The design of ARM-based automatic sun tracking system

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***Abstract*—This paper gives a design that using 32-bit ARM (Advanced RISC Machines) embedded microprocessor chip as a controller, to achieve the automatic sun tracking by controlling of the vertical and horizontal two directions through the program. Analyze the systematic error and experiment, results show that: the method of tracking accuracy can be up to the ±0.1° , in various weather conditions. The tracker system can steadily work and achieve the expected design performance.**

Keywords- ARM;CPLD; sun-tracking; solar energy;

I. INTRODUCTION

Increasing depletion of world energy, the development and use of renewable energy has bright prospects, as the focus of future energy question. Solar energy is the most important renewable energy source with its total quantity is large, and occurs widely. Resource depletion problems do not exist. How fully and efficiently use of solar energy is a key. The conventional solar receiving devices are usually fixed, this installation is simple, structural stability, but because of the location of the sun in the sky is changing, most of the time the sun can not direct solar receiver, the use of the sun inadequate.With fixed solar receiver compared to tracking solar receiver greatly improve the utilization of sunlight.

Accordingly, the paper designs a 32-bit ARM based embedded chip, dual-axis automatic sun-tracking system, which can achieve automatically tracking the sun with high precision in a variety of conditions.

II. SYSTEM DESIGN PRINCIPLE

The sun's rays can be decomposed into two components, one perpendicular to the daylighting panel surface, and the other parallel to the surface, only the former radiation can be received by the daylighting panel. Thus, the angle between the sun’s rays and the normal of panel what is incident angle θ should be as small as possible. Incidence angle θ changes with the diurnal variation and seasonal variation. Therefore, the fixed-installed solar collectors can not fully absorb the solar radiation energy. If at any time by automatically tracking solar collectors can adjust daylighting panel position according to the sun's trajectory to reduce the incidence angle θ, it will be able to absorb more solar radiation energy than the fixed daylighting panels in the same irradiation conditions. The daylighting panel of dual-axis sun tracking system rotates around the two mutually perpendicular shafts, azimuth shaft and elevation shaft. It will track the sun's azimuth angle ω and elevation angle γ, so that daylighting panel can achieved incident angle θ of 0.

Automatic sun-tracking system has two tracking mode: date-time calculate mode and camera mode. First of all, the date-time calculate mode is that the system calculate the theoretical value of the solar elevation angle and azimuth on a certain day at a certain hour under the laws of astronomy in the formula, and then run the control program to adjust the angle of daylighting panel to track the sun. Camera mode is that the system use a image sensor shooting the projection of sun through the convex lens on the panel, the system then calculates the deviation value between the center of projection and the center of panel, and then run the program to adjust the elevation angle and azimuth of daylighting panels to track the sun. The date-time calculate mode works regardless of weather or stray light interference, with high reliability, but the process in the calculation of the sun angle will produce errors, thus affect the tracking accuracy. Contrarily camera mode has high sensitivity, but is easily interfered with the external environment, the system reliability is lower. So you can see two methods are highly complementary. Combination of two methods can avoid outside interference by the greatest degree, but also modify errors that produced by theoretical calculation to improve the reliability of automatic tracking device and tracking accuracy.

At the running time, the system collects GPS and image data once per minute. According to GPS information, it access to the local time、latitude and longitude, and then calculate the sun's azimuth angle ω and elevation angle γ of the next minute and $\Delta\omega$, $\Delta\gamma$ of the difference between the current position. For image data, using the appropriate algorithm find the center of the sun projection. The sun projection as shown in Fig.1:

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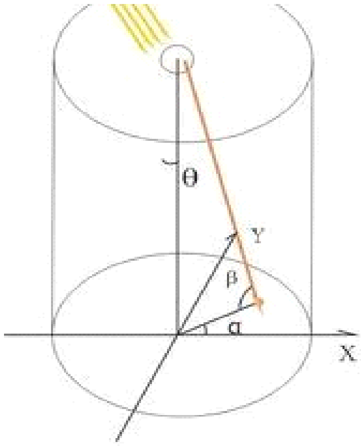

Fig .1.Camera image of the sun projection

When the angles α and β are zero, the center of sun projection has been superimposed on the centre of panel, and at the same time the incident angle θ is zero too. It means that the tracking is successful. In this sense, α and β can be considered as the error of the trace a minute ago. So that, the azimuth angle and elevation angle the system needed to move in the next minute are $\Delta\omega+\alpha$ 、 $\Delta\gamma+\beta$ .Finally, according to stepper motor and mechanical gear ratio, the system calculates the output pulse number and pulse frequency.

III. SYSTEM HARDWARE DESIGN

The system hardware modules, including MCU 、 camera 、 GPS 、 EEPROM and stepper motor signal output five parts, as shown in Fig.2 .

The system's MCU is used in NXP's ARM7 family LPC2294, this chip is based on a 16/32 bit ARM7TDMI-S™ CPU with 16 KB on-chip Static RAM and 256 KB on-chip Flash Program Memory, together with two 32-bit timers (with 4 capture and 4 compare channels) and additional serial interfaces include two UARTs, Fast I2C (400 kbits/s)., fully meet the system requirements.

GPS chip sends the GPS data to the MCU in serial communication wi ... e stepper motor pulse signals are di ... O interface.

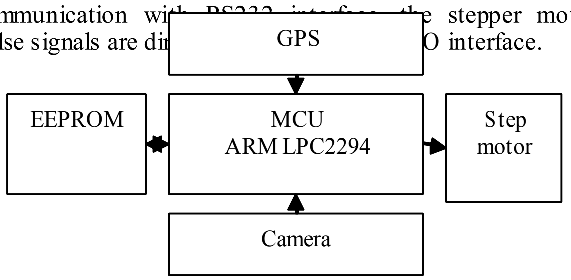

Fig .2. System hardware modules

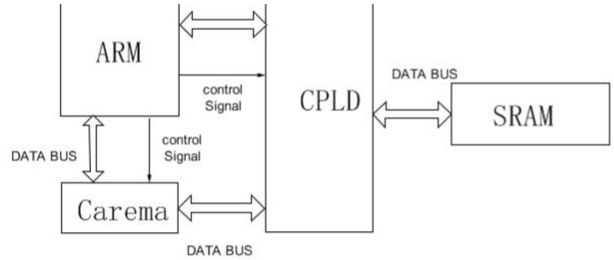

Fig .3. System hardware modules

The CPLD chip is for the realization the COMS camera timing, and extends an SRAM to save the image data. ARM read and writes Camera registers by I2C. CPLD also has a function of the realization of data and address bus switch between the camera and SRAM, ARM and the SRAM, so ARM can access the image data by only accessing SRAM. This workflow makes a lot of good Advantages. The important thing is that ARM can be free from the monotonous time-consuming data reading process and concentrate on angle calculation and correction. Sram1 and sram2 were stored image data of current time and the next moment .ARM access the two memory storage alternately which can read the results in real time. The system achieves the control of handshake between the CPLD and MCU through I / O port lines, as shown in Fig.3.

IV. SYSTEM SOFTWARE DESIGN

When system running, the first thing is determining whether it is in the normal working hours, if not the system doesn't start until the working hours, otherwise, the system starts tracking. When tracking begin, the system first takes GPS information to calculate the sun's azimuth angle and elevation angle of the current time, then serve these angles as targets to move. After achieving the target location, the system will collect the GPS information and image information every one minute. Using this information to calculate the next position, it begins the next minute tracking. And so on until the end of work time reaches. Finally, when this day is over, the light board backs to the initial position to wait for the next day.

The following highlight is the processing of the image information which is an important work that decides the tracing precision. After an image being collected, the system will select one of the brightest pixel points and determine whether the brightness of it is lower than the lowest brightness. If it is we can consider that now is cloudy or there are some interference signals, and go on without image processing. Otherwise, set this pixel as a threshold value and treat all the pixel data by binarization processing, so come to a bright and dark spots binarization image. Then calculate the center of the graphic formed by all the bright spots. We believe that this is the center of the sun projection. Finally, calculate α and β.

System flow chart is as Fig.4:

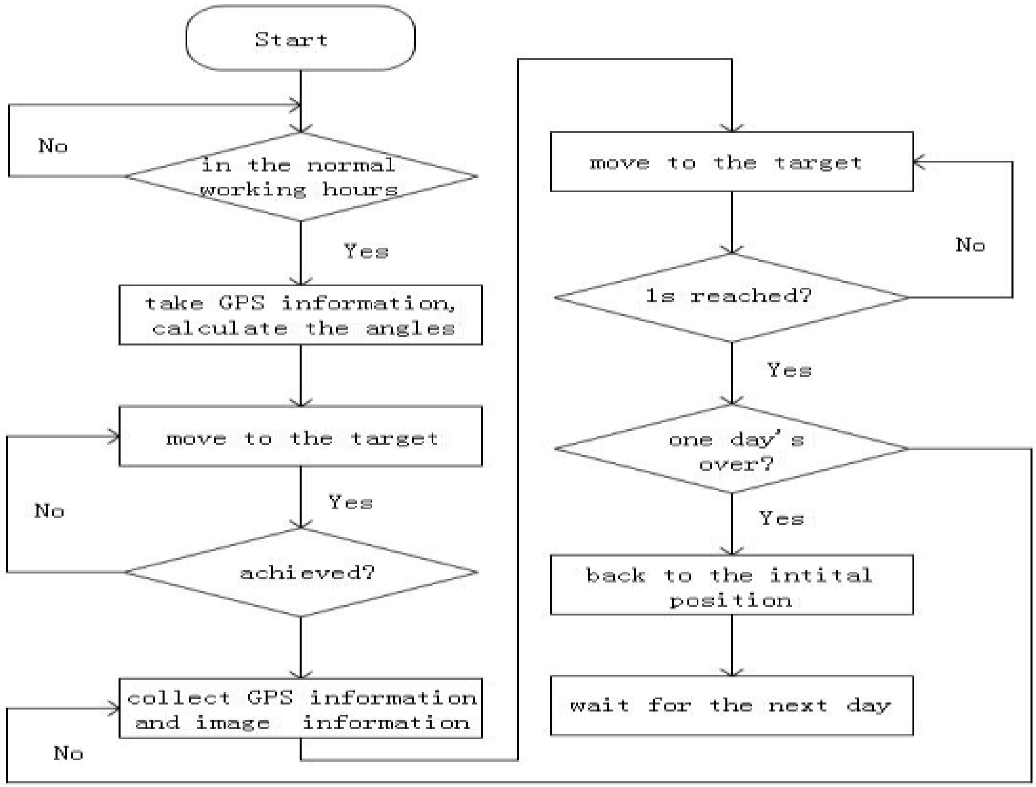

Fig .4. Flow chart of software

V. EXPERIMENTAL RESULTS

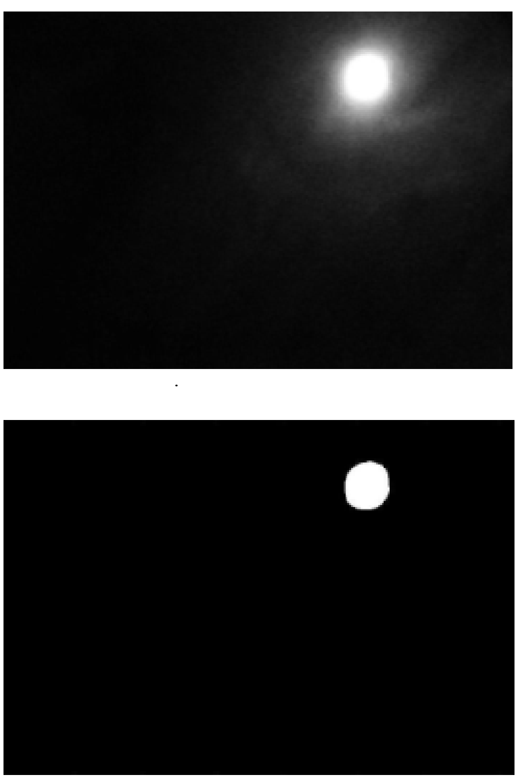

Fig .4. The binarization image

As the LPC2294 hasn't LCD module, so in order to test the effect of image processing, send the original image data and binarization image data to the post-PC and the received data are saved as bmp images.

The spot in binary image is clearly and marked, and shows a good agreement with the sun projection. This shows that finding the sun projection center by binary image is feasible.

To test the system's tracking performance and accuracy. We set a reference system. A straight bar is established in ground with x-axis and y-axis. X direction share the same direction of system initial direction (east-west direction). This reference system placed next to the tracking device. So the angles of sun's rays they received can be considered the same. Suppose that the length of straight shadow in the sunlight is m. The angle between shadow and x-axis is λ. So at this moment the sun's azimuth $\omega = \lambda$, the sun's altitude

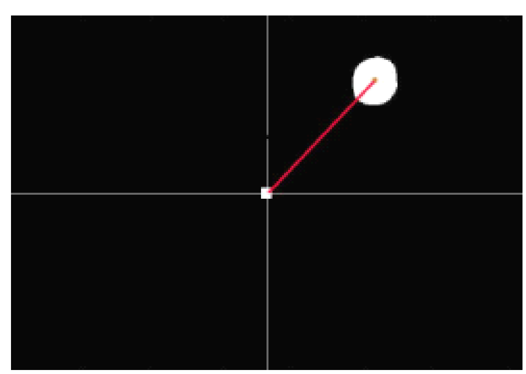

Fig .5 The center of spot and center of image angle $\gamma = \arcsin(\frac{l}{\sqrt{l^2+m^2}})$.The sun's azimuth angle and elevation angle that the sun should appear in theoretical point in next minute are respectively ω_1、 γ_1. We can get them through the date-time calculating mode and camera mode : $\omega_1 = \Delta\omega + \alpha$ and $\gamma_1 = \Delta\gamma + \beta$. Record the next minute length of straight bar l and angle of the shadow λ in the next minute. From the formula we know $\omega_2 = l$ 、 $\gamma_2 = \arcsin(\frac{l}{\sqrt{l^2+m^2}})$. Tracking precision can be obtained by comparison of ω_1 、 γ_1 and ω_2、 γ_2. In this experiment, we have gathered two sets of data recorded in the morning, every set include 30 collection points respectively, as shown in Fig.6 and Fig.7.

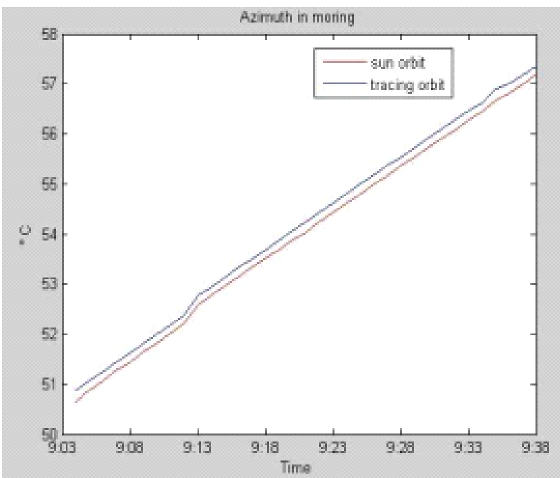

Fig.6 . The azimuth in the moring

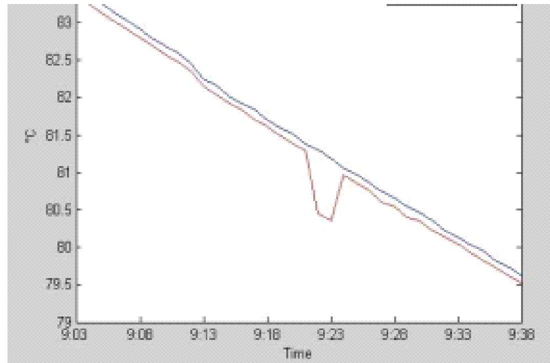

Fig.7.The elevation angle in the morning

From the experimental data above, we can get that the deviation is up to the ±0.1°. The dual-axis sun tracking control system which using the date-time calculating mode and camera mode works highly efficiently. The system can solve the problem of low utilization of solar energy.

Test result indicates: the sun tracking control system is stable and reliable, which can be used in power generation device, solar cookers, solar dryers and other devices. It has popularization value and wide application prospect.

REFERENCES

[1] Ren hongshen and Chen xiaofu,The Technology of Solar Cooker,1st ed.,Chemical Industry Press,September2006,pp.7-8

[2] K.K. Chong,C.W.Wong,"General Formula For On-axis Sun-tracking System And Its Application In Improving Tracking Accuracy Of Solar Collector",Solar Energy,200983(3).

[3] LPC2294 USER MANUAL, Philips Electronics,2004 May 03.

[4] Xiang Ping,Bi Yuqing,Cheng Jianmin,Chen Fang,"Design of a Sun-tracking System Based on ARM",Northwestern Polytechnical University,COMPUTER MEASUREMENT & CONTROL,2009 17(6).

[5] Muneer Al Sabbagh,Ahmad Al Nabulsi,Rached Dhaouadi,Habib-ur Rehman,"Design and Control of a Novel Sun Tracking System",2009 IEEE 6th International Power Electronics and Motion Control Conference-ECCE Asia.