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An adaptive solar tracking system with a maximum energy output

Cui yuanhui[2], Zhao yue[2], Chen xiguang[2], Wang zhisen[2], Cao Yinghong[2]

Abstract. A photovoltaic solar tracking control system is designed and implemented. The electrical and mechanical control segments were represented in detailed. In the electrical part, it was made of seven main parts: an illuminance transducer, a photo-voltaic sensor, two stepper motors, a gyroscope, a solar panel, a NI myRIO control unit and the software program written by LABVIEW2015. In the mechanical part, a screw mechanism was adopted to control the solar panel's inclination; a steering gear mechanism was used to control the solar panel's direction. The system can output a maximum solar energy in real time. To gain the maximum solar energy, three control patterns was designed: photoelectric tracking, time tracking and angle tracking. Through the real-time acquisition of light intensity from the photoelectric sensor, light displacement from the photovoltaic sensor, combined with the local latitude, the best receiving efficiency can be calculated. According to the calculation, the solar photovoltaic panel was adjusted by driving two-stepper motors which were controlled by a mechanism. A NI myRIO was adopted to process these parameters, and LabVIEW2015 was chosen to write the host computer control program. The prototype has been implemented, and the seamless switching between the three modes had come true successfully. The system is easy to operate with a friendly interface. The successful development of this system has a significant guide for the practical application of photovoltaic system.

Key words. Photovoltaic energy system, labview, ni myrio, solar tracking control system, maximum energy output.

1. Introduction

Green energy has been played an important role in our day life in these days. It is clean and unexhausted compared with the traditional energies. Solar energy is very popular among them. A photovoltaic tracking control system is a solar energy

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[2]Workshop 1 - School of information and engineering, Dalian Polytechnic University, Dalian, 116034, China

output device. It depends on controlling the direction of solar photovoltaic panels at different time and place to obtain maximum output energy by controlling the position irradiation of sunlight. Theoretical analysis shows that the energy reception rate of solar photovoltaic panels is much higher in a tracking system compared with a fixed system[1]. Therefore, it is very significant and useful to study and design a tracking system.

Nowadays, the solar tracking system has been paid more attention in energy futures field. Researchers are looking for methods to obtain higher efficiency rate from the system or instruments to the algorithm. Eldin,S.A[2] ,Quesada Guillermo[3], Wei CC[4] in their papers showed us the feasibility to establish a solar tracking system in hot and cold regions or high latitudes or in the brightest region. And Khalid Md Iqbal[5]represented an off-grid tracking system with an adaptive algorithm. The system can drive the solar panel to trace the sunlight in real time. Fucai Liu [6] focused on how to enhance the reliability of a moving tracking system with STM32 main-chip. MiZhe[7] designed an open loop tracking system. These literatures above mentioned only can control single axis of the solar panel. Two-axis control is another research point for higher accuracy.

Mohammad Burhan[8] elaborated a two-axis solar tracking system with a double lens collimator solar feedback sensor and master slave configuration. Hassan Fathabadi[9] designed a novel high accurate sensor-less dual-axis solar tracking system. Among the algorithm, Gupta Ankit , Verma Deepak and SkouriSafa represented their work on MPPT algorithms. These researches are focused on the relationship between the angle, irradiation power and the position of the solar panel.

This paper represented a close-loop and adaptive real time tracking system. The system can output the maximum energy in real time with a hybrid algorithm. The paper was constructed as follows: Section 1 presented the background, the popular topics of this field and the art-to-date research algorithms. Section 2 elaborated the hybrid algorithms which were used in this system. Section 3was about how to implement the system in electric and mechanic physical hardware and how to write the host software program by Labview 2015, Section 4 is the results of the system compared with other system.

2. Control strategy

2.1. Hybrid algorithm

In order to obtain the maximum energy in each day, a hybrid algorithm was implemented according to the irradiation power which is from the illuminance sensor. If the power is above 2000 LX, that is usually mean it is a lovely day, photoelectric tracking was chosen to track the sunlight; if the power is between 500 and 2000 LX, it is a cloudy day, timing tracking was on the way. And if the power is below 500 LX, it is rainy or it is at night, angle tracking is the best one. When the algorithm worked on, the solar panel would keep 500ms at least. Figure 1 is the block diagram of the hybrid algorithm.

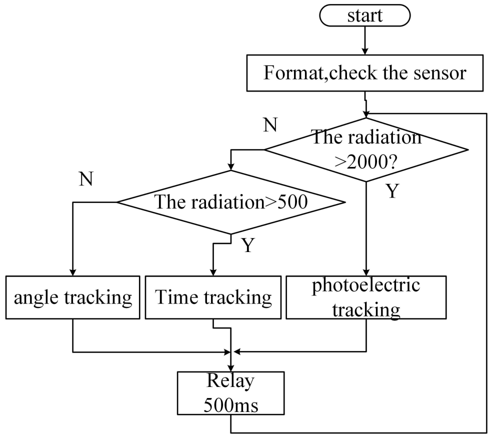

Fig. 1. The block diagram of the hybrid algorithm

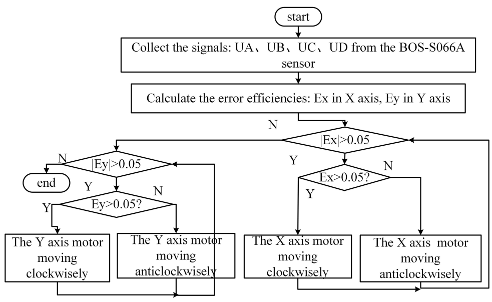

Fig. 2. The block diagram for stepper motor with a four-phase photovoltaic sensor

2.2. Photoelectric tracking key function

When the irradiation power is above 2000LX, the photoelectric tacking algorithm worked. Firstly, the signals from the BOS-S066A were obtained; it is UA, UB, UC and UD. BOS-S066A is a four-phase photovoltaic sensor, and UA, UB, UC and UD are four signals from four directions. Then the error efficiency is calculated by equation (1) and (2).

$$E_x = ((UA + UD))/(UA + UB + UC + UD) \tag{1}$$

$$E_y = ((UA + UB) - (UC + UD))/(UA + UB + UC + UD) \tag{2}$$

Where, UA, UB, UC, UD are voltages, their unit is V; Ex is the error form the X axis. Ey is the error from Y axis. According to these two errors, the solar panel was driven by the motor. Figure 2 shows how the photoelectric tracking worked. The photoelectric tracking is closed loop control. The accuracy depended on the irradiation power, if there is cloudy, the light on the edge of the sun would probably influence the output of the sensors. Therefore, sunlight must be very strong.

2.3. Timing tracking key function

Timing tracking is an open loop control, the solar panel always moved with the sun's orbit. When the irradiation power is between 500LX and 2000LX, the timing tacking algorithm worked.

Timing tracking algorithm depends on the solar zenith angle H0 and the solar azimuth A. These two parameters can be calculated in the following Equations. Firstly, calculate the distance Er between the sun and the ground in Equation 3, it is a function with the angle θ which is the angle the sun and the ground.

$$E_r = 1.000423+0.032359\sin\theta+0.000086\sin 2\theta-0.008349\cos\theta+0.000115\cos 2\theta \quad (3)$$

Secondly, calculate the sun yaw angle, it is also a function withθ.

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

In Equation 3 and Equation 4,

$$N_0 = 79.6764 + 0.2422 \times (YYYY - 1985) - INT(YYYY - 1985)/4$$

Here, N is an integer between 1 and 366. The number is the day's position among the whole year. For example, if today is Dec, 31 2017, and this year is nonleap year, N=365. If it is a leap year, N=366. YYYY is 2017, INT is the function of integer.

Thirdly, calculate the time difference Et, usually the parameter need to correct.

$$E_t = 0.0028 - 1.9857\sin\theta + 9.9059\sin 2\theta - 7.0924\cos\theta - 0.6882\cos 2\theta \quad (5)$$

The solar hour angle can be calculated in Equation 6:

$$\tau = (E_t - 12) \times 15^\circ \quad (6)$$

Finally, the solar zenith angle $\mathrm{h_0}$ can be calculated in Equation 7

$$\mathrm{sinh_0} = \sin E_d \sin\phi + \cos E_d \cos\phi \cos\tau \quad (7)$$

Here, $\phi$is the local altitude. $\tau$is the solar hour angle.
The solar azimuth A can be calculated in Equation 8.

$$\cos A = (\mathrm{sinh_0}\sin\phi - \sin E_d)/\,\mathrm{cosh_0}\cos\phi \quad (8)$$

2.4. Angle tracking key function

The system's mechanical transmission part and the microprocessor itself need power to work. But solar illumination at night or in the lower solar radiation of photovoltaic panels can absorb little absorption efficiency. In order to achieve the maximum utilization of energy, the system optimization model into the best angle of inclination when the illumination intensity is less than 500lx.

The relationship between the optimum tilt angle and latitude of photovoltaic panels can be analyzed by correlation test, and the relationship between the dip angle of photovoltaic panels and the local latitude under different surface conditions can be deduced by curve fitting method. The optimal tilt angle algorithm of the system has been quoted in Equation 9:

$$\gamma = a \times \phi^2 + b \times \phi + c \times \rho_R \tag{9}$$

When the photovoltaic panel is located in the northern hemisphere, the azimuth angle named initial azimuth is 0 degrees and there will have a maximum solar radiation received. Therefore, when the system enters the best dip angle mode, the system recovers the initial azimuth and achieves the best tilt angle, which can achieve the purpose of energy saving and efficient absorption of solar radiation.

3. System implementation

3.1. Electrical control system

The tracking system consists of seven parts: an illuminance transducer to collect the radiation power; a gyroscope sensor to gain the solar panel's position; a four-phase photovaltiac sensor to feel the sunlight's input angle's change; a X axis motor to drive the solar panel moving in X axis; a Y axis motor to drive the solar panel moving in Y axis; a hardware control unit to collect and process all signals; a software to display and interface these results. The block diagram was shown on Figure 3.

The illuminance senor is BH1750. It is a digital sensor with a two-stage serial bus interface, and the range span is from 1 to 65535LX The four-phase photovaltiac sensor is BOS-S066A. Its speculum is from 400 to 1100nM. And the peak wavelength is 940nM and the dark current is 1nA.The gyroscope sensor is MPU-60X0, it can get the solar panel's position in three dimensions in real time. But this sensor's signal cannot send to the processor, so an Arduino module was added to transmit the signal into the signal processing center

The processor is NI myRIO. In here, the signals from these three sensors above mentioned are collected, processed and controlled. All the control strategies are implemented. LABVIEW 2015 is the software language. It gives instructions to calculate, control and display the process and the results. The tow motors are the DC stepper motors, and the voltage is 24V. The real system is shown in figure 4.

3.2. Mechanical control system

To control the movement of the solar tracking system smoothly and precisely, a mechanical segment was designed. It consists of two parts of transmission mechanism: a screw mechanism to control the angle, a steering gear mechanism to control the direction. The solar panel was installed on the bracket. The bracket was connected with two hinges and a bottom bracket. When the screw rotation was driven by the motor, the photovoltaic panel would change the angle. The steering mechanism with pressure bearings was driven by a motor pinion rotating. To gain a higher accuracy, a pair of gear transmission was adopted, and the reduction ratio is 1:12.5 which guaranteed the minimum solution of the solar panel's rotation was only 0.08° .

3.3. Software design

3.3.1. software design In this system, each function has been written in a corresponding VI program. And there are 16 VI programs. Each VI program corresponds to a function. These programs carried out all the functions. To transmit data in different VI program, Shared variables technology were used shown. Compared with other existing data in the LabVIEW method such as UDP/TCP, LabVIEW queue, and real-time FIFO, this method can configure the parameters in the edit properties dialog box, it is very convenient and easy to operate. Using the Shared variables in a certain extent can solve the problems of data sharing. But when there is more than one write or/and reading behaver occurred in the same time, the server is busy and probably congested, and the system cannot work. In order to make the system long-term, stable operation, this shared variables technology use multi-element buffer type configuration.

For example, in display VI program, in order to realize the function, the altitude of the sun VI program, the sun azimuth calculation VI program, photovoltaic energy storage and control system database VI program were called. When the local longitude, latitude were input, the solar altitude Angle and azimuth VI programs would calculate the current solar altitude Angle and azimuth Angle and send these data to the Shared variables FIFO.

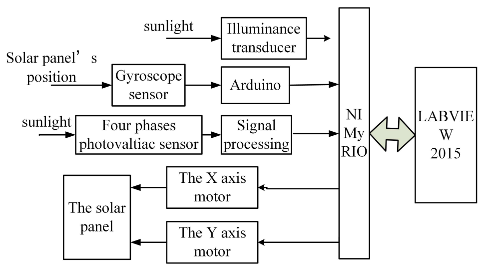

Fig. 3. The flowchart of the solar tracking system

In figure 5: 1.screw hole 2.center bore 3. big gear wheel 4.wire hole 5. pinior 6. stepper motor 7. upper part bracket 8.photovaltaic panel bracket 9.stepper motor 10.motor bracket 11.coupling 12.screw 13.hinge 14.screw nut 15.support plate 16.motor seat 17.angle bracket 18.leg

3.3.2. System test To configure the NI myRIO is the first step. NI MAX (NI) configuration management software is the tool. Wi-fi hotspots is selected to realize the NI my RIO with PC connection, and then drive motor, Arduino module, various data sensors would be detected in turns. After all devices worked, the local latitude and longitude data, longitude 121 and north latitude 38 were input into the relative

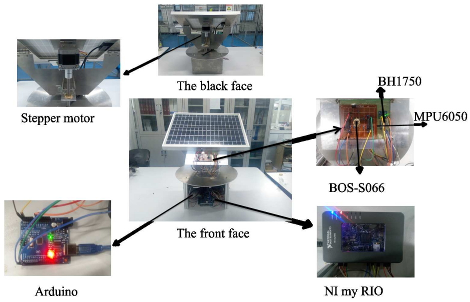

Fig. 4. The real tracking solar system

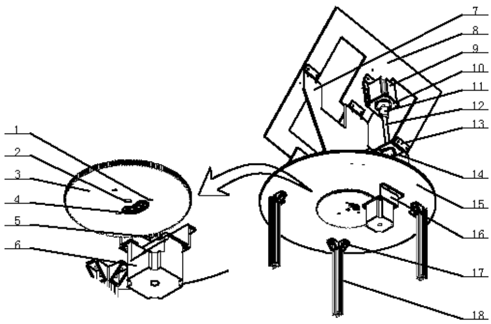

Fig. 5. The mechanical segment of the tracking system

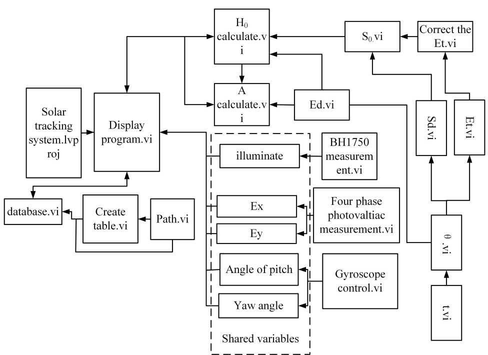

Fig. 6. The block diagram of the software

boxes for the system worked in Dalian, China, clicked the beginning button, the system would be automatic tracking the solar. After two months working continuously, the system worked well. It showed the system is successful for tracking the solar in real time.

4. Conclusion

A tracking solar system with maximum energy output was designed and implemented according to the sun illumination and light change, taking into account all weather conditions. This system is a round-the-clock with photo-electricity tracking, time tracking, and angle tracking complex solar tracking control system. This system had the functions of real-time data acquisition, processing and data storage. After tested the system, and compared with other existing solar tracking system, this design is easy to operate, remote control and higher accuracy. The system can provide theoretical guide for the perfection of the follow-up system.

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