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Intelligent Solar Chasing Street Light System Design and Fabrication Summaries

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Abstract: This project adopts an advanced microcontroller as the core control unit, which accurately commands the servo drive, realizes the real-time light chasing and charging function of the solar panel, and effectively manages the power supply system of the street light. At the same time, the system is able to continuously monitor the operation status of the servo within the range of 0 ° to 180 ° to ensure that it is trouble-free and not offline. The hardware system construction consists of five modules: a power module, solar panel module, servo module, street light module, and Organic Light-Emitting Diode (OLED) display module. Each module works together to support the stable operation of the whole system. The system workflow is to accurately determine the direction of the light source by collecting real-time light intensity data through four precision photoresistors. Subsequently, the microcontroller intelligently controls the helm module based on these data to drive the solar panel to rotate within a range of 180 ° to accurately track the sun's orientation. The street light provides two lighting modes, automatic and manual, to meet the needs of different scenarios. During the daytime, the solar panels work actively to monitor and collect solar energy efficiently in real-time, meanwhile, when night falls, the solar panels switch to standby mode and the streetlights light up automatically, illuminating the road ahead for pedestrians. Compared with the traditional solar street lights on the market, the intelligent solar light chasing road system introduced in this project has significant advantages. Its unique light-chasing algorithm enables the solar panel to continuously track the light source from sunrise to sunset, thus significantly improving the charging efficiency. Compared with traditional street lights, the biggest advantage of this project is the proposed light-chasing algorithm, which can always charge from sunrise until sunset, making the charging efficiency increase by 38% to 47%. The charging efficiency is 20% to 38% higher than that of traditional street lamps. Simultaneously, the biggest advantage of this project is that the power storage capacity is higher than 35% of the traditional solar street light. Bringing users a more durable and stable lighting experience.

Keywords: Microcontroller control; Power supply module; Solar panel module; Servo module; Street light module; OLED display module

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1. Introduction

To reduce the dependence on non-renewable resources and improve the efficiency of energy utilization, we have innovatively designed the Intelligent Solar Light Chasing Street Light System. The system cleverly integrates core components such as motors, controllers, and photovoltaic panel light sensors, and can accurately track the direction of the sun's strongest radiation, demonstrating a high degree of safety and the feasibility of utilizing light energy. The core innovation of this microcontroller-based solar chasing street light is its ability to automatically adjust the angle of the solar panel with the change of the sun's orientation like a sunflower, thus maximizing the capture and use of solar energy for power generation. To solve the problem of instability of traditional solar power supply and to significantly reduce energy loss, we have specially optimized the power supply module. By adopting the advanced servo module, the system rotates more smoothly and reduces the lagging phenomenon. The system automatically collects and stores solar energy to be converted into electricity during the daytime and is used for street lighting at night, realizing the independent supply and efficient use of energy. Its high degree of safety, good development prospects, and significant economic benefits make the Intelligent Solar Light Chasing Street Light System the preferred solution for future green lighting [1].

2. Intelligent solar light chasing street light system modules

2.1. Light sensing module

The photoresistor tracking method involves placing photoresistor sensors around the solar energy receiving system in a specific arrangement. These sensors collect light intensity information, which is then converted into a digital signal by an analog-to-digital (AD) converter module. This digital signal is sent to a microcontroller, which compares the voltage differences from various directions to determine light intensity levels. Based on these comparisons, the microcontroller issues commands to control the tracking mechanism and adjust the system's orientation to maximize light capture [3].

The photoresistor sensor is a critical component in this tracking method. Its accuracy and stability in collecting light-intensity information directly affect the precision and reliability of light tracking. Photoresistors work by utilizing the photosensitive resistive effect of semiconductors, changing resistance based on incident light intensity. Resistance decreases with strong light and increases with weak light.

Photoresistors are commonly used for light measurement, light control, and photoelectric conversion, where they convert changes in light intensity into changes in electrical resistance. In the darkness, their resistance is very high. When exposed to light, if the photon energy is greater than the semiconductor material's forbidden bandwidth, electrons in the valence band absorb this energy and jump to the conduction band, creating positively charged holes in the valence band. This process generates electron-hole pairs, increasing the carrier count in the semiconductor material, thereby reducing its resistivity and lowering the photoresistor's resistance. The stronger the light, the lower the resistance.

Once the light is removed, the photon-excited electron-hole pairs gradually recombine, and the resistance of the photoresistor returns to its original value. The principle of the photoresistor sensor is illustrated in **Figure 1**.

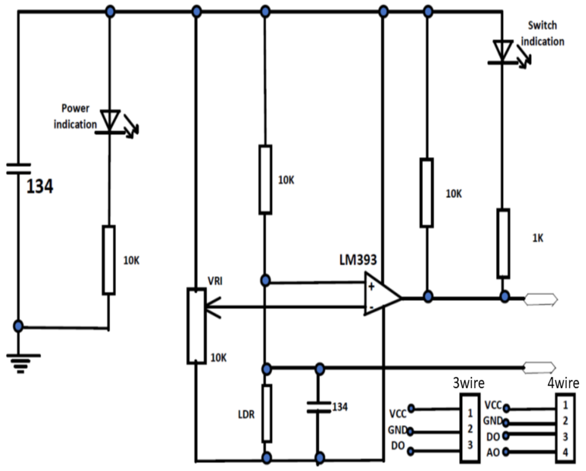

Figure 1. Photoresistor sensor

2.2. Servo module

The control circuit board accepts the control signal from the signal line and controls the motor rotation. The twin-axis servo drives a series of gears, decelerates, and drives to the output rudder. The output shaft of the servo and the position feedback potentiometer are connected, while the rudder rotates, it drives the position feedback potentiometer, which outputs a voltage signal to the control circuit board for feedback, and then the control circuit board decides the direction and speed of the motor rotation according to the location, to achieve the target stop [4]. The workflow is: control signal → control circuit board → motor rotation → gear set deceleration → rudder rotation → position feedback potentiometer → control circuit board feedback, servo output angle, and the relationship between the input pulse is shown in **Figure 2**.

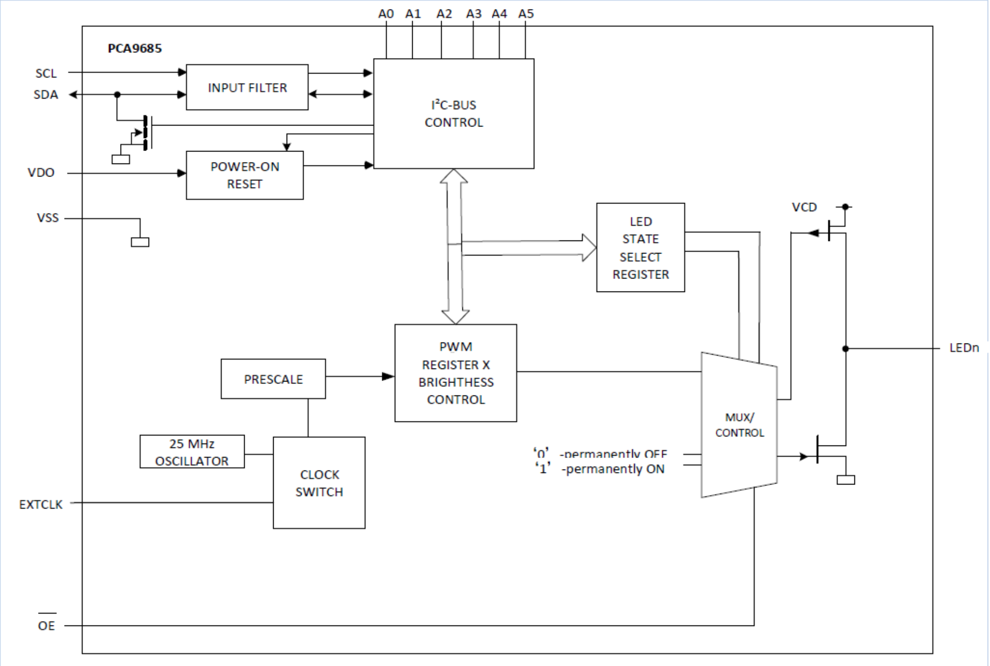

Figure 2. Schematic diagram of the servo module

2.3. Power supply module

The power supply module is a key component of the solar street light system, which is responsible for monitoring and managing the total power of the system [5]. When the system detects that the total power is lower than the preset safety value, the controller will respond quickly and automatically switch the power supply from solar power to utility power to ensure the continuous and stable operation of the system. This design is intended to prevent the system from being paralyzed due to insufficient power and to improve the reliability and stability of the overall system.

2.4. System self-test module

The power failure self-test program includes:

(1) power supply;

(2) embedded function module, that is, the function module of the intelligent robot, which is connected to the STM32 controller through the communication interface UART;

(3) switch circuit, set between the power supply and the embedded function module;

(4) switch control circuit, electrical connection with the switch circuit, to control the opening or closing of the switch circuit;

(5) STM32 controller, which is electrically connected to the switch control circuit and the embedded function module, to detect the operation status of the embedded function module and control the switch control circuit according to the power-up operation status;

(6) voltage detection module, set between the power supply and the embedded function module, to monitor the power supply voltage and output the abnormal signal to the STM32 controller when the power supply voltage is abnormal;

(7) indicator fault module, used to indicate the working status of a specific function module and connected to the STM32 controller.

2.5. OLED display

With a self-luminous electromechanical excitation photodiode, this system requires no backlight and offers high contrast, a thin profile, a wide viewing angle, and fast response time. It is also adaptable for flexible panels, operates across a wide temperature range, and benefits from a simpler structure and manufacturing process. These features enable the product to display the azimuth angle and intensity of collected solar energy, optimizing the orientation and functionality of solar-powered street lamps.

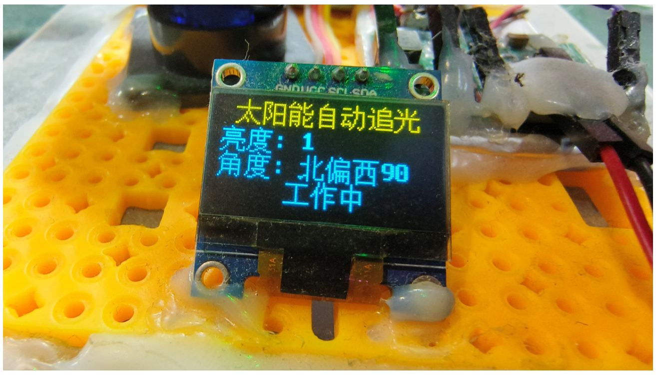

Figure 3. Physical image of OLED display

2.6. Arduino Uno extended version

This version provides wireless connectivity for the Uno and includes a Motor Shield, enabling control of both direct current (DC) and stepper motors. With some coding and minimal setup, users can easily use the expansion board to integrate key features into their Arduino Uno system.

3. Core functions of the HOLTEK MCU

This project involves a solar-tracking street lamp powered by a HOLTEK microcontroller unit (MCU) at its core [6]. The system operates by using a light sensor module that detects the light source's position and sends this data to the microcontroller. The MCU then directs a servo module to adjust the solar panels accordingly, ensuring they track the light source accurately and efficiently. The solar panels convert the tracked sunlight into electrical energy, which is stored in a power supply module that powers the light-emitting diode (LED) lamps, thereby achieving solar-powered illumination. The rotation of the solar panel is controlled by a servo motor, driven by a motor driver chip capable of supporting a four-phase servo.

During the day, the solar panel charges the battery, and at night, the battery supplies power to the light source. As daylight diminishes, the voltage from the solar panel decreases. When this voltage drops below a preset threshold in the controller, the controller activates the street light. Conversely, as daylight increases and the voltage rises to a preset disconnection value, the controller automatically turns off the light, providing energy-efficient, intelligent control.

4. Structure of the work

4.1. Hardware architecture

This project comprises six key components: an Arduino Uno with an expansion board, a dual-axis servo gimbal, a photosensitive sensor, a plastic base plate, a solar lithium battery module, and an OLED display module. These modules are integrated to elevate the functionality of the solar-tracking light system, bringing it to a new level of advancement.

4.1.1. Servo module

The dual-axis servo module includes control circuits and a potentiometer (a variable resistor) connected to the output shaft. The potentiometer allows the control circuit to monitor the current angle of the servo motor. If the angle is correct, the motor remains off. If the circuit detects an incorrect angle, it adjusts the motor in the correct direction until the desired angle is reached. Typically, the output shaft can rotate up to about 180° [7].

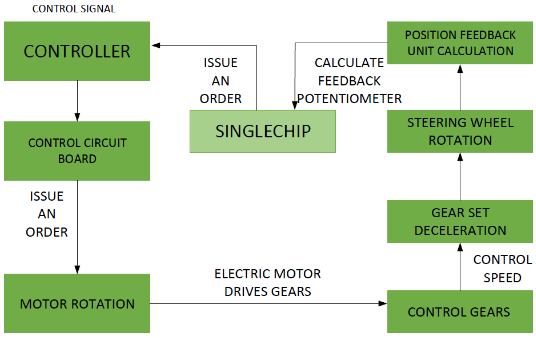

Figure 4. Servo module

4.2. Significant program and software components

4.2.1. Software execution process

Sun orientation can be more accurately calculated based on the Earth's rotation. As the Earth rotates, the orientation of the Sun changes by 15° every hour from east to west. This means that at 6 AM, the Sun's orientation will be due east along the latitude circle, and at 6 PM, it will be due west. The Sun's altitude and direction angle can be controlled by the microcontroller and program, allowing the servos to move in both horizontal and vertical directions to track the Sun, using timed and quantified light-chasing mechanisms [8]. As shown in the flow chart below.

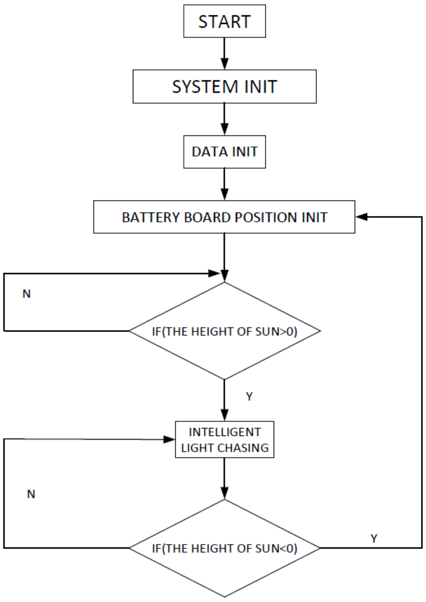

Figure 5. Flowchart of tracing system

4.2.2. Light chasing module algorithm

Determining the direction of the Sun during the day requires knowledge of two quantities, solar altitude and solar azimuth [9]. For a location on Earth, solar altitude is the angle between the direction of incidence of sunlight and the horizon. Solar altitude is the most important factor in determining the amount of solar heat energy available to the Earth's surface, and the angle is expressed in terms of h, which is numerically equal to the Sun's geoidal altitude in the celestial geoidal coordinate system, and the angle of solar altitude varies with changes in local time and the Sun's declination. The Sun's declination is denoted by δ , the geographic latitude of the place of observation by ψ, and the local time (hour angle) by t. From the formula for the sun's altitude angle:

$$\sin h = \sin \psi \sin \delta + \cos \psi \cos \delta \cos t \quad (1)$$

During sunrise and sunset, the Sun's altitude angle at a given location is constantly changing. At sunrise and sunset, the angle is 0°. The Sun's altitude angle reaches its maximum at noon, and at noon, the angle is at its highest point. The above formula can be simplified:

$$\sin h = \sin \psi \sin \delta + \cos \psi \cos \delta \quad (2)$$

Where h denotes the angle of the Sun's altitude at noon. From the trigonometric formula for the sum and difference of two angles, it is obtained:

$$\sin h = \cos (\psi - \delta) \quad (3)$$

Since the specific value of the Sun's declination angle at any moment in the anniversary motion is strictly known; it (δ) can also be expressed in an expression similar to **Equation (1)**, as follows:

$$\delta - 0.3723 + 23.2567 \sin\theta + 0.1149 \sin 2\theta - 0.1712 \sin 3\theta - 0.758 \cos\theta + 0.3656 \cos 2\theta + 0.0201 \cos 3\theta \quad (4)$$

Equation (4) represents the day angle, denoted byθ in the equation. Specifically, θ is given by:

$$\theta = 2\pi t / 365.2422 \quad (5)$$

Where t is defined as $t = N - N_0$, with N representing the cumulative day. The cumulative day is the day of the year numbered sequentially. For example, January 1 is the 1st cumulative day, and December 31 is the 365th (or 366th in a leap year).

$$N_0 = 79.6764 + 0.2422 \times (\text{year} - 1985)\ \text{INT}\ [(\text{year} - 1985)/4] \quad (6)$$

5. Test methods

5.1. No power test

After soldering the connections, the circuit needs to be checked. This inspection is an essential step to ensure the circuit functions properly. The main aspects to inspect include verifying that the component parameters and polarity are correct, the alignment is accurate and reasonable, and the solder joints are well-made. Once the static check of the circuit is confirmed to be correct, it can be powered on for further debugging.

5.2. Power-on test

Turn on the power and, following the design requirements, perform the self-test for the chase light and street light. The servo dual-axis should move from 0° to 180° both up and down, and left and right, with amplitude tuning. During the tuning process, there should be no alarms or offline issues, and the system should operate normally.

5.3. Basic function test

Perform a simulated sun test in an indoor environment using a cellphone flashlight. Upon power-on, the self-test should run, the indicator lights should light up, the display should begin to function, the system data should initialize, and the battery board position should also initialize.

Table 1. Light intensity in different badlands

Photoresistor	Ambient light intensity	Servo working angle	Ambient light intensity	Servo working angle
d1	$h > 3$	15° continuous tracking to a stable light source	$h < 2$	Finding the light source at 15°
d2				
d3				
d4				
The solar panel reaches a steady state if the photoresistor is greater than 2			If the photoresistor is less than 2, the solar panel searches for the position of the light source	

Table 2. Charging efficiency

Pitch angle	Generation efficiency
> 100 °	10%
> 120 °	22%
> 140 °	38%
> 160 °	47%

When *h* > 3 and the angle is greater than 160°, the power generation efficiency is approximately 45%. When *h* > 8, the power generation efficiency reaches its maximum at 47%.

In the indoor environment, a mobile phone flashlight is used to simulate sunlight during testing. The self-test operation indicator light turns on, the display starts to function, the system data is initialized, and the position of the battery board is initialized. When the photosensitive device detects the light source, the received signal is sent to the microcontroller, and the battery begins to charge.

The microcontroller calculates the direction of the Sun. When the Sun's height is greater than three, the system begins to operate. When the Sun's height falls below two, the system enters the intelligent tracking state. The lighting is activated from around 7:00 PM to 12:00 AM during the summer, and from around 5:00 PM to 12:00 AM in the winter.

6. Conclusion

Intelligent solar chasing streetlight systems use microcontroller control and precise tracking algorithms to automatically adjust the orientation of solar panels, maximizing solar energy capture. The system efficiently collects solar energy during the day and converts it into electricity, which is then stored for use in powering the streetlight at night, enabling an autonomous energy supply. Compared to traditional solar streetlights, this system significantly enhances charging efficiency, increases power storage capacity, reduces energy loss, and improves system stability and reliability. Additionally, the system features intelligent control that adapts to varying lighting conditions, ensuring efficient operation in any environment. As a result, this intelligent solar chasing streetlight system offers an efficient, energy-saving, and environmentally friendly green lighting solution.

Disclosure statement

The authors declare no conflict of interest.

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