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Star detection and tracking algorithm of autoguiding

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Abstract: The basic principle of autoguiding was introduced in detail, which included the proper star selection and tracking algorithm. Considering that the star energy distribution in the image was approximately Gaussian distribution, a reliable target star selection method was proposed. The algorithm analyzed a threshold value of the image firstly, and then a number of candidate stars were detected according to the threshold condition. The target star was selected from the candidate stars by guiding criterion. Finally, the centroid coordinate of the target star was calculated through Gaussian fitting. The accuracy of the target star detection and calculating speed were both improved, the experimental results showed that the proposed algorithm can achieve a good autoguiding performance.

Key words: star tracking; star selection; autoguiding

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自动导星星点检测及跟踪算法研究

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摘　要: 详细介绍了自动导星的工作原理,对自动导星的星点检测及跟踪算法进行研究,结合星点能量在星图上分布近似高斯分布的特性,提出一种稳定可靠的目标星点提取算法。算法首先分析了星点目标的阈值判断原则,根据阈值条件确定一定数量的候选星点,然后在候选星点中筛选出最优的目标星点,最后通过高斯曲线拟合的办法求取最优目标星点的质心坐标。该方法提高了目标星点提取的准确性和计算速度,实验结果表明:改进后的算法能够达到良好的效果。

关键词: 星点追踪; 星点检测; 自动导星

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0 Introduction

In the deep sky astrophotography, in order to offset the phenomenon of the movement of stars caused by the Earth' s rotation and eliminate stars cable resulting from enough exposure time, equatorial is used to drive the telescope to move in the opposite direction of the Earth's rotation so that the real-time tracking of stars can come true. The method can achieve a good result at the same time. However, the equatorial rotation rate is not exactly the same as the Earth, because of its production and installation errors[1].

The equatorial cannot correct errors mentioned by itself. In order to improve the tracking precision, two cameras are often used in tracking photography, a main camera and a tracking camera. The tracking camera can view the brightest star on account of its characteristics, including short exposure time, short telescope's focal length, small relative aperture and a large field of view. Tracking the brightest star in the relatively large field of view can compensate the gap quickly, which makes a good result in deep sky photography.

Specific approach is as follow: Firstly, the star images are captured by CCD fixed behind the guider. Then the computer will deal with the real-time images. When the shift of tracked target star is detected, the offset will be calculated and transmitted to the equatorial as feedback. Then the equatorial will correct the tracking error, to achieve the goal of real-time tracking. In autoguiding algorithm, target star point extraction and centroid location are the key steps. The recognition accuracy of target star and the precision of centroid coordinate calculation directly affect the final equatorial tracking accuracy.

In the traditional star detection process, all the stars in the image are detected. This method is a waste of time. To improve the calculating speed, combined with the practical application of autoguider, a new target star point detection algorithm is proposed, which considers the brightness, size and position of the stars in the image.

1 Introduction of autoguiding procedure

Autoguider works through real-time detection of the position of the target star to achieve the star tracking. As shown in Fig.1, under the conditions of long exposure, CCD transfers the captured star image to a computer, the computer automatically selects the optimal picture as the tracking target star, and then calculates the target star centroid coordinate, compared with that of the same star in the initial picture. If offset occurs, the computer sends the offset to equatorial to drive the lens to rotate corresponding to the offset. So real-time tracking is achieved.

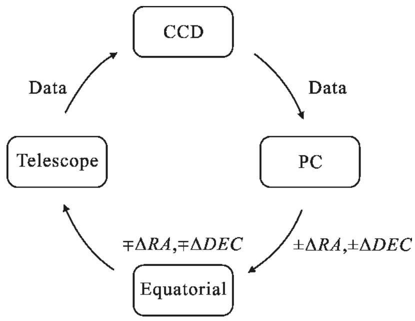

Fig.1 Flow chart of automatic guide

Assuming that the tracking target star is in a coordinate axis composed of RA and DEC, and the centroid coordinate of the tracking target star in initial image is ($\mathbf{RA_0}$, $\mathbf{DEC_0}$), so in the equatorial track target star process, the real-time coordinate of the target star can be expressed as($\mathbf{RA_0 \pm \Delta RA}$, $\mathbf{DEC_0 \pm \Delta DEC}$), ± represent the directions of the offset respectively, $\mathbf{\Delta RA}$ and $\mathbf{\Delta DEC}$ represent offset. If $\mathbf{\Delta RA}$ and $\mathbf{\Delta DEC}$ are not equal to zero, the offset and direction will be transmitted to a computer, then the computer sends the offset to the equatorial to make it move to the opposite direction. Therefore, the equatorial can correct the tracking errors.

2 Extraction and positioning of target star

The detection of star is the key step of auto guider system. Generally, star detection is mainly divided into two parts: star detection and centroid localization. The common star detection techniques are mainly connected component labeling method, gray cross projection[2-3] and so on. Star centroid extracted is mainly based on two factors, grayscale and edge. The edge-based method mainly includes edge circle fitting, Hough transform, etc., this method is suitable for large target. Grayscale-based method includes centroid, surface fitting etc., this method is more suitable for small and gray uniform target. Star targets are generally small, more suitable for the method based on grayscale.

The traditional star detection algorithm always executes threshold segmentation before detection. Allowing for that deep sky pictures taken with less noise, a high contrast ratio between background and target star area, in order to reduce the algorithm step and improve the detection rate, this paper adopts the dynamic box search method[4] to directly detect the star on the star image after filtering processing without binarization.

2.1 Star detection

In the traditional star detection process, all the stars in the image are detected. Combined with the practical application of auto guider, it only needs to find one star as the tracking target, which is called optimal star.

In order to extract the optimal star quickly and accurately, a certain number of brighter stars are selected as candidates. In deep sky astrophotography, the darkest magnitude that human eyes can differentiate is generally the sixth magnitude, which is an area of greater than or equal to 3×3 pixels in the star image. Firstly the stars that meet the above conditions are selected as candidates, and then the optimal star can be found among the candidates.

2.1.1 Star energy distribution characteristics

Star point can be seen as a point light source at infinity, so the image on the photosensitive surface of the image sensor can be regarded as a point-like spot in dark background .This energy distribution of the point-like spot approximate Gaussian distribution[5], so the star center is the energy peak[6]. For the brighter star point, its average value is much higher than noise average value, while for dark star point, its energy value is close to or smaller than the noise point energy value, so it is difficult to calculate the centroid coordinates accurately. These stars are not generally treated as the target stars.

2.1.2 Threshold determination

The threshold of star detection means effectively distinguishing star from the background and filtering out noise, and it is useful to identify the target star. The principal contributors to the background signal noise are typically: read noise, inhomogeneity of the dark current, and the dark current noise itself. It is possible to estimate the background noise as the standard deviation of all pixel values in a dark frame[7]. In consideration of the background noise, location of the target star in the real star image are constantly changing, gray average value and standard deviation of the image are considered as a threshold reference factors, an adaptive threshold selection method is chosen as the star point detection standards, the expression is:

$$\mathbf{V}_{th}=\mathbf{E}+\mathbf{k}\delta \quad (1)$$

Where $\mathbf{E}$ is the mean value of the pixels; δ is the standard deviation of the pixel values; $\mathbf{k}$ is a weighting coefficient, usually associated with the image noise, desirable 3-5[8].

2.1.3 Star detection algorithm

The dynamic search box can achieve the star extraction. However, this algorithm is more suitable for single-star detection, while for multi-star detection it is complex. In this paper, drawing on the basis of the above algorithm, an algorithm more suitable for detecting target star under multi-star condition is proposed.

The energy distribution of star is similar to Gaussian distribution, so finding the grayscale peak of star area is equiva lent to detecting the energy distribution of the center point. Firstly finding the energy center,, and then taking that point as the center and connecting the outside by square window, Dynamic search box is shown in Fig.2.

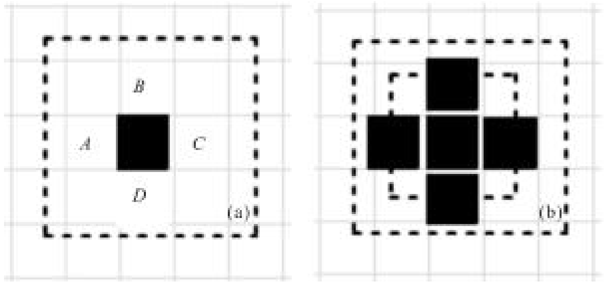

Fig.2 Schematic diagram of Dynamic search box

Taking 3×3 window for example, calculating the average gray value of **A**,**B**,**C**,**D** in the window, if the value is greater than the threshold, this area is considered belong to the target area, and then expanding the scope of the window until you find the area that doesn't meet the condition, and finally recording the center coordinates and window size of the region. The window whose effective area is smaller than 3×3 is considered as noise area. At the same time,the overexposure condition may result in bright spot which will affect the selection of the optimal star, so the area larger than the size of 15×15 is considered as a noise point, which will be removed. Finally the center coordinates and window size of the star that meet the condition are saved as candidates tothe final target star extracted.

2.2 Detection and centroid localization of target star

After the above steps, some interference noise points are exclued, so it is possible to quickly extract the target star.

2.2.1 Detection of target star

Generally, the star with bigger area, higher brightness and closer to the central field of view is detected as optimal. The part of 2.1 has already detected the candidate star group and saved the center coordinates and window sizes. In the process of extracting the optimal star, considering the regional average energy and size of the region, whether it is closer to the center of the field of view and some other factors, an optimal star point criteria is presented:

$$\mathbf{T}=k_1\mathbf{R}_1+k_2\mathbf{E}+k_3/\mathbf{R}_2 \quad (2)$$

Where $\mathbf{R}_1$ represents the radius of the star area, **E** is the average grayscale value of the star point area, $\mathbf{k}_1$, $\mathbf{k}_2$, $\mathbf{k}_3$ respectively stand for the weighting coefficient. $\mathbf{k}_1=0.3$, $\mathbf{k}_2=0.3$, $\mathbf{k}_3=0.4$. $\mathbf{R}_2$ is the distance between the target star center and the center of the field of view.

2.2.2 Centroid coordinate calculation

Because the star energy distribution is similar to Gaussian distribution, the traditional centroid algorithm could not obtain high accuracy. Gaussian fitting method can achieve a better result in calculating centroid coordinate.

Based on **n** a point light source law which is generally symmetrical two-dimensional Gaussian distribution, Gaussian fitting extracts the coordinates of the center point of the target star. Imaging feature of point light source is highest pixel gray value in the center, the nearer to the edge the smaller. So Gaussian surface fitting can fit the digitized target star, and then determine the target star gray center position.

Gaussian fitting equation can be expressed as:

$$f(\mathbf{x},\mathbf{y})=\mathbf{A}\times\exp\left\{-\frac{1}{2(1-\rho^2)}\left[\left(\frac{\mathbf{x}-\mathbf{x}_0}{\sigma_x}\right)^2-2\rho\left(\frac{\mathbf{x}}{\sigma_x}\right)\left(\frac{\mathbf{y}}{\sigma_y}\right)+\left(\frac{\mathbf{y}-\mathbf{y}_0}{\sigma_y}\right)^2\right]\right\} \quad (3)$$

A represents the maximum of Gaussian surface that is related to the level of star, the higher level, the brighter it is. $(\mathbf{x}_0,\mathbf{y}_0)$ is the center of Gaussian function, σ_x and σ_y are the standard deviation of x-axis and y-axis; ρ is a correlation coefficient. To simplify calculation, often let $\rho=0$, $\sigma_x=\sigma_y=\mathbf{B}$, So the equation can be expressed as:

$$f(\mathbf{x},\mathbf{y})=\mathbf{A}\times\exp\left(\frac{-\mathbf{r}^2}{\mathbf{B}}\right) \quad (4)$$

B stands for the size of the light spot, $\mathbf{r}^2=(\mathbf{x}-\mathbf{x}_0)^2+(\mathbf{y}-\mathbf{y}_0)^2$, $\mathbf{x}_0$ and $\mathbf{y}_0$ are the coordinates of star centroid.

Gaussian surface fitting makes use of the Gaussian distribution of the star grayscale value, so the accuracy of the target star centroid is relatively high, but computational complexity increases a lot, To simplify the algorithm and improve calculating rate, only **x** and **y** directions are respectively Gaussian curve fit.

The star extracting process has already get the maximum points of star area (x_p, y_p), which has completed the star point centroid coarse positioning in fact [9]. Additionally this step had already saved the size of star region. So it can make Gaussian curve fitting.

The pixel grayscale distribution equation can be expressed as:

$$g_{ij}=A_1\times\exp\left(-\frac{(x_i-x_p-\Delta x)^2}{B_1}\right) \tag{5}$$

$$g_{ij}=A_2\times\exp\left(-\frac{(y_i-y_p-\Delta y)^2}{B_2}\right) \tag{6}$$

Δx and Δy are the coordinate deviations of centroid, $(x_p+\Delta x, y_p+\Delta y)$ is the centroid coordinate after Gaussian fitting.

3 Realization of autoguiding

Firstly, the target star is selected from the image that CCD captured, and then its centroid coordinate is calculated, this will be regarded as the original reference. The new centroid coordinate of the target star in the image captured later is also calculated. These two centroid coordinates are used to get the offset position of the target star. The offset values are the tracking error of equatorial and are transmitted to the computer equatorial for tracking error correction and real-time tracking.

4 Experimental results

As shown in Fig.3 and Fig.4, the candidate star group is obtained through detection of the star image, then the optimal star can be find through the candidate star group, finally by Gaussian fitting respectively in the **x**-direction and **y**-direction, so Gaussian curve fitting can be got, thus the desired coordinates of the centroid of the star can be obtained.

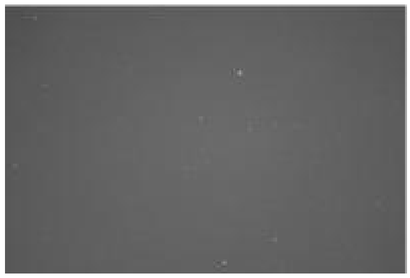

Fig.3 Original star image

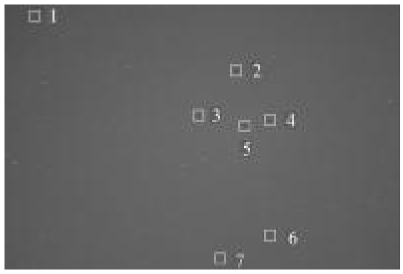

Fig.4 Detected star point

The **T** value of the marked star found is shown in Tab.1.

Tab.1 T values of candidate stars

Star	1	2	3	4	5	6	7
T	329	1 122	376	374	352	355	448

It follows that the largest value of **T** of candidate stars is the second one. So the second star is chosen as the target star.

As shown in Fig.5 and Fig.6, the result shows that

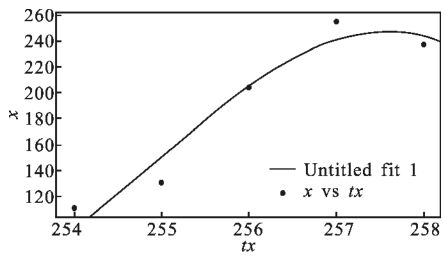

Fig.5 **x**-direction Gaussian fitting

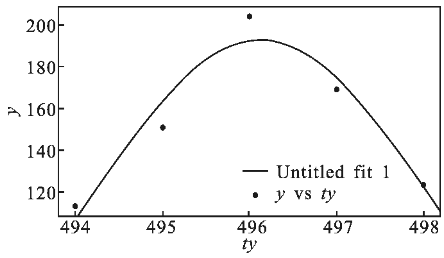

Fig.6 **y**-direction Gaussian fitting

the crude target star coordinates is (496,256), while calculated through Gaussian fitting centroid, the final coordinates is(496, 258).

This method will remove noise ponits, including brighter but small ponits. In addition, it will make the equatorial always track the optimal star, which has a relatively larger average gray value, bigger area and more closer to the center of the field of view.

5 Concluions

The algorithm proposed in this paper firstly finds the candidate star group, then extracts the target star search process, it simplifies the calculation process compared with the traditional star point tracking algorithms. In the target star discovery process the goal is clearer. However, based on Gaussian fitting, the centroid algorithm is still complicated and computationally intensive; the rate of the algorithm has yet to be further improved.

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