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Small target detection using main directional suppression high pass filter

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ABSTRACT

Small target detection in deep space background with a complex background is one of the most important tasks in space technology. Undulant background and stars have a great influence on the target detection for low signal to noise ratio targets of imagery. In this paper, a main directional suppression high pass filter is proposed for background suppression, furthermore applied in small target detection. First, target and background models are created. Second, the problems and the necessity of the deep space background suppression are proposed. Then, the main directional suppression high pass filter is presented for background suppression. Experimental results prove that the presented algorithm is efficient and adaptable to small and dim target detection under undulant background with star lines.

1. Introduction

With the development of space technology, small target detection in deep space background plays a more and more crucial role [1], has become a fascinating research topic. These small targets include space debris and satellite etc. Among them, the space debris is more of a threat to space aircraft. So, it is necessary for us to detect and recognize the space debris. In military fields, detection systems have been used to identify monitor and the satellite and space debris [1]. Currently, scholars at home and abroad have proposed many algorithms for small target detection in deep space background. These small targets are detected by these algorithms under fixed background condition, that is, these algorithms can work well under fixed star background condition. If the stars are moving, we have to compensate the motion. Hence, the performances of these algorithms are greatly influenced by motion compensation [2]. Therefore, the small target detection is becoming one of the key techniques for the deep-space exploration [3–6].

The deep space background is comprised of a lot of noise, targets and celestial bodies (stars, planets, asteroids and comets etc.). The function of the small target detection is to segment targets from their complex background. But, with the development of detection technology, we can detect more celestial bodies in the deep space background, that is to say, the weaker stars can be detected by the higher detection capabilities [7]. So, the small target detection is influenced greatly by the stars. Another reason that the small target detection is a very difficult problem is that the features of small targets and celestial bodies are nearly identical. To overcome the influence of deep space background for small target detection, we need to suppress the deep space background. Johnson C. R. et al. proposed two different color suppression techniques for star background suppression. Accordingly they analyze the performance of the algorithm. The first technique is temperature-ratio discrimination; the other is short wave elimination. These two methods can also suppress the background from the principle of lens imaging. Moreover, their paper presented a moving target indicator process. The sensitivity of the star sensor was enhanced [7]. But these methods are based on the sensors of two line arrays which had been eliminated. Jinqiu Sun et al. presented a small and dim target detection based on motion integration in visual attention model in deep-space background. They made full use of the sensibility of human visual attention for direction and the features of motion. Then the response diagram was created by using composite feature. It is efficient for small target detection [2]. Jinqiu Sun et al. also presented a small and dim target detection based on attention integration map and Connect The Dots model in deep space background. The small and dim target in fixed background can be detected [8]. But under actual conditions, the shake of background always exists. Hong Zhang et al. presented an algorithm of small and dim target detection in deep space background based on feature space of distance (FSD). This algorithm uses the feature space to calculate the transform parameters and realizes the dim and small target detection through the suppression of the star background [1].

The detection system mainly includes three kinds of working patterns: the fixed tracking pattern, the fixed star tracking pattern and the target tracking pattern [2]. Under the first pattern condition, the detection system moves in fixed tracking trajectory. The

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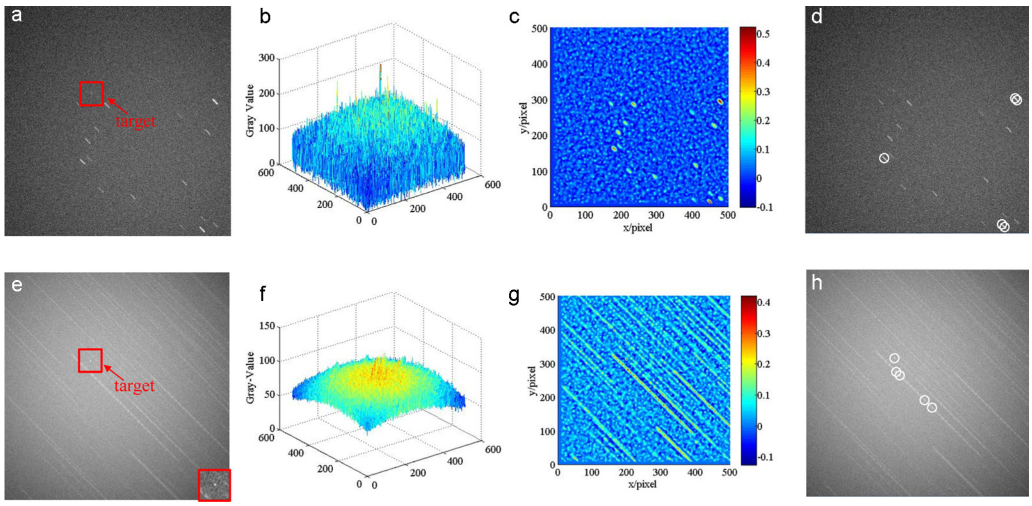

Fig. 1. The results of the small target detection in deep space background.

stars and target are also smeared, while their directions of smearing are different. Under the second pattern condition, the detection system is not moving. Under the influence of earth rotation, the stars are not smeared but the target is smeared. So, the shapes of stars are similar to two dimensional Gaussian functions which have radial symmetry. Under the third pattern condition, the detection system tracks the target. Hence, the shapes of the target and stars are opposite to that in the second pattern. The target shape is similar to two dimensional Gaussian point-like function and the stars are smeared. If the stars are smeared, the energies of them are dispersed. For efficiently detecting the small targets, we adopt the third pattern for detection, that is, the shape of the target is point-like, and the energy is concentrated while the shapes of the stars are smeared, and the energies are dispersed. For the small target detection problems in the third pattern, we propose a novel main directional suppression high pass filter for deep space background suppression.

The outline of this paper is organized as follows. In Section 1 the introduction is described. In Section 2 we describe the target and background models. In Section 3 we propose the problems and the necessity of the deep space background suppression. In Section 4we present the main directional suppression high pass filter. In Section 5 we compare the performance of our method and other traditional background suppression algorithms through the experiments and then the results are given. We come to a conclusion in Section 6.

2. Target and background models

In general, an image consists of three parts: dim targets, background and noise. The additive model is given as follows [5,9]:

$$f(r,t)=f_T(r,t)+f_B(r,t)+f_N(r,t) \quad (1)$$

where $f(r)$ is the gray intensity of a pixel in $\mathbf{r}$ at the original image, $f_T(r)$ is the gray intensity of a pixel at the target region, $f_B(r)$ is the gray intensity of a pixel in $\mathbf{r}$ at the background, $f_N(r)$ is the gray intensity of a pixel at additive noise.

Distant targets are smeared because of atmospheric dispersion, refraction, optical defocusing, lens aberration, diffraction deformation of mirror, and detector tilt. The shape of target is alike to the two-dimensional Gaussian point-like function. So, one obtains:

$$f_T(r)=f_{T0}(x,y)=\lambda\exp\left\{-\frac{1}{2}\left[\left(\frac{x}{\sigma_x}\right)^2+\left(\frac{y}{\sigma_y}\right)^2\right]\right\} \quad (2)$$

where σ_x and σ_y are horizontal and vertical extent parameters, λ is the target intensity amplitude, $f_{T0}(r)$ is the spatial intensity function of target.

3. The problem and necessity of deep space background suppression

Under some conditions, the target in single frame is very dim. It is very difficult to detect the small target, as shown in Fig. 1(a). The target is marked with a square, this image is the first frame in the image sequence, the three dimensional mesh view of image intensity is shown in Fig. 1(b). The response of Fig. 1(a) by using LOG algorithm is plotted in Fig. 1(c). The lighter the color is, the higher the response. The responses on stars are higher obviously. Because the target is very dim compared with stars, its response is very low. The result of detection is shown in Fig. 1(d). The detection objects are marked with circles. The real target is not detected out. Under the third working pattern of detection system and accurate target tracking conditions, the target position in the field of view is approximately unchanged. On the premise of the same distribution of the random background noise, the background clutter can be suppressed by using image superposition method, as shown in Fig. 1(e). It is the superposition result of thirty frames. The real target is shown in square. To well show the target, the target region is enlarged and then its contrast is enhanced. After this, the local image of target region which is marked with square is shown in the lower-right of Fig. 1(e) .Apparently, the target is enhanced greatly. The signal-to-noise ratio (SNR for short) of the target region is higher. Fig. 1(f) is the three dimensional mesh view of the superposition image intensity. This mesh view shows that the deep space background is undulant. Though the random noise is suppressed by superposition method, the undulant deep space background cannot be suppressed. So it is very necessary to suppress the undulant background in image. For instance, we can use the normalization method. Then the small target detection algorithm can work normally. The response of Fig. 1(e) by using LOG algorithm is shown in Fig. 1(g) with the same mean of Fig. 1(c). It is easy to know that the response value in the real target position is high. But obviously the response values in the superposition star line are also high. The specific reasons are shown in the following. Fig. 1(h) is the detection result with the same mean of Fig. 1(d). Though the real target is detected, the response value is also high in superposition star line which leads to many false alarms.

The reason of high response value on the superposition star line is shown in Fig. 2. Fig. 2(a) and (b) are two sequential frames in