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A Method for Selecting Auto-Focusing Window of Photoelectric Theodolite

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***Abstract*—The selection of focusing window is an important part in the process of auto-focusing ing of photoelectric theodolite. The selection method of focusing window of traditional photoelectric theodolite has the disadvantages of large amount of calculation, poor resistance to cockroach and poor adaptability. Aiming at this problem, the method of selecting the auto-focusing window of photoelectric theodolite is proposed, which is based on the off-target amount. The experimental results show that the method has a small amount of calculation, and the corresponding evaluation function curve has higher sensitivity. At the same time, it reduces the influence of the background on the focusing process, and meets the real-time and accuracy requirements of real-time auto-focusing of the moving target by the photoelectric theodolite.**

Keywords—photoelectric theodolite; auto-focusing; focusing window; the off-target amount

I. INTRODUCTION

The photoelectric theodolite is an important equipment for photoelectric tracking and measurement. It can quickly capture and lock the target entering its field of view, and calculate the deviation of the target from the center of the field of view - the off-target amount, according to the off-target amount and the angle measuring system, the motion and physical characteristics of the aircraft, the state record and the angle measurement information such as azimuth and elevation angle were measured, to obtain the actual angular position of the target. In foreign countries, photoelectric theodolites have achieved higher intelligence, and manual intervention is rarely performed when tracking flight target tests. China's photoelectric theodolites still have shortcomings in many aspects, and manual intervention is required to obtain clearer imaging to capture and track targets. When the photoelectric theodolite is tracking the moving target, the distance between the target and the lens changes constantly. The shape, location and size of the target changes continuously, which will cause the target to defocus and affect the tracking measurement. Therefore, the technical requirement of auto-focusing is generated. Auto-focusing based on image processing is rapidly evolving due to its simplicity, flexibility, and no need to add additional hardware , as in [1]-[3]. At present, the depth of focus method is widely used in the field of focusing based on image processing, and mainly includes: focusing window construction, image quality evaluation, and focus search strategy execution. As the first step of the auto-focusing process, constructing a focusing window with a target body and accurate position can overcome background interference and reduce the amount of calculation, which is essential for the entire focusing system, as in [4].

II. FOCUSING WINDOW SELECTION METHOD

A. The Necessity of Focusing Window Selection

The selection of the focusing window is to find a valuable target area in the focusing process. It is a very important part of the auto-focusing process, which directly affects the amount of calculation, accuracy and complexity of the auto-focusing algorithm. In the focusing process, only evaluation function value of the image sharpness needs to be calculated in the focusing window.

The reasons for choosing the focusing window are as follows: Firstly, when calculating the image sharpness evaluation function value, the number of pixels participating in the operation is directly proportional to the amount of calculation, and the real-time performance of auto-focusing must be improved by reducing the number of pixels participating in the operation. Secondly, the proportion of the background information in the image may be large, the accuracy of the focusing will be affected, and the background and the imaging subject are easily mistaken, which may cause the imaging subject to be in focus to be in a defocused state. Thirdly, if the focus window selection is too small, some of the imaged subjects may be outside the focus window, thereby increasing the probability of false positives caused by auto focus, as in [4]-[7].

In order to improve the real-time performance of auto-focusing while ensuring its accuracy, the proportion of the imaging subject in the focusing window should be as large as possible, and the focusing window should be as small as possible to avoid the effect of the accuracy of the auto-focusing due to excessive background area.

B. Several Typical Focusing Window Selection Methods

Many scholars have done a lot of research on the selection of focusing window, and put forward many feasible methods, including: Central window selection method, Multi-region window selection method, Non-uniform sampling window selection method, Image first-order matrix window selection method.

1) Central Window Selection Method

The Central window selection method is a basic method of establishing a focusing window, as in [8]. It usually selects a certain range of area in the center of the image as a focusing window, and its size is generally in a fixed proportional relationship with the entire image. The focusing window established by the method has a fixed position and a fixed size, and the adaptability of the position and size of the target body is poor in practical applications. If the target is off center, the window establishment may fail directly. The central area method is used to establish a focusing window for the image f(x, y) with resolution M×N as shown in (1) and (2):

$$S_1 = \sum_{\frac{1}{4}M \le x \le \frac{3}{4}M-1, \frac{1}{4}N \le y \le \frac{3}{4}N-1} f(x,y) \quad . \tag{1}$$

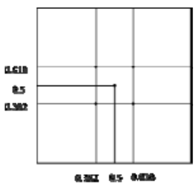
$$S_2 = \sum_{\frac{3}{8}M \le x \le \frac{5}{8}M-1, \frac{3}{8}N \le y \le \frac{5}{8}N-1} f(x,y) \quad . \tag{2}$$

Where, S1 is a set of pixels when coarse focus is adjusted, and S2 is a set of pixels when fine focus is adjusted.

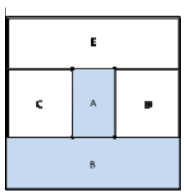
2) Multi-region Window Selection Method

Multi-region window selection method as the name implies, as in [9] multiple regions are selected as the focusing window in the image range, which is more advanced than the central region selection method. The window selection is compensated to some extent. There are two typical methods: Golden section method and inverted T-shaped method.

The golden window selection method is based on the principle of photography and artistic composition. While considering the center point, it also pays attention to the four golden points, so as to establish the focus area of these five points as the focus window; the selection of inverted T-shaped focus area is based on the habit of photographic framing, usually the target body is placed in the middle and lower part of the whole picture, therefore, the inverted T-shape is established in the image as the focusing window. The focusing window created by The golden window selection method and the inverted T-shaped method is shown in the figure below.



(a)



(b)

FIGURE I. MULTI-REGION WINDOW SELECTION METHOD: (A) THE GOLDEN WINDOW SELECTION METHOD. (B) INVERTED T-SHAPED WINDOW SELECTION METHOD.

3) Non-uniform Sampling Window Selection Method

When the imaging subject deviates from the central area of the image and the imaging subject is small, such as selecting a larger focusing window, although the imaging subject is included, it also contains a large number of background images, which increases the amount of calculation. If a smaller focusing window is selected, the imaging subject may not be included, resulting in a false positive. The Non-uniform sampling window selection method can solve the above problems, as in [10].

The Non-uniform sampling window selection method is designed according to the principle of bionics. The retinal region of the human eye can be divided into a central region and an edge region. The photoreceptor cells in the retina have different distribution uniformity and performance depending on the region. By using such a feature, the image center area is maintained at the original image resolution when the image is processed, and the edge area is subjected to a low-resolution non-uniform sampling method, which reduces the amount of calculation and fully includes the target body content. On this basis, many scholars have established a model of non-uniform sampling, in which Gaussian non-uniform sampling is the most representative one, and its sampling radius varies according to Gaussian function law,as in [11]. At the same time, in order to simplify the complexity of the non-uniform sampling model, some scholars have proposed an improved method. It is proposed in the literature that the image is divided into 8 equal parts in the horizontal and vertical directions, and then centered on the central area and gradually oriented in the horizontal and vertical directions. The 1/8 extension is performed to divide the image into four areas consisting of a central area and three rectangular annular areas. The central area maintains the original resolution, and the resolution of the rectangular annular area decreases in multiples along the expansion direction.

4) Image first-order Matrix Window Selection Method

Reference [12] proposed a region selection method based on image first-order matrix.

This method is an improvement of the central region selection method. The central idea is to replace the geometric center with the "center of gravity" of the image, by calculating the first-order matrix of the gray value of the image to obtain the center of gravity of the image, and the focus window is obtained as the center. In order to prevent the image center of gravity from shifting due to the change of light intensity during the imaging of the scene, the first-order matrix of the binarized edge image or the gradient value image may be calculated instead of the gray value "center of gravity", and the focus window is obtained as the center. For a grayscale image f(x, y) of size M×N, the center of gravity $[x_c, y_c]$ can be expressed as:

$$\left[x_c, y_c\right] = \left\lfloor \frac{\sum_{x=0}^{m-1}\sum_{y=0}^{n-1} y f(x,y)}{\sum_{x=0}^{m-1}\sum_{y=0}^{n-1} f(x,y)}, \frac{\sum_{x=0}^{m-1}\sum_{y=0}^{n-1} x f(x,y)}{\sum_{x=0}^{m-1}\sum_{y=0}^{n-1} f(x,y)} \right\rfloor. \quad (3)$$

$\lfloor\ \rfloor$ Represents a rounding operation. For image gradients, the position of the center of gravity$[x_{grad-c}, y_{grad-c}]$ Calculated as follows:

$$\left[x_{grad-c}, y_{grad-c}\right] = \left\lfloor \frac{\sum_{x=0}^{m-1}\sum_{y=0}^{n-1} y f_{grad}(x,y)}{\sum_{x=0}^{m-1}\sum_{y=0}^{n-1} f_{grad}(x,y)}, \frac{\sum_{x=0}^{m-1}\sum_{y=0}^{n-1} x f_{grad}(x,y)}{\sum_{x=0}^{m-1}\sum_{y=0}^{n-1} f_{grad}(x,y)} \right\rfloor. \quad (4)$$

Where, $f_{grad}(x,y)=\sqrt{\nabla_x^2+\nabla_y^2}$, $\nabla_x = \left| f(x+1,y) - f(x,y) \right|$, $\nabla_y = \left| f(x,y+1) - f(x,y) \right|$.

Although the Image first-order matrix window selection method is more adaptable than the fixed window method, this method is more suitable for the case where the target subject is smaller. When the target subject is too large, the established focusing window is less effective, and the effect is poor. The method is susceptible to noise interference during the actual application process, resulting in window setup failure.

5) Focusing Window Selection Method Advantages and Disadvantages Comparison

Summarize the above several typical focusing window selection methods. The advantages and disadvantages of the comparison analysis are shown in Table I.

TABLE I. FOCUSING WINDOW SELECTION METHOD ADVANTAGES AND DISADVANTAGES COMPARISON

Focusing window selection method	Disadvantages	Advantages
The central window selection method	the window is relatively fixed, the adaptability is poor	easy to implement
Multi-region window selection method	the window is relatively fixed, the adaptability is poor	easy to implement ,better than the central window selection method
Non-uniform sampling window selection method	the window is relatively fixed, the adaptability is poor	easy to implement ,better than the Multi-region window selection method, in line with visual observation characteristics
Image first-order matrix window selection method	easy to fail when the target is large, and the resistance is poor	The window can be dynamically adjusted and the adaptability is strong.

III. Method for Selecting Auto-focusing Window of Photoelectric Theodolite

In the tracking process of photoelectric theodolite, the position of the imaging target in the field of view is uncertain and the imaging target is relatively complex. As the imaging target moves in the relative position, the response changes continuously on the image for the target size, so it is very difficult to complete the auto-focusing function by using the traditional window selection method on the photoelectric theodolite. Reference [13] proposed a method suitable for selecting auto-focusing window of photoelectric theodolite. A method for calculating a focus area based on encoder and the off-target amount. With research and improvement based on this, to obtain an optimal method for selecting auto-focusing of photoelectric theodolite based on the off-target amount.

A. *The Off-target Amount Tracked by Photoelectric Theodolite*

Figure II is a schematic diagram of the theodolite image window interface, where the O point is the origin of the optical axis coordinate system coordinate, which is the center point of the selected image array. Since the pixels in the digital image array are stored in the image memory column by column in the order of the scanning lines, when the target is captured or tracked, the target positioning is performed based on the optical axis coordinate system. Therefore, the coordinates of each pixel in which the coordinate system is the reference are converted into coordinates in the optical axis coordinate system. Assuming that there is an irregularly shaped body target T in the field of view, when the target enters the theodolite field of view, the theodolite will quickly capture the target and give the off-target amount and off-target status valid bits. The off-target amount is ΔX, ΔY. The measurement of the off-target amount is the key technology in the theodolite image measurement. The theodolite image measurement system calculates the off-target amount of the centroid or toroidal coordinates of the target image and the coordinates of the relevant matching points field by field or frame by frame relative to the origin of optical axis coordinates. The off-target amount includes the horizontal off-target amount ΔX and the pitch off-target amount ΔY, and the image off-target amount of the theodolite is sent to the servo system and the main control computer of the photoelectric theodolite field by field or frame by frame. The servo system uses the image off-target amount to track the target, and the main control computer uses the off-target amount to correct the trajectory and other post-processing.

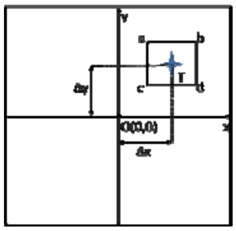


FIGURE II. OFF-TARGET AMOUNT OF PHOTOELECTRIC THEODOLITE

B. *Focusing Window Selection Method Based on Off-target Amount*

In this paper, a selection method for auto-focusing window via using image off-target amount is proposed for auto-focusing window of photoelectric theodolite. The selection method of focusing window is: the theodolite is in the target stable capture and tracking stage, the image off-target amount is effective, assuming the target For T, as shown in Figure Ⅱ, the minimum rectangular area abcd containing the target T is set as a focusing window, and the size of the focusing window is 100×100 pixels centered on the target T off-target amount, and the area is performed the definition evaluation function calculation. This method is similar to the region selection algorithm of image first-order matrix. The difference is that the f calculation amount of focusing area centered on the image off-target amount is smaller. The focusing window can track the moving target and meet the requirements of focusing accuracy. It also reduces the impact of the background on the focusing process.

In order to verify the effect of different focusing windows on the focusing effect, this paper tests two types of images of the photoelectric theodolite. The two types of images are images whose target is located at the center of the field of view and the target deviates from the center of the field of view. Two types of images are shown in Figure Ⅲ and Figure Ⅳ. For the two types of images, 10 images are acquired at different positions of the forward defocusing of the optical lens, the focus position, and the post-defocusing. The image sequence is from fuzzy to clear to fuzzy, using the central window method, the golden window method, the non-uniform sampling window method, and the window selection method centered on the off-target amount, the DB4 wavelet lifting definition evaluation function proposed in Reference [2] is adopted. The calculation is performed, and the calculated function values are subjected to data normalization processing to obtain a graph of the evaluation function of different window selection modes. The two types of images are evaluated in different focusing window evaluation functions as shown in Figure V and Figure VI.

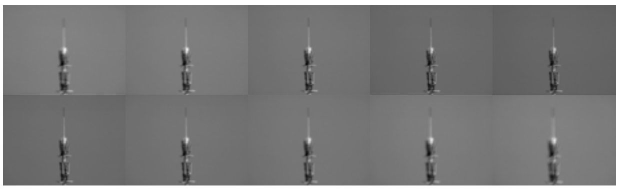


FIGURE III. IMAGE OF THE TARGET AT THE CENTER OF THE FIELD OF VIEW OF THE PHOTOELECTRIC THEODOLITE

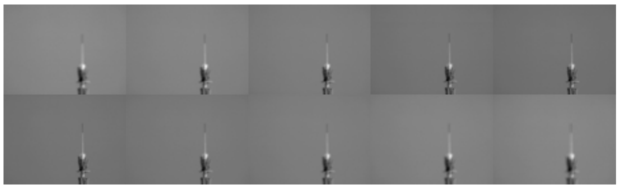


FIGURE IV. IMAGE OF THE TARGET DEVIATING FROM THE CENTER OF THE FIELD OF VIEW OF THE PHOTOELECTRIC THEODOLITE

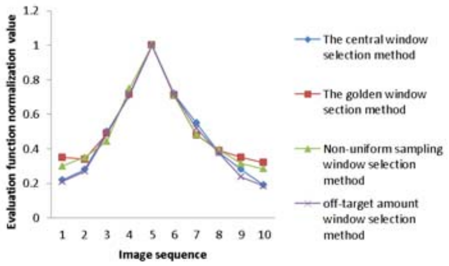


FIGURE V. VARIOUS FOCUS WINDOW EVALUATION FUNCTION CURVES WHEN THE TARGET IS AT THE CENTER OF THE FIELD OF VIEW

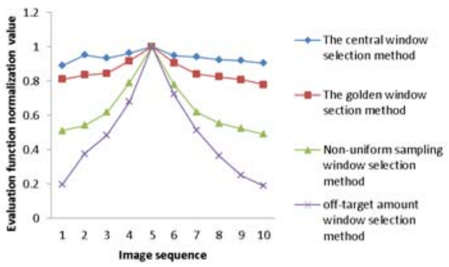


FIGURE VI. VARIOUS FOCUSING WINDOW EVALUATION FUNCTION CURVES WHEN THE TARGET DEVIATES FROM THE CENTER OF THE FIELD OF VIEW

It can be seen from the experimental results that when the target is at the center of the field of view of the photoelectric theodolite, various window selection methods show a good function evaluation curve, and the function has good sharpness and sensitivity. When the target deviates from the center of the field of view of the photoelectric theodolite, the evaluation function curve of the Central window selection method and the golden windowing method is very poor, mainly because there is no target or a small amount of target image gray value in the focusing window area, but this article mentions the window selection method centering on the off-target of the photoelectric theodolite still has a good function characteristic, which can meet the requirements of automatic focusing.

IV. CONCLUSION

This paper states the necessity and influence of focusing window selection in auto-focusing, introduces several typical focusing window selection methods, and analyzes their advantages and disadvantages. Aiming at the shortcomings of various focusing window selection methods, an auto-focusing window selection method based on the off-target amount of photoelectric theodolites is proposed. The method has the ability to adapt to the position of the imaging subject, and its corresponding evaluation function curve has higher sensitivity.

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