The Elimination and Detection Method of Ballistic Missile Infrared Images Bright Line Noise in Middle Trajectory

MinZhu¹, MingGuo*¹ and Zhaoqun Shao¹

¹College of Nuclear Science and Technology, Naval University of Engineering, Wuhan, Hubei, 430033, China
*Corresponding author’s e-mail:morpheusgwo@163.com

Abstract. The bright line noise of the infrared images in middle trajectory of the ballistic missile is similar with the track of the target. This will increase the difficulty in the detection and recognition of the target. So it is very important to eliminate the bright line in the infrared images. Firstly, the paper analyzes the characters of the bright line of the infrared images in the middle trajectory of the ballistic missile in the time domain and the frequency domain respectively. Secondly, the innovative method is put forward to detect the bright line automatically. Finally, the elimination and restoration method of the bright line is proposed in the time domain and the frequency domain. Numerical simulations are given to demonstrate the efficiency of the proposed control schemes and the experimental results show that the proposed method can eliminate the bright line effectively and improve the performance of the infrared images.

1. Introduction
When a highlighted star appears in middle trajectory of the ballistic missile, the readout circuit voltage of the infrared detector is too high due to the imaging of the highlighted star, and the gray value of pixels in the same row (or column) is too high, and bright lines in the horizontal or vertical direction of the star centre will be generated in the image[1,2]. Because the character of the bright line is similar to the trajectory of the target, the existence of the bright line has great interference on the detection of the target in the middle of the trajectory. So it is very important to detect and filter the bright line automatically for the detection of the target in the middle of the trajectory.

Many literatures [3-5] have made some achievements in star image processing, but few of them have been researched in the automatic filtering of bright lines of infrared image in the middle of trajectory. For a single frame image, it is easy to detect the existence of bright lines by using the mode of artificially interprets. However, for the sequence observation image, especially when there are many frames in the image, it is necessary to automatically determine whether there are bright lines in the image and filter the bright lines. In this paper, an automatic detection algorithm of bright line in the middle infrared image of ballistic trajectory is proposed. The algorithm uses the isotropic property of star image in frequency domain and the self registration property of Fourier transform to detect the bright line automatically, and filters the bright line in spatial domain and frequency domain. It is proved that the algorithm can effectively filter out the interference of bright lines.

2. Time and frequency characteristics of bright line
The infrared image of the middle ballistic section with bright line is shown in Figure 1. The bright line has the following characteristics:
1) The bright line is caused by the overflow of the whole row or column of electrons in the detector due to the high brightness of the star. Therefore, the bright line area is usually a straight line which passing through the centre of a highlighted star and the direction of the whole image row / column.

2) Generally, the images taken by the same detector only show bright lines in the row or column direction, but not appear in both row and column directions.

3) The width of the bright line is usually 1~3 pixel.

![Infrared images in the middle trajectory of ballistic missile with light line](image)

Suppose $L(x,y)$ is the bright line image in the row direction, and $C(x,y)$ is the bright line image in the column direction. Take the bright line in the row direction as an example, assuming the width of the bright line is $\tau$, the ideal bright line image $C(x,y)$ in the column direction can be expressed as:

\[
C(x,y) = \begin{cases} 
\text{const,} & x = m + 1, \ldots, m + \tau; y = 1, \ldots, N \\
0, & \text{else}
\end{cases} 
\]  

Where const is constant, $M$ and $N$ are pixel width and height of infrared image respectively.

The amplitude spectrum of $C(x,y)$ is obtained by Fourier transform:

\[
|F_C(u,v)| = \left| \frac{(\tau - 1)(N - 1)}{MN} \sin \left( \frac{u(\tau - 1)}{M} \right) \sin \left( \frac{v(N - 1)}{N} \right) \right|
\]  

In the above formula, $F_C(u,v)$ represents the Fourier transform of $C(x,y)$, and $(u,v)$ represents the coordinate relative to the spectrum centre (Note: the origin of frequency domain has been moved to the spectrum centre by default here).

It can be seen from the analysis of the above formula that when there is a column direction bright line in the image, a sinc$(x)$ function will be superimposed on the spectral line passing through the vertical direction of the image spectrum centre.

The infrared images with bright lines in the middle of the trajectory observed at a certain time can be described as follows:

\[
f_I(x,y) = f_T(x,y) + f_S(x,y) + f_b(x,y) + f_N(x,y) + f_c(x,y)
\]  

Among them, $f_T(x,y)$ is the space target image, $f_S(x,y)$ is the star target image, $f_b(x,y)$ is the deep space background image, $f_N(x,y)$ is the noise image, $f_c(x,y)$ is the bright line image.

Suppose $f_{b_0}(x,y) = f_T(x,y) + f_S(x,y) + f_b(x,y) + f_N(x,y)$, According to the superposition property of Fourier transform, we can see that:

\[
F_I(u,v) = F_{b_0}(u,v) + F_C(u,v)
\]
Where, $F_x(u,v)$ represents the Fourier transform of the image $f_x(x,y)$, and the above formula meets the following requirements:

$$|F_x(u,v)| \leq |F_y(u,v)| + |F_z(u,v)|$$

(5)

It can be seen from the above formula that the spectrum amplitude of the infrared image in the middle of the trajectory is smaller than the superposition of the spectrum amplitude of the image $f_y(x,y)$ and $f_z(x,y)$. Because of the isotropic nature of $F_y(u,v)$, if there is no interference of bright lines, the spectrum of $F_x(u,v)$ should also be isotropic. However, because of the existence of bright lines, a spectrum line passing through the spectrum centre and perpendicular to the direction of the bright lines will be formed in $F_x(u,v)$, resulting in a big difference between the spectral line through the spectrum centre and in the vertical direction and the spectral line in other directions (in this paper, the direction through the spectrum centre and parallel to the bright line is chosen). In this paper, we use this difference to determine whether there is a bright line in the image.

3. Automatic detection of bright line

Construction of binary hypothesis test:

$H_0$: there is bright line in infrared image

$H_1$: there is no bright line in the infrared image

The hypothetical criteria are as follows:

$$H_0: \quad T < Th_r$$

$$H_1: \quad T > Th_r$$

Where, $T = \sum_{u=1}^{M} \left| F_x(u, N/2 + 1) \right| - \sum_{v=1}^{N} \left| F_x([M/2] + 1, v) \right|$

(6)

How to select $Th_r$ is discussed below. From the above analysis, $T$ is the absolute value of the difference between the amplitude spectrum in the horizontal and vertical directions of the image spectrum centre. The difference is caused by the $sinc(\theta)$ function superimposed on the image spectrum. According to formula (2), the threshold value can be determined by the integral of $|sinc(\theta)|$ function. Table 1 lists the Frequency spectrum integral of light line in the horizontal / vertical direction of the spectrum centre, and the width of bright line in the vertical / horizontal direction is 1.

| Width r (pixel) | 1  | 2  | 3  | 4  | 5  |
|-----------------|----|----|----|----|----|
| Integral value of $sinc$ function | 0.86 | 1.17 | 1.33 | 1.45 | 1.53 |

Because the width of the bright line is usually 1~3 pixels, and the infrared image is inevitably disturbed by noise, combined with the analysis of the infrared image in the middle of the trajectory, it is found that if $Th_r = 0.3$, according to equation (6), it can be determined whether there is a bright line in the infrared image. If the filter shown in formula (6) is used to filter $F_x(u,v)$, the spectrum of the bright line image can be preserved and the spectrum of other imaging components can be removed. The Fourier inverse transform of the filtered image can enhance the bright line image and detect the position of the bright line conveniently.

$$H_L(u,v) = \begin{cases} 1, & u=0; v = -M / 2 + 1, \ldots, M / 2 \\ 0, & \text{else} \end{cases}$$

(7)

$$H_z(u,v) = \begin{cases} 1, & u = 0; v = -N / 2 + 1, \ldots, N / 2 \\ 0, & \text{else} \end{cases}$$
The essence of the above filter is an ideal low-pass filter with a pixel width in the horizontal / vertical direction, which can retain the frequency components of all bright lines and filter the frequency components of other components to the greatest extent [6].

Filter Fig. 2 (a). The filtered image is as shown in Fig. 2 (b). The filtered image can obviously detect a straight line.

4. Removal of bright lines

Through the above bright line detection algorithm, we can find the location of the bright line accurately. The next step is to remove the bright line. This paper discusses the methods of removing bright lines in space domain and frequency domain.

(1) Space domain repair method

Take the row / column where the bright line is located as the centre to take the sub image, and use the 5×5 window to median filter the sub image.

(2) Frequency domain repair method

The FFT spectrum value of the corresponding position in the horizontal / vertical direction is taken out, and it is interpolated and repaired, and the repaired image frame is obtained by IFFT transformation.

All the above algorithms can realize the filtering of bright lines, as shown in Figure 3. In comparison, the spatial domain repair method is simple and effective.

5. Experimental analysis

In order to verify the effectiveness of the algorithm, three groups of typical mid trajectory infrared sequence images are tested, each group includes 60 images, and the image size is 1024×1024 pixel. Due to the global motion of the sequence image, there are bright lines caused by bright stars in the first 35 frames of the first group of images, bright lines in the second 40~60 frames, and no bright lines in the third group of images. Three groups of sequence images are detected, and the results are shown in
Figure 4. It can be seen that the algorithm can accurately determine whether there are bright lines for all three groups of images.

![Figure 4](image)

Figure 4. Light line checking results.

6. Conclusion

When the bright star passes through the field of view in the middle part of the trajectory, there will be bright line noise interference in the horizontal or vertical direction of the star center in the observed image. In this paper, we use the isotropic property of star point imaging in frequency domain and the self registration property of Fourier transform to detect the bright line automatically, and obtain good results. The advantages of the algorithm can be summarized as follows:

1. It has a strong adaptability, the calculation does not increase with the complexity of the infrared image in the middle of the trajectory, and the bright line can be detected directly without filtering the stars.

2. The detection method based on FFT is not sensitive to noise and stars. According to the imaging properties of the infrared image in the middle of the trajectory, the influence of noise and stars on the Fourier spectrum is uniform, which can be proved by computer simulation (adding noise and stars to the infrared image, and proving the results of linear detection).

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