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Electronic Sunflower Design

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Abstract: ***Solar energy is known as the most primitive source of energy; it's clean, renewable, abundant, and widely distributed, offering a very broad prospect for utilization. However, the low efficiency of solar energy utilization has always been affecting and hindering the popularization of solar energy technology. The design of a solar tracking system offers a new approach to solving this problem, thereby greatly improving the efficiency of solar energy utilization. This design employs a photoelectric tracking method, using a stepper motor driven by photoelectric sensors, which generate feedback signals to a microprocessor based on the intensity of incident light. The microprocessor runs the program and controls the tracking mechanism to adjust the angle of the solar panels to track the sun. A single-chip microcontroller-implemented solar tracking system can effectively improve the photoelectric conversion efficiency of solar panels and has a broad application prospect.***

Keywords: STM32 microcontroller; Solar energy; Tracking; Photoresistor; Stepper motor.

1. INTRODUCTION

1.1 Background and significance of the study

In the twenty-first century, with the development of the economy, people's demand for energy is increasing, and the energy crisis is becoming more and more prominent. According to information from the relevant departments, about 95 per cent of the world's commercial energy comes from fossil fuels, and it is still growing at a rate of 20 per cent. Today, conventional mineral energy sources such as coal, oil and natural gas are becoming increasingly scarce, and the world's major economies are facing an energy crisis. According to the current rate of exploitation and use, the proven mineral energy is only enough for human use for a few more decades, so it can be said that it is already in a situation of increasing depletion. In the years to come, traditional fossil fuels will still account for a large proportion of the energy mix, but mankind has also come to realise that fossil fuels, as a non-renewable source of energy, will eventually run out, and that it is therefore necessary to attach greater importance to new types of energy, such as solar energy.

As a new type of green energy, solar energy has a broad development prospect. However, due to the shortcomings of solar energy itself, the utilisation rate of solar energy is generally low now. Therefore, many scholars at home and abroad have conducted research on how to improve the utilisation rate of solar energy, and the problem mainly starts from two aspects, one is to improve the energy conversion rate of solar energy device, and the other is to improve the rate of solar energy reception, the former belongs to the field of energy conversion, which is still to be further researched, and the latter belongs to the field of reception, which can be solved by using the existing devices and technologies, i.e. solar energy tracking technology. As we all know, no matter what kind of solar energy equipment, as long as its receiving device is always perpendicular to the sunlight, it can receive more solar energy in a limited area, that is to say, it improves its receiving efficiency. However, the sunlight is in constant motion, to always keep the receiving device and the sun to remain perpendicular to the sun, then the sun must be tracked. In order to improve the efficiency of solar energy utilisation as much as possible, and to improve the shortcomings of the existing solar tracking control, this paper designs a high-precision solar tracking control system. This tracking control system adopts the method of combining software control and sensor control, designing a reasonable mechanical structure, and realising high-precision solar tracking through a hardware control system.

1.2 Status of domestic and international research

The main types of solar tracking systems we use today:

(1) Pressure difference solar tracking system

Principle: When the sunlight is not perpendicular to the receiving device, there will be deviation in the area of light on both sides of the closed container, which will make the temperature inconsistent, deformation inconsistent, and stress inconsistent, and a pressure difference will be generated, and under the action of this pressure difference, the system will be adjusted to achieve equal pressure, and ultimately make the sunlight perpendicular to the plane of the receiving device. Depending on the medium in the closed container, there are gravity differential pressure, pneumatic differential pressure and hydraulic differential pressure. These systems are purely mechanical and relatively simple, with no electronic devices or equipment, but with low precision and only single-axis tracking.

(2) Clock-based solar tracking system

Principle: This system is more widely used, by the knowledge of astronomy can be In order to know the angle of rotation of the sun per minute, according to the perpendicular relationship between the sunlight and the receiving device can be calculated receiving device. The angle at which the unit turns per minute, which in turn calculates the rotational speed required by the motor, controls the perpendicularity of the receiving unit to the sun's rays. The system has a simple circuit and is easy to apply, but the main disadvantage is that errors accumulate and need to be adjusted at intervals. section and runs around the clock, wasting energy.

(3) Comparative solar tracking system

Principle: 4 identical photoelectric sensors are placed at the edge of the sunlight receiving device, when the sun shines vertically, the electrical signals converted by the 4 photoelectric sensors are the same, there is no deviation, and the motor is stationary; when the sun shines at an angle, the electrical signals converted by the 4 photoelectric sensors are not identical, and produce a difference, which is processed through the relevant circuit, and the difference signals are converted into control signals, which control the motor rotation, until the sun shines vertically with the receiving device again, and the motor stops rotating. Through the processing of related circuit, the difference signal is converted into control signal to control the rotation of the motor until the sun is perpendicular to the receiving device again. This system has a relatively high tracking accuracy, and the circuit is simple and does not require complex electronic equipment, but for the advantage of light is not strong, such as cloudy days, may be tracking failure.

Currently, the more common application in China is the photoelectric tracking method, with electric, electromagnetic and gravity. The principle is to use photosensitive sensors to produce differential signals when the light is different, which are processed by the relevant circuits and adjust the position of the solar receiving device through the action of the servo mechanism to achieve the tracking of sunlight. This photoelectric chasing method has higher sensitivity, simple circuit and easy to implement structure, but the disadvantage is that it is limited by the weather.

1.3 Main content and significance of this topic

The electronic sunflower system designed in this project adopts the photoelectric tracking method, and the system is designed around devices such as microcontroller, photoelectric sensor, stepping motor, including three aspects of hardware part, software part and mechanical transmission part. This research takes the microcontroller as the core, uses the photoelectric sensor to convert the light signal into an electrical signal, and controls the rotation and stopping of the motor through the signal processing module and the microcontroller control module to realise the biaxial tracking of the sunlight, so as to make the receiving device keep perpendicular to the sunlight, which is of strong practical significance.

2. OVERALL PROGRAMME DESIGN

2.1 Comparison of tracking programmes

According to the search for relevant information, although there are many tracking programmes, the main ones are no more than three: photoelectric tracking, sun-sighted motion tracking, photoelectric tracking and sun-sighted motion tracking combined . The following is a comparison and analysis.

2.1.1 Day-of-view motion tracking

The apparent solar motion tracking method, also called angle tracking method, determines the position of the sun by calculating the sun's altitude and azimuth. This method needs to know the local latitude and longitude information as well as the time information at that time, so as to calculate the local solar altitude angle and azimuth angle at that time, calculate the solar altitude angle and azimuth angle once every fixed period of time, and at the same time, calculate the angular difference between the two times, and then make adjustments through the rotation of driving stepper motors. The biggest advantage of the sun-sighted tracking method is that it is not limited by light intensity and can achieve all-weather sun tracking. However, the sun position algorithm of this method is relatively complex, the cumulative error can not be eliminated, and this method has very high requirements in system design and installation level. The control principle is shown in the figure below.

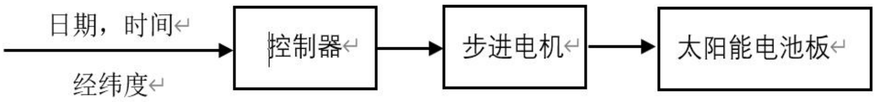

Figure 1: Schematic diagram of apparent day motion tracking control

2.1.2 Optical tracking

The basic principle of the photoelectric tracking method is to use silicon photocells, photodiodes, photoresistors and other photosensitive elements as photoelectric sensors, and install the photoelectric sensors around the solar energy receiving device according to a certain law, using the photoelectric sensors to output signals of different light intensities under the principle of different output signals, the processor by comparing the output signals to control the corresponding regulating mechanism, real-time adjustment of the solar energy receiving device to ensure that the The sunlight always shines vertically on the solar receiving device. The photoelectric tracking method is a kind of closed-loop control system, which can realise adaptive adjustment and timely feedback of the sun's position, and its structure is simple, with good tracking accuracy and high sensitivity. The control principle is shown in the figure below.

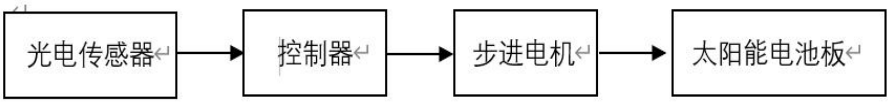

Figure 2: Schematic diagram of phototracking control

2.1.3 Combination of photoelectric tracking and sunlight motion tracking

Visual day motion tracking requires precise positioning at the beginning, and errors cannot be eliminated automatically. The photoelectric tracking method has poor stability, accuracy and photosensitive components have a great relationship, and even in some special circumstances tracking errors, especially in cloudy conditions, the motor tends to run back and forth, resulting in unnecessary losses. However, if the two are combined and complement each other's strengths, unexpected results can be achieved. The idea is: the use of high-precision photosensitive sensors for the initial positioning, tracking device operation process to visual day motion tracking, photoelectric tracking as a supplement. The result of photoelectric tracking is input as error feedback to the tracking of visual sun movement, and cumulative error correction is carried out for the procedure of visual sun movement tracking, so that high-precision tracking can be achieved under any weather. The control principle is shown in the figure below.

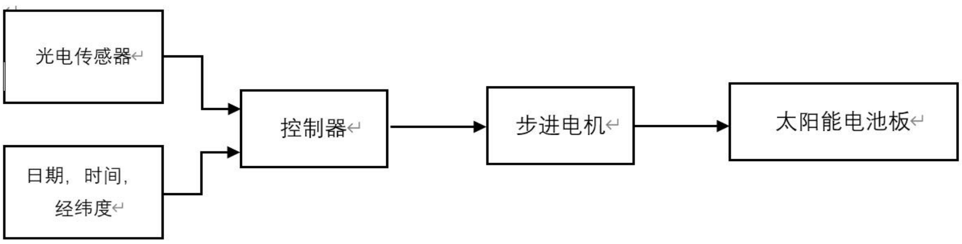

Figure 3: Schematic of the combined control of optical tracking and apparent-sun motion tracking

2.2 Tracking programme options

From the above discussion, it can be seen that there are advantages and disadvantages of both sunlight motion tracking and photoelectric tracking. Although the combination of sunlight motion tracking and photoelectric tracking can combine the advantages of the two solutions and has obvious advantages, but his cost is expensive, and is only applicable to large-scale solar power generation installations, which is not suitable for small enterprises and so on. The photoelectric tracking scheme is low cost, has a better cost-effective, at the same time compared to the visual sun motion tracking scheme, can better eliminate errors, do not need complex sun position algorithms, can be better to complete the design requirements. Combined with the practical situation, this system adopts photoelectric tracking as the automatic tracking part, and high sensitivity photoresistors are used as the photoelectric sensors. Therefore the photoelectric tracking scheme is used as the scheme selection for this design.

3. SYSTEM HARDWARE STRUCTURE DESIGN

3.1 System Functional Analysis and General Structure Block Diagram

3.1.1 Analysis of system functions

This design collects the photoresistor light intensity signal for detection and judgement, the solar photovoltaic panel battery converts the collected light energy into electricity, the photoelectric detection sensor realises the detection of the sun's light intensity, the photodetector is used to detect the sun's azimuthal signal, through the use of signal amplifier, it can convert the current signal into the voltage signal and amplify it, the MCU carries out the data arithmetic and controls the motor, and judges the effective tracking control. The microcontroller calculates the data and controls the motors to determine the tracking mode and then realise effective tracking control. The motors of different motion directions are used to drive the battery panel to realise the pitching motion of the height angle and the rotating motion of the azimuth angle in turn.

3.1.2 Block diagram of the overall system structure

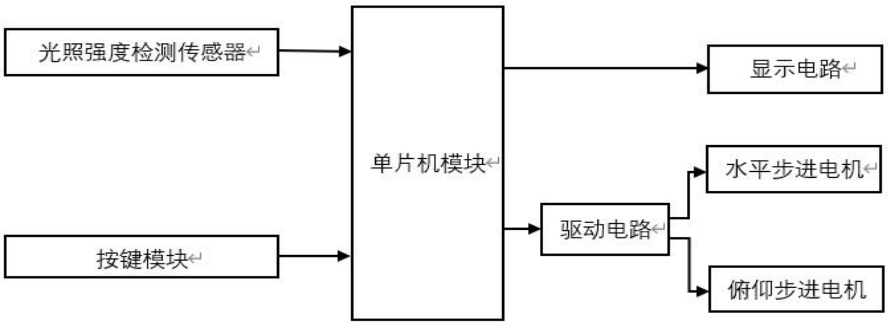

Figure 4: System Block Diagram

Through the key module and light intensity sensor can be input signal collection, and then through the processing of the microcontroller module on the stepper motor drive, to achieve the electronic sunflower on the light intensity perception and collection of light energy. The display circuit can show the remaining of electric energy.

3.2 Design of Module Circuit

3.2.1 STM32 microcontroller core circuitry

This design uses the STM32F103C8T6 as the main control chip, STM32 series processor is STMicroelectronics ST company produces a 32-bit ARM 7 architecture based on real-time simulation and tracking microcontroller. This control chip is chosen because the design of this system is not to pursue the lowest cost or smaller power consumption, but to provide richer interfaces and functions under the premise of achieving the functions of this design so as to facilitate the design of the experimental system for the experimental projects of the peripheral expansion circuits required. This control chip in the completion of the microcontroller course is easier to get started, has a good learning, experimental research value. STM32F103C8T6 microcontroller core board interface circuit diagram is shown in the following figure.

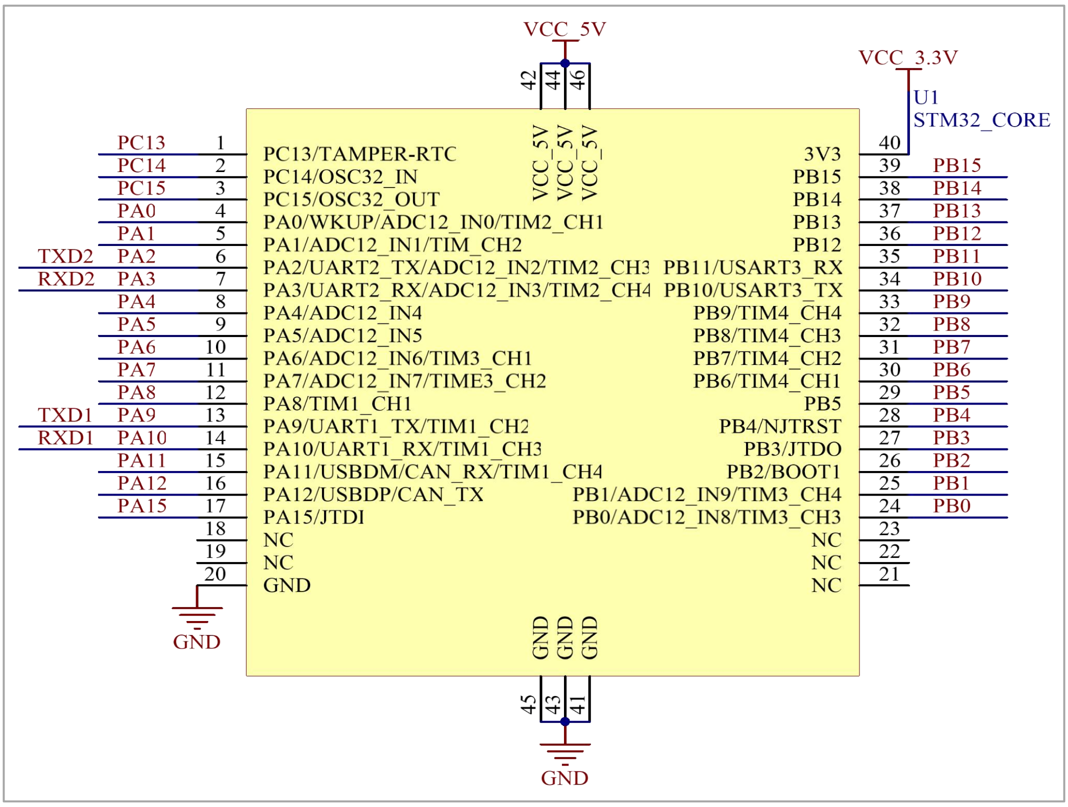

Figure 5: STM32 microcontroller core board interface schematic

3.2.2 Light Intensity Acquisition Module

This system selects the phototransistor as the device to detect light phototransistor is shown in the figure below.

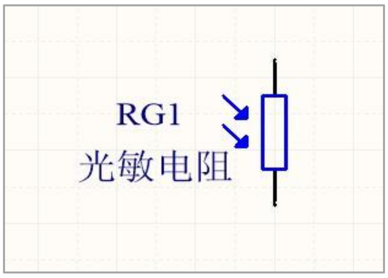

Figure 6: Photoresistor diagram

This module detects light through four photoresistors, which are placed in the four directions of the board. When the sun shines vertically, the electrical signals converted by the four photoresistors are the same, and at this time it is tracking the positive orientation of the sun. When the sun is tilted, the resistance value of the four photoresistors is different, and the electrical signals generated are also different, resulting in a difference, which is converted into a control signal through the calculation of the difference to control the rotation of the motor until it tracks the sun's positive orientation before it stops.

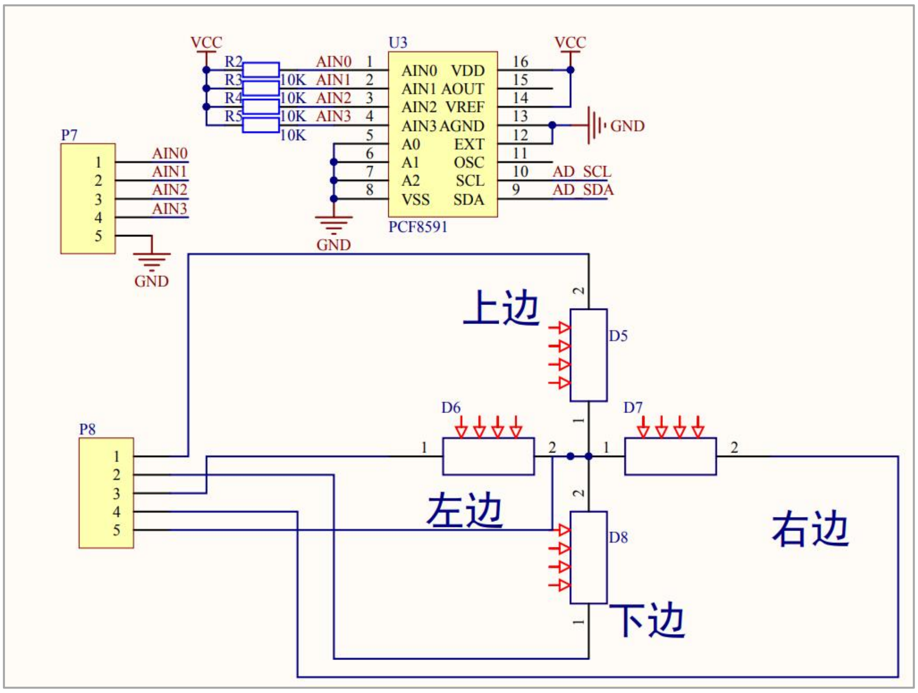

Figure 7: Circuit diagram of light intensity acquisition

As shown in the above figure, when there is a deviation in the light intensity, then the solar panel is rotated by the motor control, which makes the solar panel receive solar energy on a larger area, so that it receives solar light more fully. In the light intensity detection module, when the external natural light is stronger, the resistance value of the photosensitive resistor is smaller, and the voltage divided by the circuit is smaller, and when the light intensity is smaller, the resistance value of the photosensitive resistor is larger, and the voltage divided by the circuit is more.

3.2.3 Stepper motor drive module

Stepping motor is an open-loop control motor that transforms electrical pulse signals into angular or linear displacements, and is the main execution element in modern digital programme control systems, which are extremely widely used. In the case of non-overload, the motor's speed and stopping position only depend on the frequency and number of pulses of the pulse signal and are not affected by the load change. When the stepper driver receives a pulse signal, it drives the stepper motor to rotate by a fixed angle in the set direction, which is called the "step angle". It runs step by step. The number of pulses can be controlled to control the angular displacement to achieve the purpose of accurate positioning; at the same time, the frequency of pulses can be controlled to control the speed and acceleration of the motor rotation, so as to achieve the purpose of speed regulation.

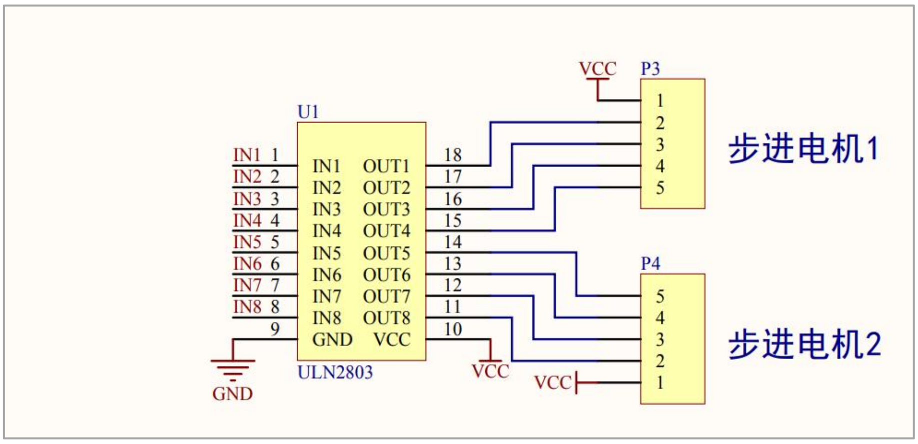

Figure 8: Stepper motor drive circuit diagram

The drive module is driven by two motors, which control up and down rotation and left and right rotation respectively. The two motors are driven through a relay drive system ULN2803. The microcontroller has a weak driving capability, so ULN2803 is chosen to drive the stepper motors.

3.2.4 Battery storage modules

All the power in this design comes from solar panels, so the system is designed with an energy storage module to complete the charging control of lithium batteries or supercapacitors. This module uses the TP4056 charge management chip, which can charge lithium batteries such as 18650. Energy storage device using a 18650 battery, photovoltaic charging panels and charging module is connected, so that the solar panel can collect electricity, while the charging module and 18650 battery connection, the collection of electricity can be stored in the battery to supply the power generation of the electronic sunflower.

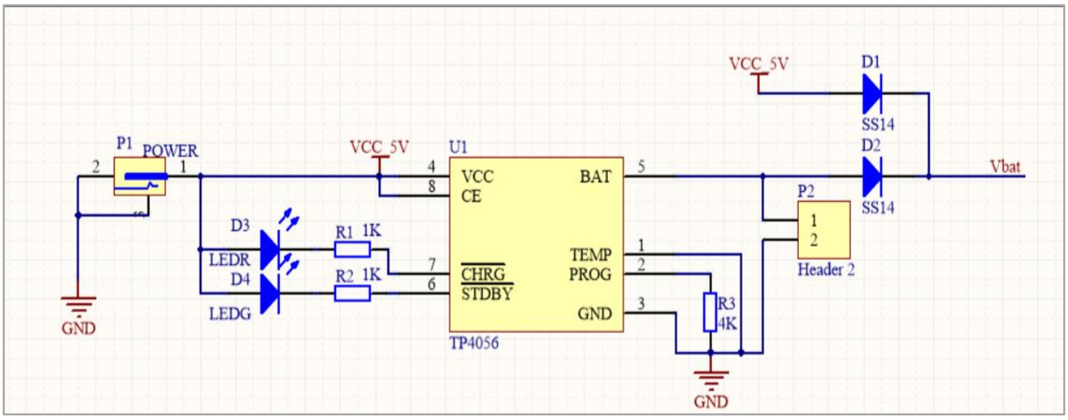

Figure 9: Schematic diagram of TP4056 charge management chip

P1 is the power input connector with 5-8V;
D3 and D4 are charging status indicators;
P2 is the lithium battery connector;

The role of D1 and D2 is to control the unidirectional flow of current. When there is power input, the Vbat current is provided by the power input, and the lithium battery is charged independently without mutual interference; when there is no power input, the Vbat current is provided by the lithium battery.

3.2.5 Display Module Circuit

This module uses a LCD1602 display to show characters on the screen.The LCD1602 display screen is 16 x 2 in size and is able to show the remaining power of the solar cell at this time in order to remind whether it can work normally.

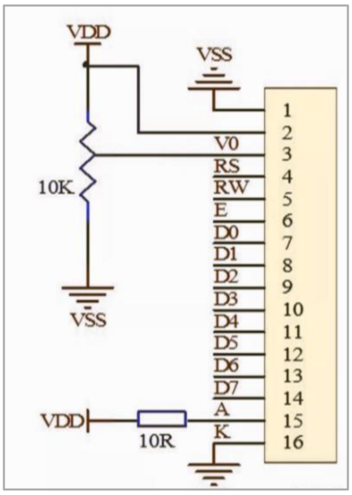

Figure 10: Display Module Circuit

3.2.6 Key Module

There are five buttons in this module, the buttons only have two states of pressing and popping up, their functions are the automatic manual switching of the system, the upward rotation, the downward rotation, the left rotation, and the right rotation when manual. The keys can be used to achieve the automatic rotation of the sunflower and control the sunflower to reach the best position. Figure 3.8 shows the circuit diagram of the key module.

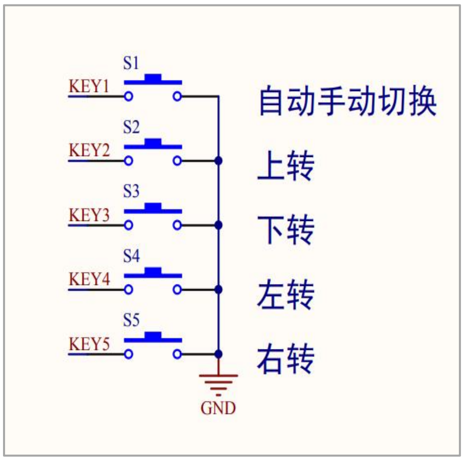

Figure 11: Circuit diagram of the key module

3.3 Introduction of special devices

3.3.1 Photoresistors

Photoresistors, or light pipes, are commonly made of cadmium sulphide, as well as selenium, aluminium sulphide, lead sulphide and bismuth sulphide. These materials have the property of rapidly decreasing resistance when exposed to light of a specific wavelength. This is due to the light produced by the carriers are involved in the conductive, in the role of the applied electric field for the drift movement, the electrons run to the positive pole of the power supply, holes run to the negative pole of the power supply, so that the resistance value of the photoresistor quickly decreased. Photoresistors are special resistors made of semiconductor materials such as cadmium sulphide or cadmium selenide, and their working principle is based on the internal photoelectric effect. The stronger the light, the lower the resistance value, with the increase of light intensity, the resistance value decreases rapidly, the bright resistance can be as small as 1KΩ or less. Photoresistors are very sensitive to light, and its in the absence of light, was a high resistance state, the dark resistance is generally up to 1.5MΩ. Photoresistors are generally used for light measurement, light control and photoelectric conversion (the change of light into electrical changes). Commonly used photoresistors cadmium sulfide photoresistors, which are made of semiconductor materials. Photoresistor sensitivity to light (i.e., spectral characteristics) and the human eye on the visible light (0.4 ~ 0.76) μm response is very close, as long as the human eye can be felt by the light, will cause it to change the resistance value. Design of light-controlled circuits, are used incandescent light bulbs (small beads) light or natural light as a control light source, so that the design is greatly simplified.

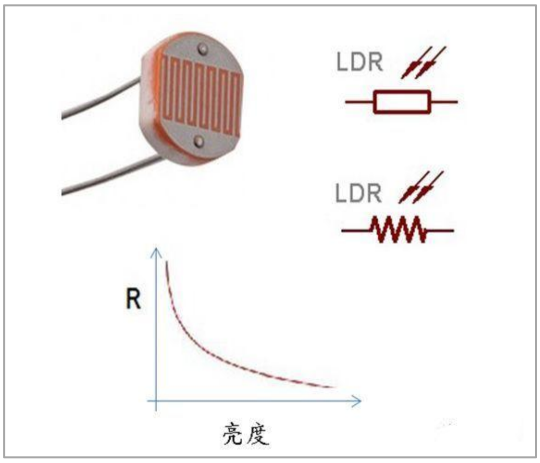

Figure 12: Photoresistor Characteristics and Schematics

3.3.2 ULN2803 Driver

The ULN2803 is an open collector output that can only accept potted current and it can drive 8-bit pins. It contains eight Darlington pairs of transistors, each capable of handling up to 500 mA of current, and can withstand higher voltages up to 50 volts. It is designed to accept a lower voltage control signal, such as from a microcontroller, and amplify it to drive a higher current load.

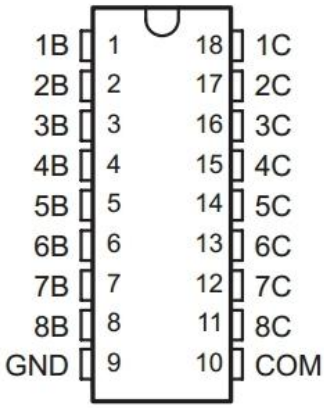

Figure 13: ULN2803 chip pinout diagram

The ULN2803 has a total of 18 pins, 10 of which are input pins, each connected to an internal Darlington pair. In addition, 8 output pins are also connected to 8 Darlington pairs. The following is the pin diagram of the ULN2803 and its function.

Table 1: ULN2803 Pin Function Table

Pin Number	Pin Name	Functional Description
1-8	1B-8B	Input control signal
9	GND	ground pin
10	COM	Positive voltage to power supply
11-18	8C-1C	output pin

1B to 8B are input pins which are connected to a control signal source such as a microcontroller.

1C to 8C are output pins to drive external loads.

The COM pin is normally used as a connection point for its internal flywheel diode, and the voltage from the external load needs to be connected to this pin.

GND is the ground pin.

When designing circuits and connecting loads, it is necessary to correctly input the signal to the IN pin and ensure that the positive terminal of the external load is connected directly to the power supply and the negative terminal is connected to the corresponding OUT pin. If driving inductive loads such as motors or relays, the COM pin needs to be connected to the positive side of the power supply to provide protection using the built-in flywheel diode. When driving these loads, the ULN2803 is able to absorb voltage spikes returning to the circuit to protect the microcontroller and other sensitive components. In use, when a controller (such as an STM32 microcontroller) sends a logic high signal to the input of the ULN2803, the corresponding Darlington pair opens, allowing current to flow from the output to the connected load. This enables a larger load current to be driven using a smaller control current.

3.3.3 TP4056 Li-ion battery charging chip

The TP4056 is a single-cell lithium-ion battery constant-current/constant-voltage linear charger in a SOP8 package with a heat sink at the bottom and simple external application circuitry. It is ideal for portable device applications and is suitable for both USB and adapter power supply operation, and has an internal anti-inversion charging circuit that does not require an external isolation diode. Thermal feedback can be automatically adjusted to the charging current in order to limit the chip temperature in high-power operation or high ambient temperature conditions. The following figure shows the pin diagram of the TP4056 package.

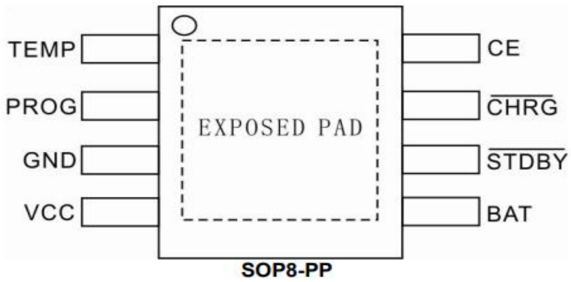

Figure 14: TP4056 chip pinout diagram

The pin functions of the TP4056 are shown in Table 2.

Table 2: TP4056 Pin Function Table

Pin Name	Functional Description
TEMP	Connected to a temperature sensing resistor for monitoring battery temperature (optional).
PROG	The charging current is set by connecting a resistor to ground; the smaller the resistor value, the higher the charging current.
GND	Ground connected to the power supply (0V reference point)
VCC	Connection to a 5V input power supply (e.g. USB powered)
CE	Charge enable pin, usually ground to enable charging, suspend or input high to disable charging
BAT	Connect to the positive terminal of the battery
STDBY	Charge completion indicator
CHRG	Charge Status Indicator

The main functions and features of the TP4056 include:
(1) Constant current/constant voltage charging: This ensures that lithium batteries are charged in the safest and most efficient way.

(2) Auto Restart: Charging automatically restarts the charging process when the battery voltage falls below a certain threshold.

(3) Temperature protection: If an external temperature sensor detects a high temperature, the TP4056 can suspend charging to prevent overheating.

(4) Charging Status Indication: The TP4056 provides pins to indicate the charging status, which can be easily indicated by LEDs.

(5) Input Voltage Range: 4.5V to 5.5V input voltage range for USB power supplies.

(6) Programmed charging current: The constant charging current of the charger can be adjusted by an external resistor.

The key point to note when using the TP4056 chip is to make sure that the chemistry type (which should be Li-Ion) and voltage of the connected battery is as specified in the TP4056. Setting the correct charging current is usually done by modifying the value of one of the fixed resistors next to the chip. If it is to be used for USB charging, make sure that the voltage and current output of the USB power supply meets the requirements of the chip. Care needs to be taken with wiring and layout, especially for thermal management and safety requirements, as Li-Ion batteries may heat up when charging.

4. SOFTWARE DESIGN

A complete control system consists of a hardware system and a software system, the previous chapter mainly describes the design of the system's hardware circuitry, to give full play to the system's design function, it is necessary to support the hardware platform of the software programme, that is, burned into the internal program of the microcontroller. This design uses ARM as the control centre, the chip used is STM32F103C8T6, the development environment is Keil uVision5 by ARM software.

4.1 Software Design Principles and Tools Used for Design

The electronic sunflower design should use the principles of modularity and real-time to design the software, starting with breaking down the tracking control system into separate functional modules, such as the communication module, the sensor data acquisition module, the data processing module and the motor control module. This helps to reduce the coupling between the parts and makes the code easier to understand, test and maintain. Second, the design is based on satisfying real-time operation. The processor needs to respond quickly to changes in sensor data and adjust the position of the panels in time to maximise sunlight reception. At the same time, the system should respond quickly to sensor data through efficient algorithms, real-time adjustments to the panels, handling of unforeseen situations, and configuration management to flexibly respond to parameter adjustments. The aim is to achieve reliable, stable and economical operation of the system, while considering the energy limitations of the system for code optimisation to ensure the effective use of energy.

Choice of programming language: Because the whole programme is complex and has a large amount of calculations, using more floating point calculations, the programme is written in C language. Compared with assembly language, C language has many advantages, such as: do not need to know the instruction set of the processor, do not have to understand the memory structure; register allocation and addressing mode managed by the compiler, programming does not need to consider the details of the memory address and data type; specified operation of the variable selection combinations to improve the readability of the program; compared with the use of assembly language, the development and debugging time of the program The development and debugging time of a programme is much shorter than in assembly language, etc.

Microcontroller programme development environment: this paper design ARM development environment is Keil uVision5, is currently embedded more popular development environment, Keil uVision5 is ARM company developed the latest generation of ARM processor compilation, connection and debugging integration software. keil uVision5 not only provides a complete Windows development environment Keil uVision5 not only provides a complete Windows development environment interface, support for C / C + + language development, and its C language editing efficiency is very high, enabling developers to make use of the C language for research and development is very convenient.

ARM software development process: ARM development first need to establish a "Project" project, click the Keil uVision5 interface in the menu "Project", select "New uVision Project", for the new project name and click Save;

and then select the development of microcontroller chip model, the project selected STM32F103C8T6, so that the establishment of the "Project" is completed. When the project has been established, click on the "Source Group", you can add the .c file, click Add to edit the file, you can also copy the commonly used .c file to the established "Project" directory. Below, the last completed project software has been created.

The Keil uVision5 development interface is shown in Figure 15.

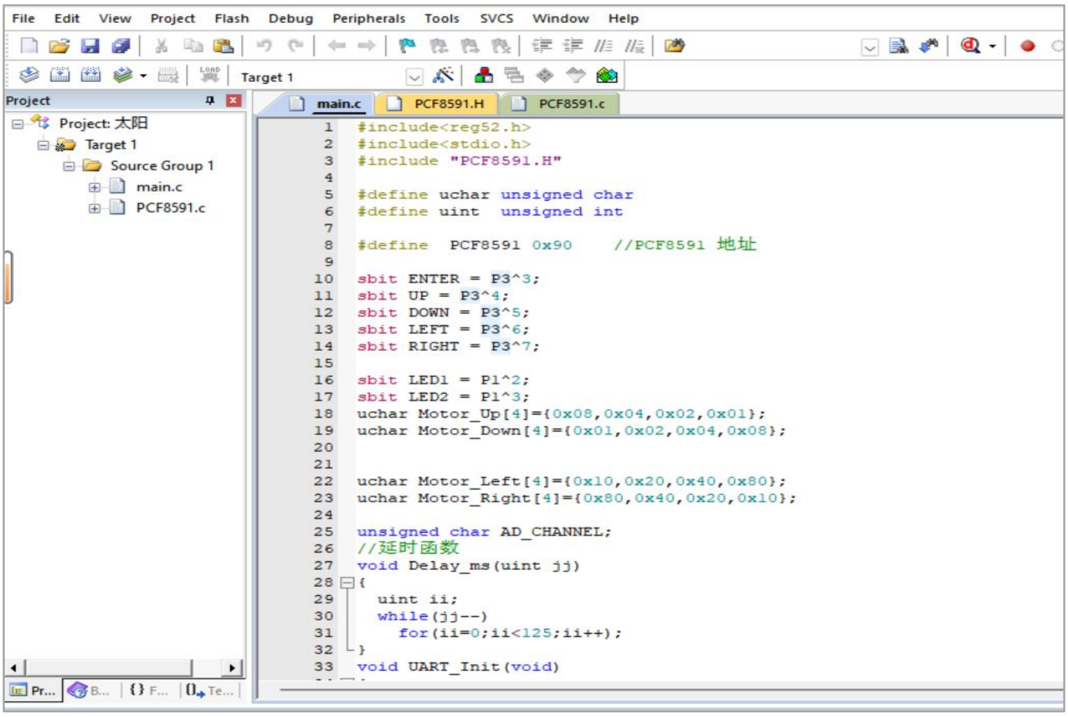

Figure 15: Keil uVision5 development interface

4.2 System software design structure diagram and its functions

In designing the software structure of the electronic sunflower system, this programme divides the software modules mainly into the application layer and the driver layer, and connects them in series through the main control loop. The system software design structure diagram is shown in Figure 4.1.

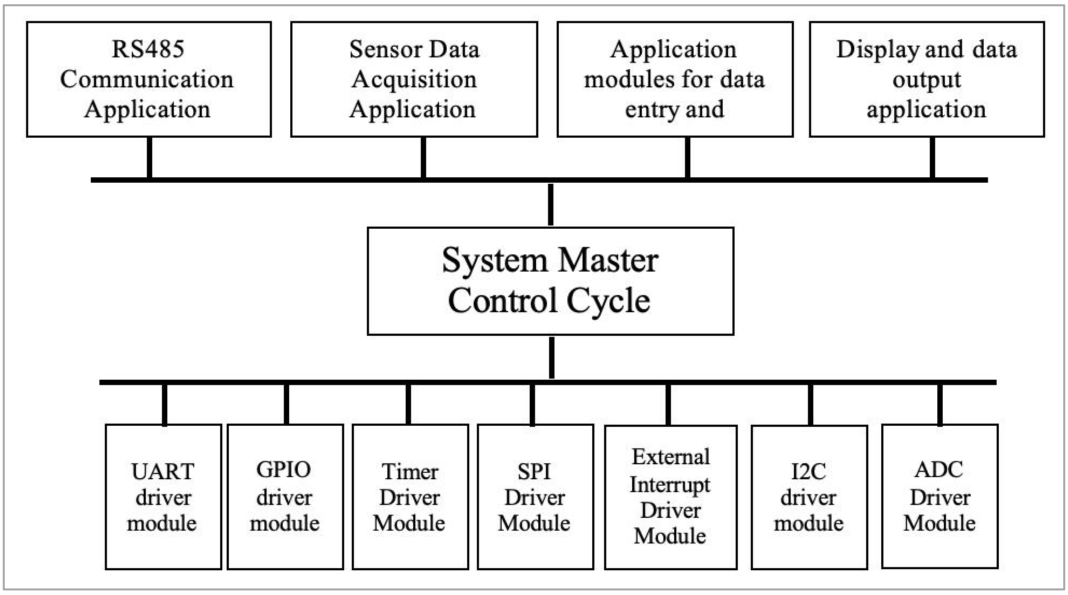

Figure 16: System software design structure

The main control loop is the heart of the system, which connects all functional modules in series and ensures the coherence and accuracy of the tracking behaviour. The application layer provides the user interface and control strategy by encapsulating complex logic and algorithms, while the driver layer is responsible for communicating directly with the hardware to perform the underlying data acquisition and device control. The main control loop sits on the application layer and monitors the transmission in real time.

Sensor inputs are used to adjust the orientation of the panels based on position data, and user inputs are also processed to maintain system status and keep the system operating efficiently.

In terms of the specific operation of the software design, the CPU, GPIO, ADC, TIMERS, NVIC, etc., are firstly set up through the system initialisation, and then the data acquisition module is called in the main control loop to read the sensor data, and pass the data to the data processing module to carry out the necessary algorithmic processing, and finally the results are transmitted to the executive control module to adjust the position of the stepper motor. In this framework, the application layer module is responsible for processing logic and decision making, while the driver layer module is responsible for direct interaction with hardware components.

4.3 Main software module design and overall flow block diagram

Firstly, an overview of the overall software flow is given. The entire software system starts at the "Start" stage, followed by the "Driver Module Initialisation", where the necessary drivers are loaded to support the hardware functionality. After the initialisation, the process moves on to the "Data input and parameter adjustment application module", where the software processes external or internal sensor information and optimises and adjusts the operating parameters based on the data received. Subsequently, the data is passed along the designed path to the "Display and Data Output Application Module", where the final results are displayed to the user via the user interface and exported to other system modules or storage devices. This block diagram defines in detail the entire process from system startup to data delivery, with each critical step being an important part of ensuring overall system performance. The overall software flow diagram is shown in Figure 16.

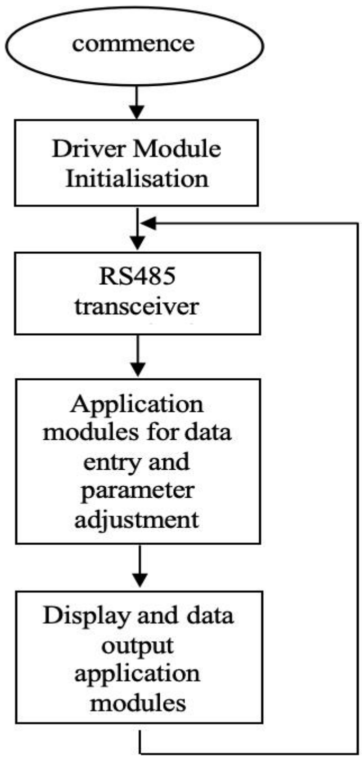

Figure 17: Overall software flow

The software modules in this design are: communication module, sensor data acquisition module, data processing module, motor control module. Their functions and descriptions are as follows:

Communication Module: The communication module is responsible for initialising the necessary hardware interfaces such as UART, I2C, SPI, etc.; waiting for and parsing the commands from outside; executing the relevant operations according to the commands and sending the execution results back to the originator of the commands.

Sensor Data Acquisition Module: The module first initialises the GPIO and ADC channels associated with the photosensitive sensor; then a timer sets the interrupt period, which periodically triggers the ADC to read the analogue value of the photosensitive sensor and convert it to a digital value to be stored in the buffer; finally, an interface function is provided to return the latest data for use by other modules.

Data Processing Module: This module periodically obtains the latest light intensity data from the sensor data acquisition module, and decides the direction and angle in which the solar panel needs to be steered by comparing the data from different sensors; this decision result is then converted into motor control commands, which are passed to the motor control module.

Motor Control Module: The module receives control signals from the Data Processing and Decision Making Module and sets PWM (Pulse Width Modulation) parameters to control the speed and direction of the motor; it also monitors and reports on the current status of the motor, such as its position and running status, to ensure that the system monitoring module has access to the motor's operating conditions.
4.4 Flowchart of electronic sunflower design procedure

In order to achieve the function of the electronic sunflower automatically chasing the sun, this system design mainly uses Keil uVision5 software to write and debug the programme, the programme language to take the readability and portability of the higher C language to write. System operation flow chart shown in Figure 17.

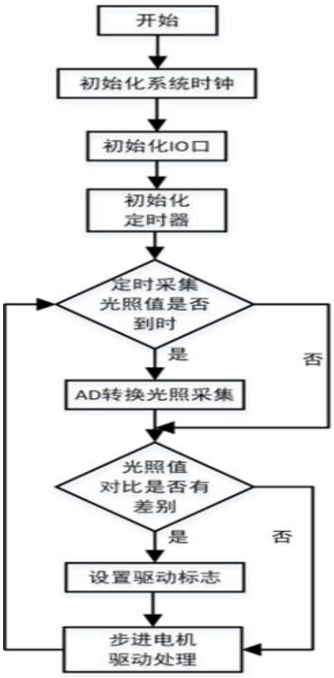

Figure 18: System Operation Flowchart

5. SYSTEM COMMISSIONING

In the debugging of the electronic sunflower design system, the first task is to verify the accuracy and responsiveness of the tracking control algorithm. Before system debugging begins, it is important to ensure that all sensors are accurately calibrated and the interface communication with the STM32 microcontroller is error-free. Next, a series of scenarios with simulated light sources are used to simulate different sunlight conditions to test the response time and accuracy of the panel angle adjustment. Power consumption is also monitored to confirm that the control system itself is kept to a minimum while capturing solar energy at the optimal angle. A meticulous commissioning process is a key step in ensuring that the tracking system achieves maximum efficiency in real-world operation.

5.1 System hardware debugging

During the development and design of the system, the circuit is simulated by protues software. Specifically, the basic composition of the circuit is shown in Figure 19.

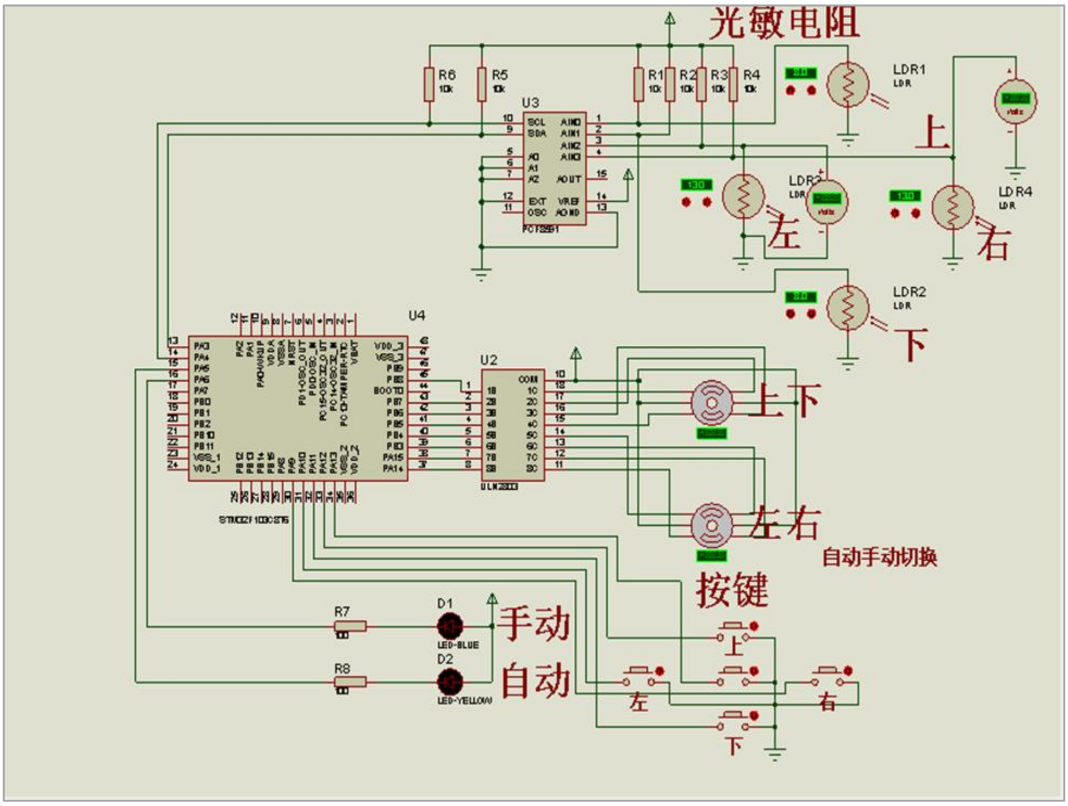

Figure 19: System circuit schematic

The hardware debugging steps are as follows:

(1) Battery storage module: to ensure the stability of power supply is the most important, so the first battery storage module adjustment. Test. Theoretical parameters: rated voltage, maximum charging current, discharging current, battery capacity, etc.

(2) The main control module: the main control module is the brain of the whole system, after confirming the stability of the power supply debugging. Theoretical parameters: operating voltage, clock frequency, I/O port level and so on.

(3) Stepper motor drive module: motor drive module debugging needs to be carried out after the main control module can control its operation. Theoretical parameters: input voltage, current parameters, stepping angle, response time and so on.

(4) Light detection module: Accurate data of light detection module is important for solar panel tracking. Theoretical parameters: detection range, sensitivity, the relationship between output voltage and light intensity.

(5) Display circuit module: module debugging is basically complete, you can debug the display circuit for display status. Theoretical parameters: operating voltage, display brightness, display resolution and so on.

5.2 System software debugging

Software modules are debugged independently:

(1) Sensor Data Acquisition Module: Run the data acquisition module alone to monitor its ability to collect data at the designed frequency and format. Perform tests using known values or analogue signals to verify the accuracy of the data. Check the error handling and alarm mechanism under abnormal conditions (e.g. sensor disconnection). From there, confirm that the module can accurately read sensor data and test the accuracy and stability of the data.

(2) Data processing module: Input the collected sensor data samples to verify that the processing logic, such as filtering and mathematical operations, meets expectations. Simulate boundary conditions and abnormal data to ensure that the algorithm can be processed correctly or report errors.

(3) Motor control module: Set the initial PID parameters, which are usually set to neutral at the beginning or based on empirical values. Run the motor control module, observe the motor response and compare it to the desired response. Based on the response, use the tuning method to adjust the PID parameters. Repeat the test tuning process until the motor response meets the design requirements.

(4) Communication module: Test the stability of data transmission between modules, including the continuous transmission of data and random timing transmission. Artificially create communication errors, check the error recovery mechanism and data calibration.

Software Module Integration Debugging: Add the tested modules to the system one by one and repeat the testing of the module to ensure that it is equally stable in the system. Then, test the addition of new modules, the original module is still working properly, whether there is no interference. Focus on the interfaces between modules, such as how data flows from the sensor data acquisition module to the data processing module and then to the motor control module. Check whether there is any loss, delay, or error in the data flow. Finally, integrate all modules and test the whole system to ensure that the whole process is error-free. Specific operations are carried out through the Keil uVision5 software.

Steps are as follows: software debugging steps are as follows:

(1) in Keil uVision5 software to create a project: click the menu bar "project", enter the new project name, and save; and then the microcontroller model is "STM32F103".

(2) New user source file: in the new blank text to write the programme source code, coding is completed to save the file and file extension name "design name.c", the new file creation is complete.

(3) program compilation and debugging: click the compile button, the system will run on the file, in the output window you can see the prompt information, if there is an error message, it is necessary to find out the error according to the prompts and correct, until the prompts are no error and simulation of the physical function are in line with the requirements of so far!

5.3 System Simulation Debugging

This system uses protues software for simulation, the corresponding .hex file of the program written in Keil uVision5 software is "burned" into the STM32F103C8T6 chip in protues software, the specific operation is as follows: double-click the STM32F103C8T6 chip in non-running state, a pop-up window will appear. STM32F103C8T6 chip in non-running state, a pop-up window will appear, select the corresponding hex file in the Program File column, as shown in Figure 20.

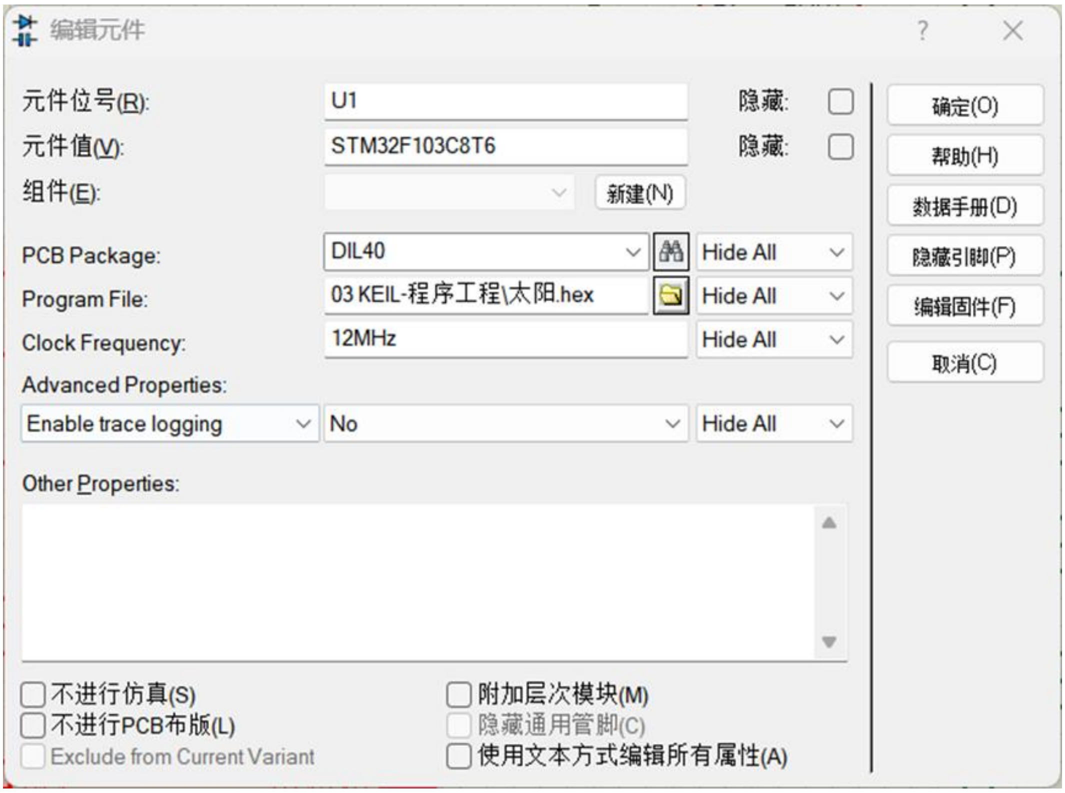

Figure 20: STM32F103C8T6 Component Edit

After the programme is loaded into the STM32F103C8T6 chip, start the simulation and debugging. Click "Debug", "Start Simulation", click the manual button on the circuit diagram, you can switch the system to manual control state, at this time in the absence of light, so that the two stepper motor rotation. The state of the two stepper motors after pressing the button in the manual state is shown in Figure 21. The circuit for controlling motor rotation in manual mode is shown in Figure 22.

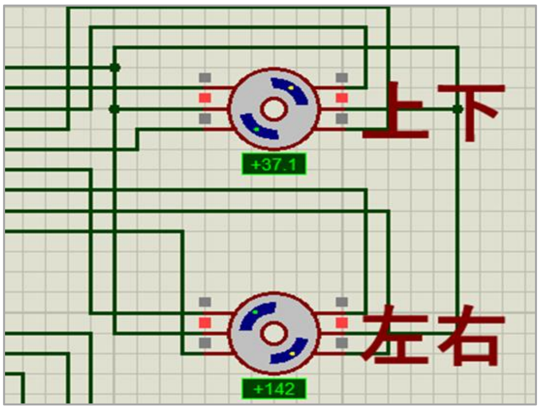

Figure 21: Stepper motor status

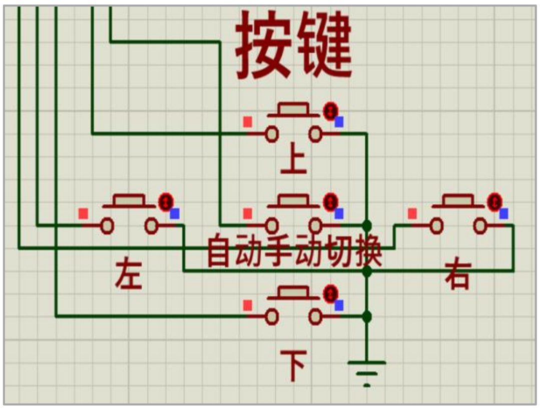

Figure 22: Manual-Automatic Switching Circuit

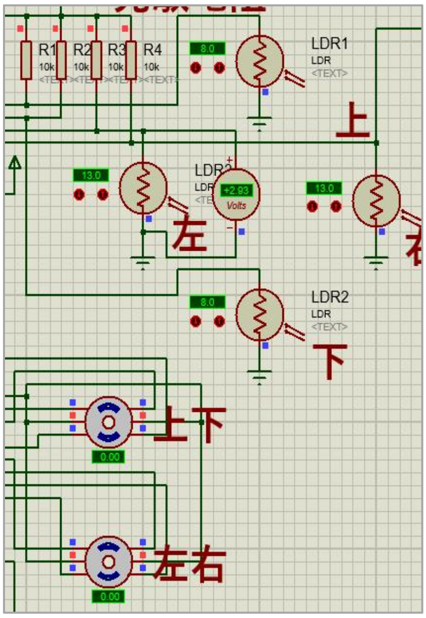

Figure 23: Motor state for initial value of resistance

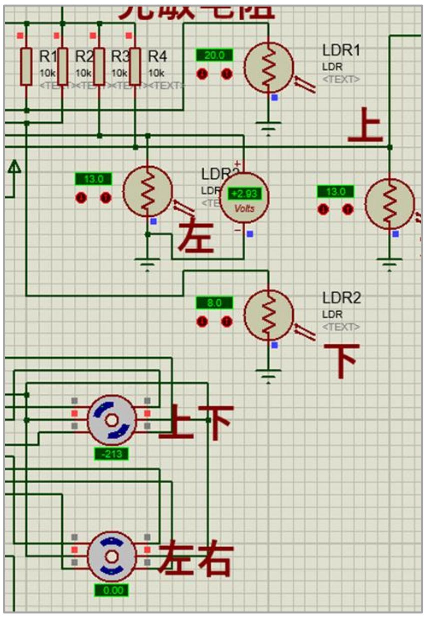

Figure 24: Motor state after changing resistance

Switch the circuit to automatic control and set the values of the four photoresistors to 13.0, 8.0, 13.0, and 8.0, respectively, and observe that the numbers on the motors are all 0 and do not rotate at this time, as shown in Figure 23. Changing the upper photoresistor to 20.0, all else being equal it was observed that the upper and lower motors started to rotate but the left and right motors did not rotate as shown in Figure 24. It can be inferred from this, when the upper photoresistor resistance increases, the current decreases, that is, on behalf of the upper photoresist receives a weaker light, the lower light is stronger than the upper, so the upper and lower motors began to rotate downward, many times to change the value of the photoresistor, the results are in line with the design requirements to prove that the system can be a good completion of the electronic sunflower tracking the sun or light intensity of high light source design requirements, the commissioning was successful. Commissioning success.

6. CONCLUSION

This design describes an advanced solar photovoltaic tracking system, the electronic sunflower, which is designed to mimic the dynamic tracking of the sun by sunflowers in nature and maximise solar energy harvesting and utilisation. We illustrate the design principles of the electronic sunflower, including the layout of the photosensitive sensors used to detect the orientation of the sun, the motor selection and control logic to drive the mechanical structure, and the algorithm and electronic circuit design to ensure system stability and efficiency. In detail, the electronic sunflower system continuously senses and determines the position of the sun through a series of finely laid out photosensitive sensors. These sensors are connected to a central processing unit, which analyses the data and controls the associated mechanics. The precise selection of the motors is particularly important, as they must be able to guarantee the smooth and accurate movement of the panels under different environmental conditions. In addition, the optimisation of the control logic and algorithms ensures stable operation and high collection efficiency in the face of complex environmental factors.

During the experimental evaluation phase, the system demonstrated superior performance to static PV panel installations, with particularly significant efficiency gains in sunny, clear weather conditions. Test results showed that the e-sunflower was able to improve energy harvesting efficiency by at least 20 per cent. In terms of cost-benefit analysis, although the initial investment increased, the payback period of the system was significantly shortened by improving the efficiency of power generation.

A number of challenges were also encountered during the research of the design, including durability testing of the mechanical components, environmental adaptation issues, and possible directions for future optimisation. The e-sunflower demonstrates the potential value of solar tracking technology, which is of great practical importance for improving the long-term sustainability of renewable energy systems. Future research could focus on improving the adaptive capability of the system, reducing costs, and expanding the range of applications.

Therefore, the electronic sunflower as an innovative solar tracking solution not only proves its effectiveness in improving energy collection efficiency, but also provides an important design and research basis for the future development of solar tracking technology. The ultimate goal of the design is to use the electronic sunflower as an efficient, smart and sustainable technological solution that provides a solid pace and direction for innovation and growth in the solar industry.