Space moving target detection using time domain feature*

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The traditional space target detection methods mainly use the spatial characteristics of the star map to detect the targets, which can not make full use of the time domain information. This paper presents a new space moving target detection method based on time domain features. We firstly construct the time spectral data of star map, then analyze the time domain features of the main objects (target, stars and the background) in star maps, finally detect the moving targets using single pulse feature of the time domain signal. The real star map target detection experimental results show that the proposed method can effectively detect the trajectory of moving targets in the star map sequence, and the detection probability achieves 99% when the false alarm rate is about 8×10^{-5}, which outperforms those of compared algorithms.

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Space target detection is one of the important ways to realize spatial control. Space target mainly refers to satellites, but also includes a variety of space debris[1], such as booster rockets and protective shields, as well as other kinds of comic flying objects, such as comets and asteroids. However, due to the point target imaging feature, it is unable to use the visual features, which are frequently employed in traditional target detection and tracking techniques, such as gray features, regional features, shapes, colors and textures, to detect the satellites from the stars in star maps. The state-of-art space moving target detection techniques for star maps include background difference method[2-4], optical flow segmentation method[5-8], track-before-detection method[9-11] and frame difference method[12-14]. These methods extract the motion information of targets mainly based on the spatial information with the time domain information as the auxiliary. As a result, they do not make full use of the time domain information. The main difference between satellites and stars is that satellites are moving while stars are stationary, so the time domain features can fully reflect the characteristics of the targets in star maps.

In this paper, a new space moving target detection algorithm based on the analysis of time domain signal is proposed, which makes full use of the time domain information to detect and extract the trajectory of space target. In the applicable scope, the foundation platform has two kinds of work modes, which are gaze modes and stellar modes. In gaze modes, telescopes follow the satellite motion, and in the stellar mode, the telescope remains static with the stellar background. Therefore, different processing methods deal with specific work patterns. In this paper, our study is under the stellar model.

The star map studied in this paper is image sequence captured by large field of view of ground-based optical telescope which is composed by space targets, stars, deep space background and noise, as shown in Fig.1. Generally, space targets and stars behave as bright spots while the background behaves as the dark pixels. In Fig.1, it can be seen that, the space targets and stars do not have particular geometry feature and specific position relationship. Therefore, the star map has no obvious feature in the space domain.

We first construct the star map cube which is composed of time series of star maps, called as “time spectral data”. The construction process is shown in Fig.2. Each frame is sorted in time order, and then merged into the time spectral data. In the time spectral data, the spatial size of the image is unchanged, but the number of bands is equal to the number of frames. Therefore, each pixel in

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the image corresponds to a "time domain curve" which represents the brightness of the pixel in different frames.

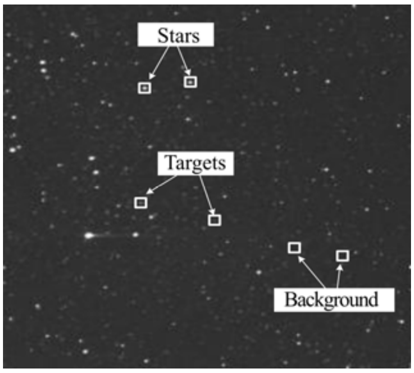

Fig.1 Star map

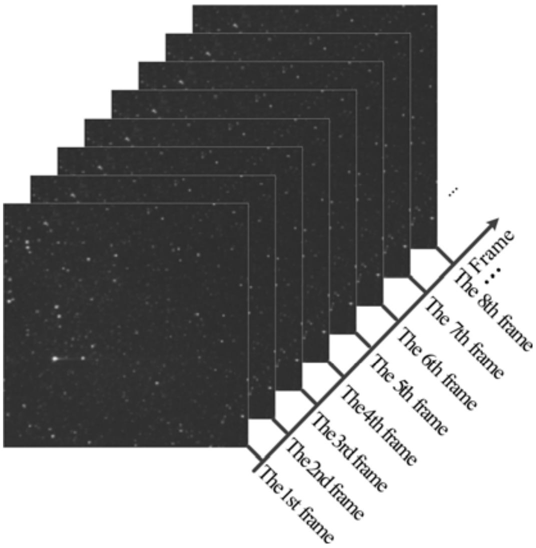

Fig.2 Time spectral data for star maps

The space target detection method proposed in this paper is based on the analysis of the time domain curves in time spectral data. The time domain signal characteristics of space targets, stars and the background are as follows.

(1) Space targets: Let $\left(x_i^k, y_i^k\right)$ be the pixel in (x_i, y_i) of the frame k. Since space targets move in high speed, they appear at different locations for different frames which mean that a target only appears in a certain position of a frame. Assuming the target appears in the position $\left(x_i^k, y_i^k\right)$, except for the frame k, the positions $\left(x_i^j, y_i^j\right), j=1,2,\cdots k-1,k+1\cdots n$ of the other frames are the background, where the total number of frames is n. Since the target brightness is much larger than the background, the pixel in (x_i, y_i) in the time spectral data is a single pulse curve, and the pulse position represents the frame number where the target appears, as shown in Fig.3.

(2) Stars: As stars are stationary and show larger brightness in all frames, they should be bright straight lines if noise is neglected. In real case, time spectra of stars are lines with large values and slight fluctuations because of the effect of noise, as shown in Fig.3.

(3) Background: Since background is dark, the corresponding time spectral curve is approximately straight line with lower brightness, as shown in Fig.3.

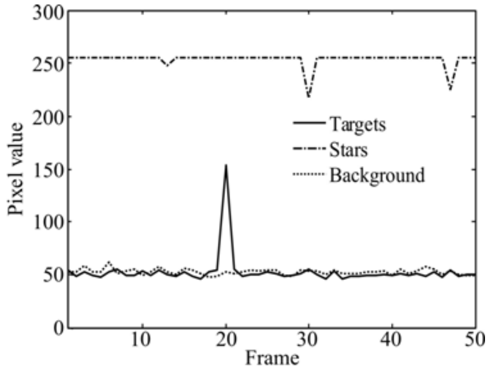

Fig.3 Time domain curves for targets, stars and background

From the above analyses, it can be seen, in order to detect the target in star maps, it is just needed to detect the time domain curve with single pulse. Based on the statistics of a large number of star maps, we have the following knowledge: ①the average brightness of the deep space background is less than 75, generally around 50, and the variance is less than 10; ②the general brightness of stars is greater than 200, with an average of around 240; ③the brightness of the most space targets is 100 or more, up to 250, with an average of around 160. As a result, we determine the time domain signal as space targets using following rules: ①the maximum value of the curve is greater than 100; ②the average brightness of the curve is less than 80 except for the maximum value; ③the variance of the curve is less than 20 except for the maximum value. The above parameters are effective to the image with gray range of [0, 255]. The range of gray can be linearly transformed to [0, 255] for other images.

The real star maps used in this experiment are acquired by the large field (4.8°) 600 mm aperture optical telescope of the Chinese Academy of Sciences. The software platform is Matlab 2010, and the hardware configuration is Intel dual-core 2.4 G CPU and 1 G memory. The astronomical positioning computer is portable industrial computer equipped with P4 3.0 CPU. Leveling and north-seeking operations have been done to the equipment before acquiring the star maps. The data used in this experiment contains 60 frames of CCD images, with spatial size of 512 pixel×512 pixel. We choose a set of images as an example, which contains two moving targets. The target trajectories are shown in Fig.4 by the lines. This paper uses the improved frame difference method[12] and the cross projection method[15] as comparison. To be fair, we first preprocess the star maps[15].

Fig.4 Real trajectory of the moving targets

The detection results for moving targets using our method, improved frame difference method and cross projection method are shown in Fig.5. As can be seen from Fig.5, these three methods can basically get the linear trajectory of the target. Our method can extract the target trajectory accurately and completely with very few false alarm points. The improved inter-frame difference method has a high false alarm rate. If the appropriate threshold is chosen to reduce the false alarm rate, the detection probability will be reduced. The cross projection method can extract the target trajectory with lower false alarm rate, but has discontinuous trajectories, implying that it missed some targets. The conclusion is basically consistent with that in Ref.[15].

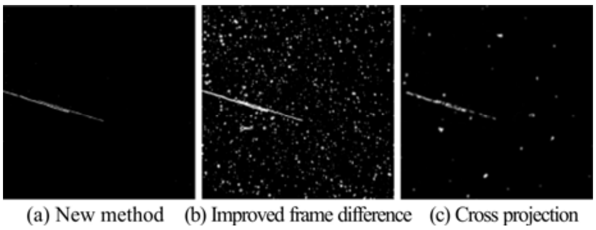

Fig.5 Trajectory extraction results of three methods

Because all the above methods require a certain threshold in the segmentation, we use the receiver operating characteristic (ROC) curve to evaluate each method to avoid the deviation caused by the threshold selection to the results. ROC uses the false alarm rate and detection probability of detection results as the horizontal and vertical axes, respectively. The detection probability is the ratio of detection targets in the actual target trajectory, and false alarm rate is the ratio of the number of non-target pixels in detection result and that of the full star map. The larger the area below the ROC curve, the better the target detection result of the corresponding method. We get multiple groups of detection results by setting a series of thresholds, and the ROC curve of these three methods shown in Fig.6.

As can be seen from the ROC curves in Fig.6, the detection probability of each method increases monotonously with the improvement of false alarm rate, which is the basic characteristic of ROC curve. It can be seen that the ROC curve of our method is higher than the other two methods, demonstrating that the overall result of the new method is the best. Generally speaking, the detection probability no less than 95% while false alarm no more than 10^{-3} can meet the requirement of trajectory detection. For these three methods, false alarm rates for detection probability more than 95% are 6×10^{-5}, 7×10^{-4} and 1.5×10^{-4}, respectively. It means that the numbers of the error detection pixels are 15,184 and 40, respectively, which are all generally acceptable. However, in some of cases with higher requirements, the detection probability should be no less than 99%, while false alarm rate below 1×10^{-4}. In this case, only our method can meet the requirement. The false alarm rates of these methods with 99% detection probability are 8×10^{-5}, 5×10^{-3} and 6×10^{-4}, respectively.

In addition, the inflection point of the upper left corner of ROC curve is the best detection point of the method, in which the detection probability and false alarm probability are optimally balanced. The detection probability and false alarm probability of three methods on the best detection points are (0.99, 8×10^{-5}), (0.95, 7.95×10^{-4}) and (0.98, 4×10^{-4}), respectively.

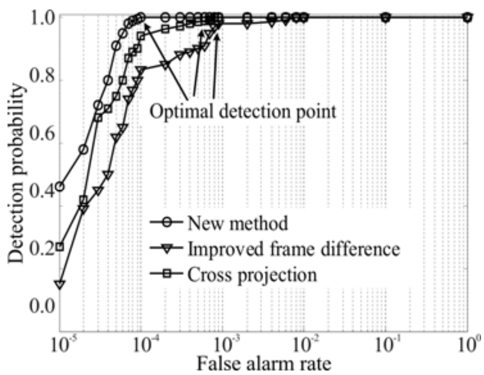

Fig.6 ROC curves of three methods

This paper presents a new detection method of moving targets for star maps based on time domain signal analysis. This method constructs the time spectral data of star maps, and uses the single pulse feature in time domain to detect space targets. The experimental results show that the proposed method can effectively detect the trajectory of the space targets while keeping the low false alarm rate. This method needs to set some thresholds, and this paper gives the reference threshold on the statistics of a large number of star maps. Experimental results show that the threshold can adapt to most images, but how to adjust the threshold automatically is our future research direction.

References

[1] Schildknecht T, Ploner M and Hugentobler U, Advances in Space Research **28**, 1291 (2001).

[2] Liu W, Yu H, Yuan H, Zhao H and Xu X, LET Computer Vision **9**, 13 (2015).

[3] Elharrouss O, Moujahid D and Tairi H, Optik-International Journal for Light and Electron Optics **126**, 5992 (2015).

[4] Niranjil K A and Sureshkumar C, Journal of Electrical Engineering & Technology **10**, 372 (2015).

[5] Wang T and Snoussi H, Sensors **15**, 7156 (2015).

[6] Bellamine I and Tairi H, Signal, Image and Video Processing **9**, s193 (2015).

[7] Patrone A R and Scherzer O, Computer Science **48**, 2724 (2015).

[8] Zhang S, Zhang W, Ding H and Yang L, Journal of Image & Graphics **16**, 236 (2011).

[9] Hadzagic M, Michalska H and Lefebvre E, Sensors & Transducers **54**, 374 (2005).

[10] Zheng D K, Wang S Y and Qin X, Chinese Journal of Electronics **25**, 583 (2016).

[11] Qiu C, Zhang Z, Lu H and Luo H, Progress in Electromagnetics Research B **62**,195 (2015).

[12] Wang E D and Wang E W, Astronomical Research and Technology **13**, 333 (2016). (in Chinese)

[13] Cheng Y H and Wang J, Applied Mechanics & Materials **490**, 1283 (2014).

[14] Yin J, Liu L, Li H and Liu Q, Infrared Physics & Technology **77**, 302 (2016).

[15] Zhang C H, Zhou X D and Chen W Z, Infrared and Laser Engineering **37**, 143 (2008). (in Chinese)