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Research on Portable Traditional Guide-Star Embedded System

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Abstract

The target object must stay in the permanent position within telescopic field of vision during the long-playing exposure of astronomical photograph; otherwise it may blur the picture. For this reason, the telescope has to track the target objects precisely in a long time. So the function of guiding star is necessary: Due to the level of accuracy of the equipment or the Polar axis, the telescope sometimes fail to track the target object precisely during the long time tracking process while the guiding star helps to adjust the telescope through monitoring the movement of the target object so that it remains a certain position within the field of vision. But the function of guiding star above is based on PC equipment which is very expensive, heavy and high power consumption. So a new study is to design a cheap, high-performance and portable embedded guide-star system to discard the previous operating system which is expensive and difficult to operate which has to run on a PC on which is installed the specific guiding star CCD..

Keywords: Guide Star; Embedded System; Track Star.

1. Introduction

Celestial bodies will be present as the original look as the enough brightness of the long-time exposure with the photographic device while the target star has to keep the fixed position in the visual field of the telescope since the most stars are very dim, otherwise the image will be blurred. So the target stars are tracked precisely by the telescope but it's very difficult because the position of the stars in the sky is changing more obviously as the multiple of the telescope is improved with the smaller visual field because the earth revolves on its own axis. Then the guiding star is necessary: the telescope is automatically adjusted through monitoring the movement of the star as the telescope can't track precisely the star because of the bad mechanical precision and the deviation of the polar axis in the long-time tracing. It is very necessary that the guiding-star function based on the tracking equipment is more important for a small and rough telescope in the observation of stars in the deep space.

Guiding-star is equal to replace the motion of human to adjust the direction of the telescope constantly. For example, the control system will adjust the telescope to move up when the position of the star move down in the visual field. The whole control process is automatic to be detected and operated more accurately and more efficiently.

2. Introduce of the mainstream scheme of guiding-star

The equipment and the accessories of guiding-star will be first introduced.

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Guiding camera is used to get the image connected with the guiding telescope as human's eyes. The professional guiding CCD must be reduce thermal noise to improve signal to noise ratio to get good quality of photos or added the interface function of guiding star to resolve the command from the guiding software sent to the device controlled by the telescope, so the price is usually higher.

Guiding software will process image sent from the guiding camera to control the command to send to the control end of the telescope for calibration through monitoring the movement of the star. A computer is running this guiding program and high-capacity mobile power is necessary for long-time running in the open accordingly.

The equatorial telescope is made to improve the shortcoming of horizon equipment for overcoming the negative effect of earth rotation for the observation of stars. The coordinate system of the equatorial telescope is the equatorial telescope coordinate system which is equal to a big network which is rotating with stars. It is that the equatorial telescope is just equipment following with the sky rotation, so it includes two axes of vertical each other: the right ascension and the declination axis. The polar axis has to be regulated that the rotation axis of the equatorial telescope is parallel with the earth rotation axis.

The control equipment of the telescope is designed to realize mechanical control of the telescope for higher efficiency and precision through the motor on the mechanical control since the manual control to the equatorial telescope is very difficult to make a great impression.

At present the mainstream scheme of guiding-star at home and abroad is to get the image through the special guiding CCD camera which is sent to the guiding software such as GuideMaster, PHD and so on at the terminal PC which will send the corresponding command to tracking equipment for correction as seen in Fig.1, but this plan has two shortcoming: costly guiding CCD camera and PC on the person.

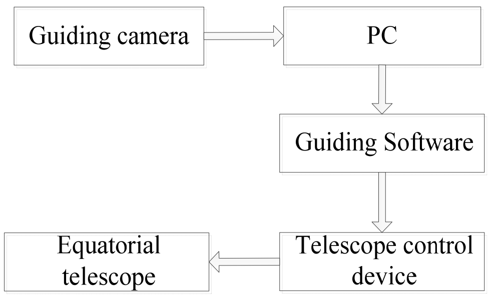

Fig. 1 Traditional Guiding-star Scheme

The key point of this design is convenient and simple to realize guiding-star with STM32 the embedded system as the control center instead of PC and AVR as the master control chip at the telescope control end is used to develop a telescope mechanical control equipment to realize looking for stars automatically, tracking automatically, adjusting telescope through hand shank and so on that is especially fit for observing stars in the open and reducing weight of the guiding equipment which is a necessary factor of the star observation in the field especially on the tops of very high mountains that is the only shortcut since it is very difficult to observe stars in the city where light pollution is very serious to cause observation more difficult and more cost to eliminate negative effect of city light harm with the light filter.

3. Hardware Scheme

A STM32 chip is used as the system control part because it's cost effective on which μC/OS-II can run for multi-tasks will swift and work efficiently.

Two parts is around STM32 which is the guiding-star part and telescope control part. The guiding-star part includes STM32 microprocessor module, guiding CCD camera module, TFT touch display screen and so on. The telescope control part includes AVR main control chip, motor and motor drive module, LCD display module and so on.

STM32 embedded system will get images from the OV7725 camera and view them on the TFT touch screen right now that are processed and calculated coordinates for tracks which are sent to AVR embedded system as the control terminal of the telescope to control motor to move a fit distance for guiding-star as seen in Fig. 2.

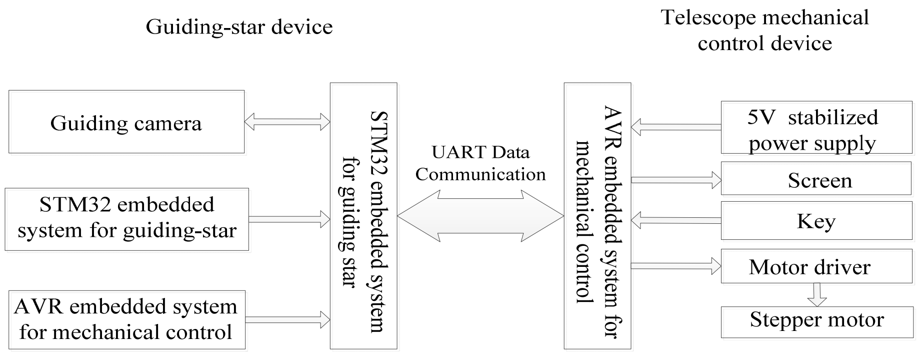

Fig. 2 Hardware Scheme

This system is designed two part but not all in one because the telescope control equipment will control the telescope to find and track stars which is used enough in low precise occasion, whereas guiding-star is more precise to track stars which belong to an alternative equipment for higher consumer layer.

4. Software Design

As beginning the star observation, the telescope control equipment will let the right ascension of the equatorial telescope running as a certain speed for an approximate tracking, and now guiding-star is working. The guiding camera gets the real-time image that is processed by the STM32 chip and the command is sent to the stepper motor driver to drive the stepper motor running at the prescriptive speed for correction through changing the direction of the right ascension and the declination of the equatorial telescope. At last the guiding camera shows the effect of star moving through the monitoring telescope moving for correction in circles.

The guiding-star part and telescope mechanical control part will be discussed in detail.

4.1 Guiding-star tracking algorithm

It's very necessary to adopt the effective image recognition because of real-time guiding-star led to adopt binarization processing method which assumed a threshold value that is compared with a data got out from the buffer. This objective is considered stars if the pixel value is lower than the threshold value, or it's the background of sky that will not be processed as seen in equation 1.

$$Z(x,y)=\begin{cases}A & F(x,y)\le Value\\ 0 & F(x,y)>Value\end{cases} \qquad (1)$$

The method is relatively simple but it's very bad performance of anti-interference, e.g. A sudden light will lead to the failure of guiding-star. But this method is used for some reason below:

It's not fit for star observation while the interference of any other source of light, e.g. the color of the background of the picture is inclined to be red or white or overexposed when it's cloudy. So it's unnecessary for guiding-star.

It's unnecessary to get out all the data to compare with the threshold value but only get the data around the real-time coordinate of the star.

The position of the star will not change violently. The telescope avoid rocking wildly during guiding-star because the control system can't find the star round the real-time position beyond the detecting range and it does't make sense since the shot picture is dim. So the stabilization of the telescope is very important.

The threshold value is the ruler to distinguish the objective and the background by making a judicious selection for recognition of the useful image information and reduction of the interfere of background and noise. The star shining in the back sky at night will be easy to be judged for the specialization of the sky. So a confirmed threshold value is set because of the experience and tests in long time before binary image processing.

4.2 Program Design of the telescope control part

The part will mechanically control the telescope to find stars (GOTO), track stars, operate manually and respond to the received command as seen in Fig. 3. The software will be explained how to designed in detail.

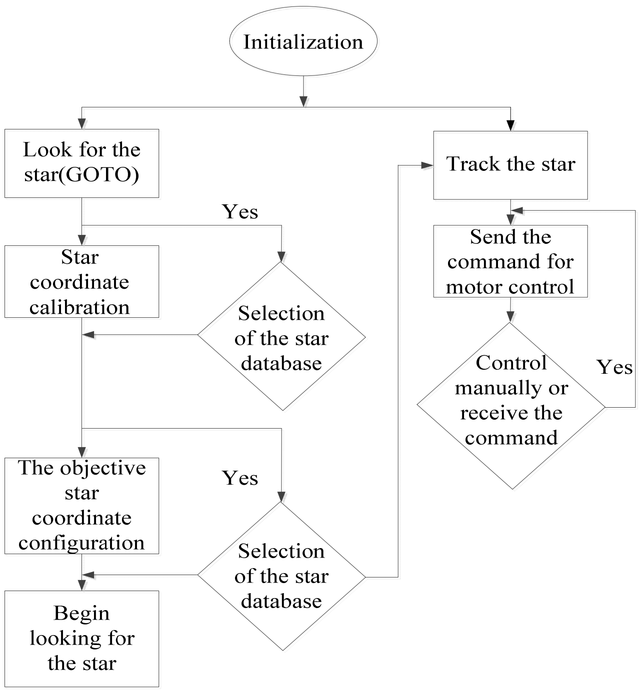

Fig. 3 Telescope Control Program Flow Chat

4.3 Finding star(GOTO) theory

The objective star must be found by the telescope at first before tracking the star. Traditionally, the direction of telescope is adjusted manually if the objective is observed in the visual field of the telescope that is a un-efficient method. The reason is as follow:

1. The visual field became smaller with the telescope magnifying the object many times that led to the fast movement of the star with a slight adjustment.

2. The rough direction is confirmed through the bright star around on the observation then to look for the objective star, but the visible stars by eyes is becoming more and more rare with the more light pollution in city. So it’s more difficult to find the star in the dim sky by eyes.

3. The number of the visible stars by eyes is about 7000 in a fine night with little light pollution that is very difficult to find a star with a man unfamiliar with the star map.

This design with an intelligent method looks for an objective star with the telescope driven by the stepper motor. How is a star positioned by the telescope automatically? A simple method is used: one star position is as follow:

The position of all stars in the sky is confirmed as the only the right ascension coordinate and the declination one with the equatorial coordinate system. For example, the Crab Nebula (M1) will be observed which coordinate is: the right ascension coordinate (RA):5h34m30s,the declination coordinate(DEC):+22°01’00’’. The star is magnitude-8.4 that can’t be seen in the city, but Sirius is very easy to find which brightness is -1.45 which coordinate is: RA:6h45m8s, DEC:-16°03’01’’ that differs from RA：-2h49m22s,DEC:+38°57 ’59’’ which is calculated to control the telescope to turn the corresponding angle and direction.

1. Angle Confirmation

The angle confirmation must be combined with the hardware design. For example, the right ascension coordinate is driven by the 6-phase 6-line deceleration stepper motor which stepper angle fraction is 1.8°, speed down ratio 1/7.2, and the right ascension 130 teeth with the turbine worm type. 2 gears is connected with the stepper motor and the equatorial telescope for transmission. The stepper motor subdivision driver is set 16-subdivision.

So, the angle which the stepper motor will rotate with one pulse is 1.8/7.2/16=0.015625°. The number of the pulse for the motor rotating a circle is 360/0.015625=23040. The number of the pulse for the right ascension rotating a circle is 23040*130=2995200. The number of the pulse for the right ascension rotating 1° is 8320.

Then the distance between 2 stars in the right ascension is $\triangle RA = h * 15 * 3600 + m * 15 * 60 + s * 15$ while the total number of the pulse for the right ascension is shown:$RA\_pulse = \triangle RA * 2.311$. At last the angle for the telescope rotation will be calculated with the above formulas. The angle of the declination axis rotation is the same principle.

2. Direction Confirmation

At first the pole axis of the telescope is adjusted to parallel with the Earth rotation axis which is parallel with the right ascension of the equatorial telescope and perpendicular to the declination axis.

According to the definition of the above direction, the right ascension axis will be adjusted west if the value of △RA is a positive number and east if △RA a negative number. The declination axis will be adjusted south if the value △DEC is a positive number and north if △DEC a negative number.

4.4 Tracking theory

Stars will move out of the visual field if the telescope keeps static because of the earth rotation on its axis which causes the sun, moon and stars rise from the east and descend from the west. Tracking automatically will eliminate the effect of the earth rotation on its axis which the right ascension of the telescope rotates at a certain speed for the objective in the center of the visual field of the telescope with high precision of the pole axis for tracking accurately , but it's very difficult for the pole axis calibration and very hard for the star to stay in the static place with the great influence of the observation equipment. So it's very necessary for tracking accurately with guiding stars and adjusting automatically in the real time.

The period of the rotation of the Earth with 23 hours 56 minutes 4.0916 seconds is a sidereal day. The right ascension axis of the telescope is controlled to rotate at the same speed with the Earth and in the reverse direction that is eliminated the effect of the Earth rotation on its axis.

The right ascension coordinate and the declination one is controlled to change the direction with the buttons after coming into the tracking state and the command sent from the guiding-star device or the computer. A speed configuration button is set on the right side of the control box of the telescope to achieve 1x, 5x and 10x speed configuration.

5. System Test

The test for the function of the guiding-star and performance is selected in the clear sky since the environment and time will affect the result of the test.

5.1 Function Test

This test is for tracking an objective star in the long time and guiding the star steadily.

The test process is as follow:

1. The telescope has to be adjusted directly at the pole axis and tested the control device running normally before guiding stars, then the primary mirror and guiding-star frame is set up with the guiding-star camera contacted with guiding-star mirror. All were normal and the objective star is found by the "finding-star" program that is tracked by the "tracking-star" program.

2. The sender for the guiding-star command is connected with the receiver of the telescope by the USB line to send and receive data.

3. Guiding-star began after a fit star found by the guiding camera for guiding with the others prepared. The test keeps 10 minutes while the star stays in the same position statically. After 30 minutes and 1 hour, the objective star is still in the same position of the center of the screen so it is shown that the function of guiding-star has been realized.

5.2 Performance Test

It is very important of 2 parameters of guiding-star that is star magnitude and guiding fluctuation which adjustment scale cannot too large to shoot blurry pictures. 2 Test for these reasons is as follow:

1. The sensitivity test of the guiding camera: The star magnitude observed by the camera is 5 through the comparison between TFT display screen and the star map.

2. The fluctuation test for guiding star: A PC program is designed for this test to collect the data for any fluctuations in movement stored in the database to generate the movement diagram of the right ascension coordinate and the declination one.

Fig. 4 is shown that the movement of the right ascension around the base line of 5. For example, one is added if the guiding mirror is moved east, or one is be subtracted if the guiding mirror is moved west. The guiding effect is bad if the fluctuation is too large. Fig. 5 is shown that the movements of the declination around the base line of 5 like Fig. 4.

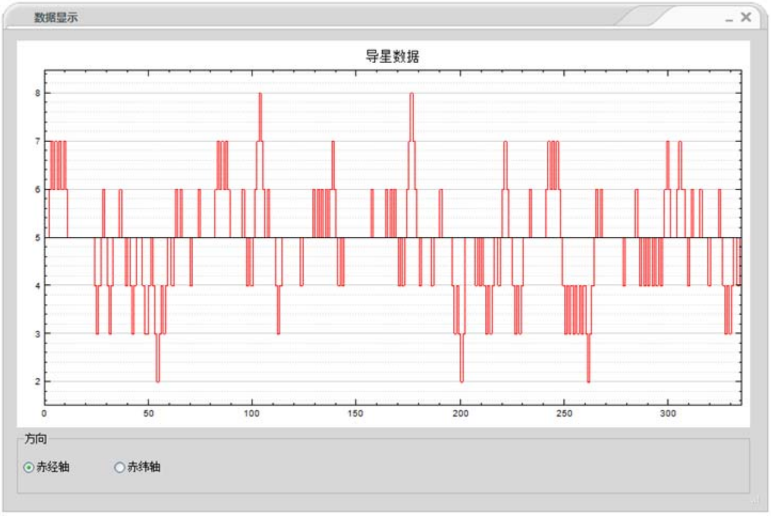

Fig. 4 The Right Ascension Movement Diagram

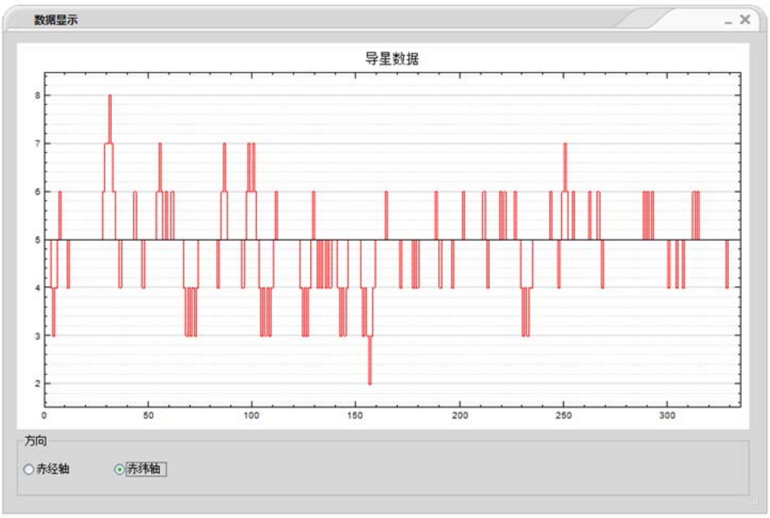

Fig. 5 The Declination Movement Diagram

6. Result Analysis

The result of the test showed that the objective star remained in the fixed position of the visual field. From above results, the following conclusion was drawn.

It is the longest time when the objective star keeps in the static position since the probability at the base line 5 is the largest.

The adjustment process of the declination axis is more smooth than the right ascension.

The adjustment of the right ascension moves more frequently than the declination one related to the performance of the equatorial telescope and the control device or the preciseness of the pole axis. The frequency of the adjustment will be rounded up if the performance of the equatorial telescope and the control device is poor.

The probability of the number of 8 is very small that means the fluctuation is little, so this system can meet our requirements basically.

7. Conclusion

A new cheap and portable guiding-star device is designed instead of the traditional guiding method with a telescope control device with AVR single-chip at its core to realize a real-time feedback uniformity to improve the convenience of the observation and precision.

The key point of this design is the recognition and tracking of stars in the night sky which is distinguished stars and the background image with the binarization algorithm, then the star is tracked indefinitely and the regulation command is sent to the telescope control device through the comparison the real-time coordinate with the reference coordinate.

A function and performance test is designed to prove this guide device satisfactory.

The next step a better guiding camera, stepper motor and bigger TFT screen will be changed for seeing further and observing more dim stars.

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