3D printing technology. PLA material is selected due to its ease of printing, dimensional stability, and sufficient mechanical strength for lightweight applications.

LOAD AND TORQUE ANALYSIS

The servo motor must overcome gravitational torque caused by the mounted platform.

The required torque is:

$$M = F \cdot r$$

where:

- $F = m \cdot g$
- r= distance from rotation axis
- m= mass of the moving platform
- $g = 9.81\ m/s^2$

Example:

If the platform mass is 0.3 kg and the center of mass is 0.08 m from the axis:

$$F = 0.3 \times 9.81 = 2.94N$$
$$M = 2.94 \times 0.08 = 0.235Nm$$

Therefore, a servo with torque greater than 0.25 Nm is required for reliable operation.

STRUCTURAL CONSIDERATIONS

The 3D printed structure parameters:

- Material: PLA
- Infill density: 40-60%
- Layer height: 0.2 mm
- Print orientation optimized to resist bending stress

Maximum bending stress in a cantilever-type support can be approximated by:

$$\sigma = \frac{M \cdot c}{I}$$

where:

- M= bending moment
- c= distance from neutral axis
- I= second moment of area

The lightweight nature of the structure reduces inertial load and improves dynamic response.

EXPERIMENTAL RESULTS

The system was experimentally tested under natural sunlight conditions. The performance evaluation focused on tracking accuracy, response time, and power consumption.

Tracking accuracy

The angular positioning error was estimated by comparing final servo position with visually determined optimal alignment. The measured deviation was approximately: $\pm 2°$, which is acceptable for small-scale solar applications.

Response time

The average response time from light intensity change to stable positioning was approximately:

$$0.7\text{-}1.0 \text{ seconds}$$

depending on light intensity difference magnitude.

Power consumption

Measured current values:

- Arduino board: ~50 mA.
- Servo (idle): ~100 mA.
- Servo (active): up to 600 mA.

Total power consumption during movement:

$$P = V \cdot I = 5V \times 0.65A = 3.25W$$

In steady state, power consumption drops significantly, making the system energy efficient.

The experimental results confirm stable operation without oscillation, overheating, or signal instability.

CONCLUSIONS

This paper presented the design, electrical implementation, and mechanical analysis of a light-sensing tracking system based on an Arduino microcontroller and 3D printed structural components. The proposed solution integrates LDR-based light detection, analog-to-digital signal processing, PWM-controlled servo actuation, and additively manufactured mechanical support.

The electrical design ensures stable signal acquisition and reliable control behavior, while the mechanical analysis confirms that the selected servo motor provides sufficient torque for the intended load. Experimental validation demonstrates accurate tracking performance, low power consumption, and stable operation under real environmental conditions.

Due to its low cost, modularity, and simplicity, the developed system is suitable for educational laboratories, small-scale renewable energy projects, and mechatronic system demonstrations. Future work may include dual-axis tracking implementation, integration of photovoltaic efficiency measurements, and application of advanced control methods such as PID regulation for improved dynamic performance.

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