Design of novel hybrid control solar tracking system

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Abstract. This paper describes a hybrid control solar tracking system consisted of sunlight gathering platform, mechanical structure and MCU controller system which is mainly based on time and light dependent resistors module. An adaptive calibration and operating algorithm are proposed to solve accumulated error for inaccuracy sun position model and servo system error of single axis solar tracking system, which can make the focused sunlight matching the solar evacuated tube well. The proposed system and algorithm effectively will improve the utilization of solar energy.

1 Introduction
Energy crisis is the most important issue in the world. Conventional energy resources are not only limited but also the prime culprit for environmental pollution. Renewable energy resources are getting priorities in the whole world to lessen the dependency on conventional resources. Solar energy, as a clean and renewable source, is rapidly gaining the focus as an important means of expanding renewable energy uses \cite{1-2}. Solar panels are the transducers which convert solar energy into electrical energy or other energy, such as heat. The conventional, i.e. fixed installation of these solar panels on a flat surface is very inefficient and less cost effective solution \cite{3}. There are many solar tracking systems presented, such as solar trajectory tracking, photovoltaic solar tracking, single axis solar tracking, dual-axis solar tracking, no-tracking solar collector and so on\cite{4-10}.

With the motivation of above literature review, the novelty of this study is to describe a design of single axis solar tracking system with MCU controller system, time module, light dependent resistors module, evacuated tube solar collector, stepper motor and mechanical structure, using a proposed adaptive calibration algorithm.

The paper will be structured as follows: Section II provides an overview of the hybrid control solar tracking system; Section III describes the hardware and software system implementation of the proposed system. Section IV presents the discussion of the proposed system. Finally, we conclude in section V.

2 Hybrid Control Solar Tracking System
As shown in Figure 1, it is the block diagram of hybrid control solar tracking system, and it is the structure diagram of hybrid control solar tracking system in Figure 2.
The hybrid control solar tracking system mainly includes sunlight gathering platform, mechanical structure and MCU controller system.

Figure 1. Block Diagram of Hybrid Control Solar Tracking System
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Figure 2. Structure Diagram of Hybrid Control Solar Tracking System
Sunlight gathering platform is made up of bearing 1, bearing 2, big gear, solar evacuated tube, holder, organic glass cover, sunlight gathering surface, big gear plate, orifice plate, limit switch stick, limit switch groove. Mechanical structure is composed of holder, small gear, stepper motor. MCU controller system consists of MCU controller with external memory chip DS1302 timer, light dependent resistors module, stepper motor driver, limit switch data acquisition, sunlight gathering platform calibration PCB.

3 Design and Implementation

3.1 MCU controller system
MCU controller system is the mainly core of hybrid control solar tracking system.

Figure 3. Block Diagram of MCU Controller System
Figure 3 is the block diagram of MCU controller system. EEPROM is the external memory chip of MCU controller, which mainly stores the time and slope of sunlight. DS1302 timer is the base data, and as for light dependent resistors module the fine tuning. Stepper motor is used to drive the sunlight gathering platform, and also limit switch data acquisition and calibration PCB are made to adjust the hybrid control solar tracking system. Figure 4 shows the sunlight gathering platform calibration PCB,
which can set time and date. When the hybrid control solar tracking system works, the sunlight gathering platform calibration PCB can also calibrate the position.

![Sunlight gathering platform calibration PCB](image)

**Figure 4. Sunlight Gathering Platform Calibration PCB**

### 3.2 Adaptive Calibration Algorithm

1. **When Mode0=1,** Limit switch data acquisition clicks firstly.
2. **When Mode0=1,** Limit switch data acquisition clicks secondly, when Mode0=0, Limit switch data acquisition clicks firstly.
3. **When Mode0=1,** the sunlight gathering platform goes back horizontal position after twice clicks.
   - When Mode0=0, the sunlight gathering platform goes back horizontal position after once click.
4. Normally working, sunlight is focusing on solar evacuated tube before 12:00.
5. Normally working, sunlight is focusing on solar evacuated tube at 12:00.
6. Normally working, sunlight is focusing on solar evacuated tube after 12:00.

![Operating Principle of the Hybrid Control Solar Tracking System](image)

**Figure 5. Operating Principle of the Hybrid Control Solar Tracking System**
Figure 6. Brief Flow Chart for Operation

Figure 5 shows the operating principle of the hybrid control solar tracking system. Figure 6 and Figure 7 are the operation flow chart of the hybrid control solar tracking system.

As is shown in Figure 5, ①, ②, ③ are designed to calibrate the sunlight gathering platform by using the sunlight gathering platform calibration PCB, limit switch stick and limit switch data acquisition. ④, ⑤, ⑥ are the sketch map for normally working of the hybrid control solar tracking system, of which the sunlight is focusing on solar evacuated tube, mainly with the help of MCU controller with external memory chip, DS1302 timer, light dependent resistors module.

S1, S2, S3 and S4 are four steps in Figure 6, representing respectively initial calibration or not initial calibration, daily calibration, working mode of brief flow chart for operating. According to Figure 7, we can get the detailed operation flow chart of the hybrid control solar tracking system, as follows:

MCU controller system resets first. Mode0 and Mode1 are two flags. When Mode0 equals to 1, initial calibration begins; When Mode0 equals to 0, it enters daily calibration. Mode1 is the flag for making sure that it can normally working after calibration. And when it enters Night mode the stepper motor is be shut down, which could save energy.

When it enters initial calibration, the position of sunlight gathering platform should be adjusted until it is on horizontal position firstly, at the same time limit switch data acquisition is clicked once with MotorPulse equalling 0. Then the sunlight gathering platform operates clockwise by using the sunlight gathering platform calibration PCB. When the limit switch stick touches the limit switch data acquisition module, the limit switch data acquisition clicks secondly, with MotorPulse equalling N, which will be copied to EEPROM storage.

When it enters daily calibration the sunlight gathering platform operates clockwise automatically. It does not stop until the limit switch stick touches the limit switch data acquisition module.

Then the sunlight gathering platform operates anticlockwise automatically until MotorPulse equals N. Here the sunlight gathering platform goes back horizontal position. Next it is the step for making sure that it can normally working after calibration. That is to say, the current time T (Y:M:D:H:M) is got by reading DS1302 module. According to T, the sunrise and sunset time (H1: M1, H2: M2) can be got through reading the EEPROM. And then slope (pulses/minute) will be got as follows:

\[ slope = \frac{N}{H2 \times 60 + M2 - (H1 \times 60 + M1) \times \frac{1}{2}} \]  
(1)
Then MotorPulse counts anticlockwise according to T platform operates anticlockwise when H is greater than 60.

The sunlight gathering platform goes back horizontal position. We should know that whether it is daytime or night mode. When it is clicked firstly, MotorPulse equals to slope and slope equals to slope when the sunrise and sunset time \( (H1; M1; H2; M2) \) can be got through reading the EEPROM. And then slope \( \text{(pulses/minute)} \) is calculated. Then the sunlight gathering platform operates anticlockwise when H is greater than 12, or it operates clockwise when H is less than 12. When MotorPulse equals to \( |\text{MotorPulse}_N| \), light dependent resistors module starts to work in order to make sure sunlight focusing on solar evacuated tube. MotorPulse_N will be corrected at the same time.

Then it will enter the working mode. We should know whether it is daytime or night mode. When it enters Night mode the stepper motor is be shut down, which could save energy. During the daytime, according to T \( (H; M) \) and slope, MotorPulse_N0 is calculated.

\[
\text{MotorPulse}_N0 = \text{slope} \times (12 \times 60 + 0 - (H \times 60 + M))
\]  

(2)
Then the sunlight gathering platform operates anticlockwise when \( H \) is greater than 12, or it operates clockwise when \( H \) is less than 12. When MotorPulse equals to \( |\text{MotorPulse}_N0| \), light dependent resistors module starts to work in order to make sure sunlight focusing on solar evacuated tube, \( \text{MotorPulse}_N0 \) will be corrected at the same time.

Next, it is the tick-tock mode. \( T3 (H3: M3) \) is the moment, and \( T4 (H4: M4) \) is the next moment after 3 minutes, so \( \text{MotorPulse}_N1 \) can be calculated as follows

\[
\text{MotorPulse}_N1 = \text{slope} \times (H4 \times 60 + M4 - (H3 \times 60 + M3))
\]  

(3)

When \( \text{MotorPulse}_N0 \) is greater than \( \text{MotorPulse}_N1 \), the sunlight gathering platform operates anticlockwise, vice versa. When MotorPulse equals to \( |\text{MotorPulse}_N0| \), light dependent resistors module starts to work in order to make sure sunlight focusing on solar evacuated tube, \( \text{MotorPulse}_N0 \) will be corrected at the same time. This method will make sure that the sunlight is focusing on solar evacuated tube at 12:00.

4 Discussion

Figure 8 shows error calculation diagram for the hybrid control solar tracking system.

![Figure 8. Error Calculation Diagram for The Hybrid Control Solar Tracking System](image)

\[
\theta = \arctan \frac{E}{R}
\]  

(4)

Recoding \( \theta (\degree) \) of 8:00—16:00 every other hour from Monday to Sunday, so we can get 63 points every week. Figure 9 is the error curve of one week, of which x-coordinate is the time point and y-coordinate is the error \( \theta \), from July to August, which the sunlight is the strongest. Through analysing Table 1 and Figure 9, we can find that the focused sunlight matches the solar evacuated tube well, which error range is less than 1.5°.

| Day | Error | Time 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|-----|-------|--------|---|----|----|----|----|----|----|----|
| 1   | 0.9   | -0.6   | 0.7 | 0.7 | 0.2 | 0.6 | 0.9 | -0.7| 0.9 |
| 2   | 0.8   | 0.6    | -1.0| 0.4 | -0.2| -0.4| 0.7 | 0.9 | -1.0|
| 3   | 1.0   | -0.6   | 0.9 | -0.6| -0.2| 0.3 | 1.05| -0.6| 0.9 |
| 4   | 1.2   | -0.4   | -0.7| -0.3| 0.2 | 0.6 | 0.6 | -0.4| 0.7 |
| 5   | -0.7  | -0.6   | 0.9 | 0.4 | -0.2| -0.3| -0.7| 0.7 | 1.0 |
| 6   | 1.2   | 0.7    | -0.7| 0.7 | -0.2| 0.7 | 0.6 | -0.6| -1.2|
| 7   | -0.6  | 0.9    | 0.9 | 0.6 | 0.2 | -0.3| -0.6| 0.7 | -0.9|
5 Conclusion
This paper describes a hybrid control solar tracking system. An adaptive calibration and operating algorithm is proposed to make sure the focused sunlight matches the solar evacuated tube well. The proposed system and algorithm will effectively improve the utilization of solar energy.

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