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Infrared small target detection algorithm based on spatial Signal to Noise Ratio

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Abstract：Dim target detection in infrared image with complex background is always a complex and difficult task in remote sensing area. A spatial Signal-to-Noise Ratio(SNR) dim target detection scheme with multi-frame accumulation for high frame rate imaging system is designed. At the same time, according to the continuity of the target motion, the multi-frame confirmation method outputs the real target trajectory. The experiment shows that the average operation time of the algorithm on vs2013 is 23 ms, and it can effectively detect infrared dim target with SNR of 2.91. Otherwise the method has an adaption to multi-target detection.

Keywords：spatial Signal to Noise Ratio；multi-frame accumulation；infrared dim target detection；multi-frame confirmation

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1 Introduction

In space-based infrared defense system, the problem of efficient clutter rejection is a great challenge for space-based dim target detecting and tracking. Due to solar scattering by clouds and earth surface, the intensities of background are several times greater than the targets that are to be detected and tracked, the spatial dim target detection which is also affected by non-uniformity correction will have a poor detection performance. When the background motion is slow, the temporal dim target detection method based on domain gray-scale changes caused by moving targets can effectively improve this situation[1-3]. Over past decades, many temporal dim target detection methods[4-7] have emerged, typically as the Temporal Contrast Filter(TCF)-based method[8] and the Temporal Variance Filter(TVF)-based method[9-14]. The temporal variance filter method applies the temporal variance as the measurement of target detection and has an ambiguity of the target position. Otherwise, the temporal contrast filter cannot fully use the imaging system noise level, which will cause the problem of threshold selection. The temporal SNR-based method can overcome above limitation by using temporal signal-to-noise to the temporal profile.

After the temporal SNR-based method target detection, there are still some residual false alarm caused by clouds and earth surface albedo changes. The multi-frame confirmation is a necessary process to confirm target and eliminate false alarm by using target motion characteristic. This article draws on multi-target tracking strategy, designs a standardized flow(Fig.1) which includes trajectory start, trajectory correlation, trajectory interpolation, trajectory prediction and trajectory confirmation.

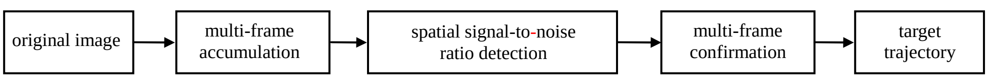

Fig.1 Block diagram of target detection

2 Target simulation

2.1 Mathematical model of an infrared image

Due to the platform jitter, a sequence of 2D images that are registered by an infrared focal plan array can be expressed as:

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$$Z_n(r_p)=\sum_{l=1}^{n} I_n S(r_p-r_l-\lambda_n)+b_n(r_p-\lambda_n)+\xi_n(r_p) \tag{1}$$

Where $\xi_n(r_p)$ is sensor noise; $b_n(r_p-\lambda_n)$ is background; $I_n S(r_p-r_l-\lambda_n)$ is the intensity of the l th target with spatial coordinates r_p and maximal intensity is $I_n(l)$; $S(\cdot)$ represents the point spread function; λ_n is the platform jitter.

2.2 Target simulation

Tzannes[7] use the derivative of the Fermi function to simulate moving target spatial model.

$$T(t)=\frac{a\exp\left[(t-b)/c\right]}{\left\{\exp\left[(t-b)/c\right]+1\right\}^2} \tag{2}$$

Where a is proportional to the intensity of the target; b is the time at which the target reaches the pixel; c respects target pulse width parameter.

Fig.2 is the temporal pixel profiles value which has a moving target appearance within different parameters.

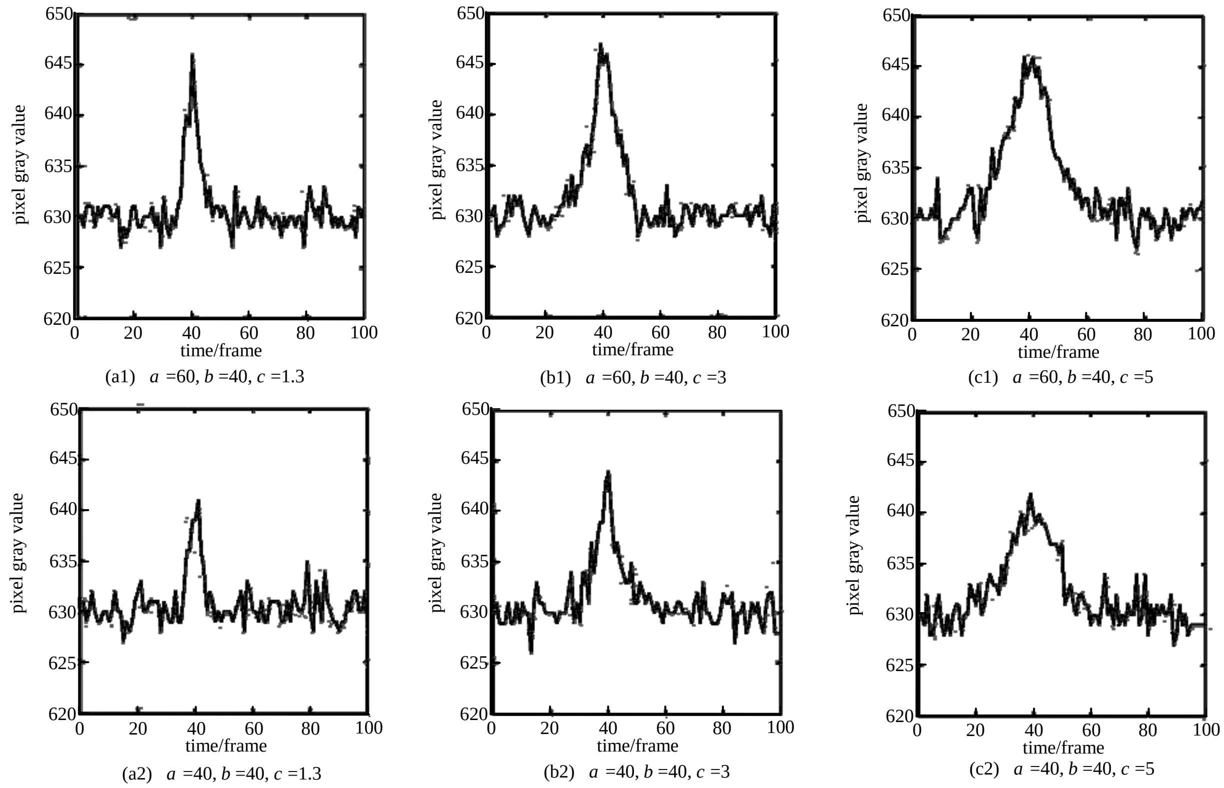


Fig.2 Temporal pixel profiles of simulation targets

3 The temporal SNR-based target detection

If $I(i,j,k)$ denotes the pixel intensity whose coordinate is (i,j) in the k-th frame, the temporal signal-to-noise is denoted as equation (5) with buffer size n+1 and n frames are adopted to estimate the image noise and background intensity.

$$\sigma(i,j,k)=var\left\{I(i,j,k-n),I(i,j,k-n+1),\cdots,I(i,j,k-1)\right\} \tag{3}$$

$$u(i,j,k)=mean\left\{I(i,j,k-n),I(i,j,k-n+1),\cdots,I(i,j,k-1)\right\} \tag{4}$$

$$SNR(i,j,k)=\frac{I(i,j,k)-u(i,j,k)}{\sigma(i,j,k)} \tag{5}$$

$\sigma(i,j,k)$ represents image noise, $u(i,j,k)$ represents background intensity, $SNR(i,j,k)$ represents temporal signal-to-noise.

4 Multi-frame confirmation

4.1 the flow chart of multi-frame confirmation

Multi-frame confirmation method is a trajectory correlation method with the target maximum frame motion displacement as the correlation gate radius and the current frame target position as the correlation gate center. The standardized process conclude five steps: trajectory start, trajectory correlation, trajectory interpolation, trajectory prediction and trajectory confirmation. The flow chart is described as Fig.3.

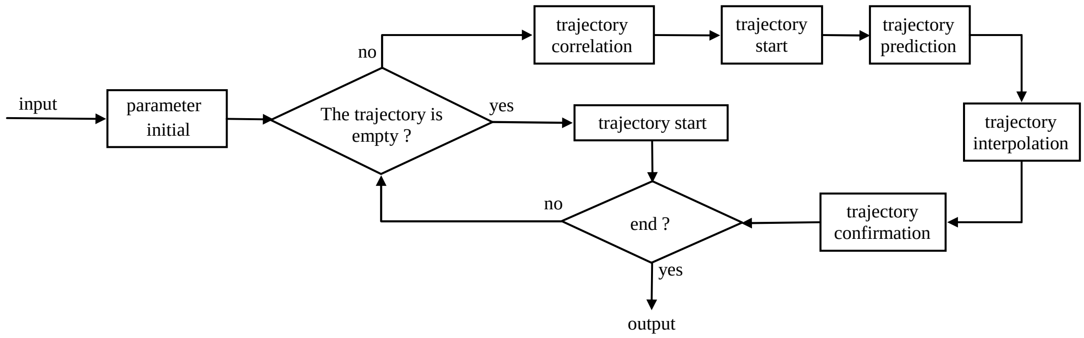


Fig.3 Flow chart of multi-frame confirmation

Parameter initial is mainly initialized the correlation gate radius, trajectory confirmation parameter which will be introduced in chapter 4.2.

Trajectory start refers to whether or not there is a target in the associated gate within consecutive frames, and if so, start a trajectory.

The trajectory association is to confirm whether there is a target associated with the established trajectory within the associated gate, and if so, update the trajectory, if not, perform trajectory interpolation.

The trajectory prediction is mainly to predict the position of the trajectory in the next frame.

The track interpolation is to use the predictive information to supplement the non-association trajectory.

The trajectory confirmation is to use the trajectory confirmation criterion to determine the authenticity of the trajectory. If the discrimination condition is satisfied, the trajectory will be output. Otherwise, the trajectory will be deleted.

4.2 the criteria of trajectory confirmation

The trajectory confirmation is based on the following criterion.

Criteria 1: The minimum number of correlation targets k_1 within the confirmation frame k_2.

Criteria 2: The number of continuous non-correlation targets k_3.

If k_1 is greater than a threshold t_1, the trajectory is confirmed as real and k_3 is greater than a threshold t_2, the trajectory is confirmed as false.

The choosing of k_1,k_2,k_3 should be explained through the theory of probability statistics. Assume the temporal signal-to-noise target detection probability is p_d , the false alarm probability is p_f , the size of trajectory correlation area is $N_x \times M_y$. The cumulative probability of real trajectory which has at least k_1 correlation targets within the confirmation frame k_2 is expressed as equation (6).

$$RC_{k_1}^{k_2} = \sum_{l=k_2}^{l=k_1} C_{k_1}^{l} {p_d}^{l} (1-p_d)^{k_1-l} = 1 - \sum_{l=0}^{l=k_2\text{-}1} C_{k_1}^{l} {p_d}^{l} (1-p_d)^{k_1-l} \tag{6}$$

At the same time, the probability p_{af} that has at least one false alarm in the correlation area is expressed as equation (7).

$$p_{af} = 1-(1-p_f)^{N_x \times M_y} \tag{7}$$

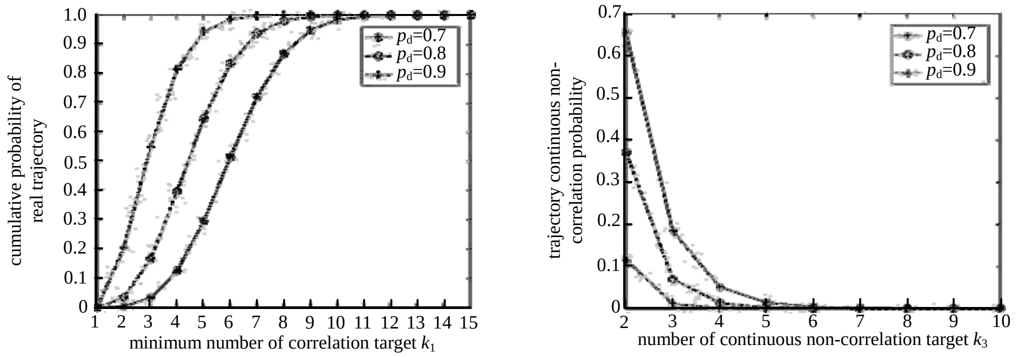
The cumulative probability of false trajectory which has at least k_1 correlation targets within the confirmation frame k_2 is expressed as equation (8).

$$FC_{k_1}^{k_2} = \sum_{l=k_2}^{l=k_1} C_{k_1}^{l} {p_{af}}^{l} (1-p_{af})^{k_1-l} = 1 - \sum_{l=0}^{l=k_2\text{-}1} C_{k_1}^{l} {p_{af}}^{l} (1-p_{af})^{k_1-l} \tag{8}$$

Otherwise, the trajectory continuous non-correlation probability is expressed as equation (9) considering that there are already two association points at the trajectory start.

$$p_{\mathrm{lose}}=\begin{cases}0 & k<k_3+2\\(1-p_d)^{k_3} & k=k_3+2\\2(1-p_d)^{k_3}p_d & k=k_3+3\\2(1-p_d)^{k_3}p_d+(k-k_3-1)(1-p_d)^{k_3}p_d^{\,2} & k>k_3+3\end{cases}\tag{9}$$

The cumulative probability of real trajectory and the trajectory continuous non-correlation probability within the confirmation frame k_2=15 is depicted in Fig.4(a) and Fig.4(b). The cumulative probability of false trajectory is listed in Table1.



(a) cumulative probability of real trajectory　　(b) trajectory continuous non-correlation probability

Fig.4 Trajectory confirmation probability

Obviously, when the confirmation frame k_2=15, the minimum number of correlation targets k_1=9, the number of continuous non-correlation targets k_3=6, the cumulative probability of true trajectory is more than 0.95 and the cumulative probability of false trajectory and the trajectory continuous non-correlation probability is close to 0.

Table1 Cumulative probability of false trajectory

confirmation frame k_2	minimum number of correlation targets k_1 within the cumulative probability of real trajectory more than 0.95	cumulative probability of false trajectory
10	6	2.08×10^{-6}
12	7	1.85×10^{-7}
14	8	1.65×10^{-8}
15	9	3.03×10^{-8}
17	9	6.96×10^{-11}
19	10	6.37×10^{-12}

5　Experiment Result

In order to validate the proposed algorithm, experiments are performed on two different star scenes which are shown in Fig.5. Fig.5(a1) and Fig.5(a2) are the original scene. Fig.5(b1) and Fig.5(b2) are the temporal signal to noise (SNR)-based method detection results of the original scene in a frame. Fig.5(c1) and Fig.5(c2) are the output trajectory after multi-frame confirmation. The spatial SNR statistics window used in the experiment is 10, and the multi-frame confirmation parameters are set up to k_1=9, k_2=15, k_3=6.

The spatial SNR of the detected stars in different scenes are shown in Fig.6. One star was detected in scene 1, and the star moved in 135° direction and two stars which moved in 45° direction were detected in scene 2. The lowest SNR of the detected star is 2.91. The running time is about 23 ms within *c* plus language, meeting the real-time requirement.

6　Conclusions

From the above experiment results, the proposed method in this paper which is not affected by detector non-uniformity correction can effectively detect the dim target with SNR greater by three times, and the real target trajectory will be output after the appropriate parameter multi-frame confirmation. The method is practical in engineering applications.

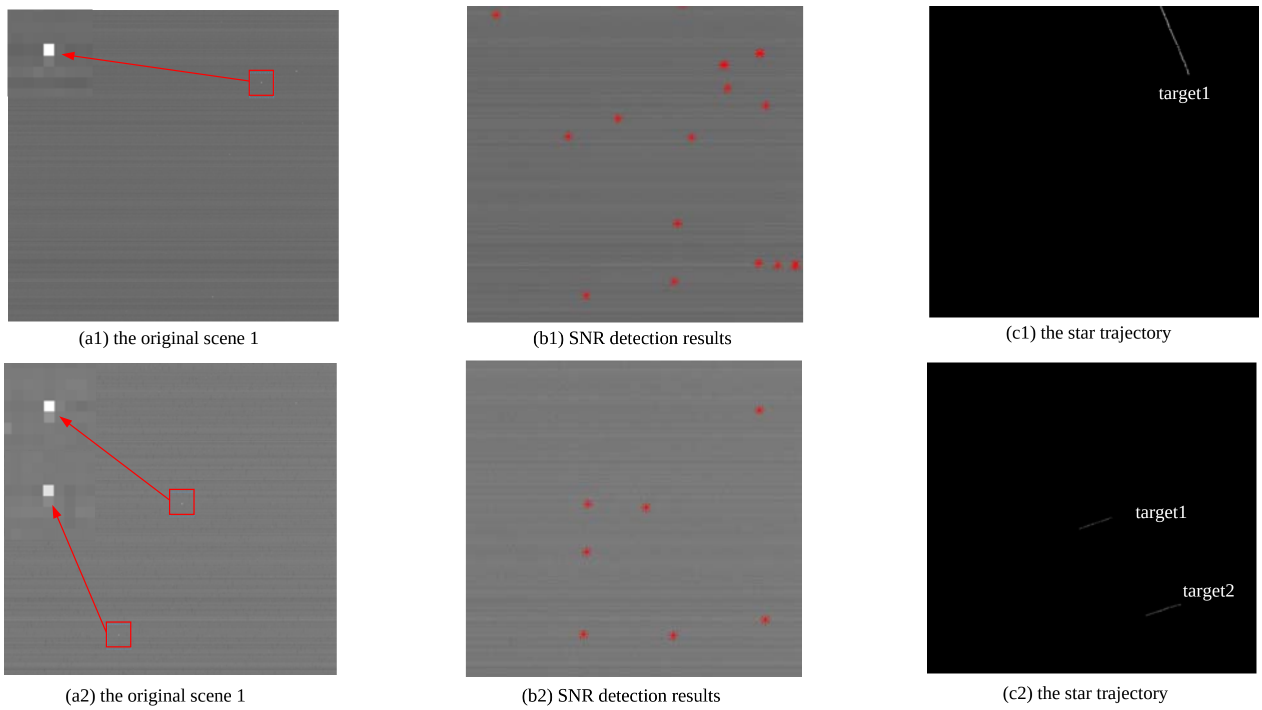


Fig.5 SNR-based detection and multi-frame confirmation results

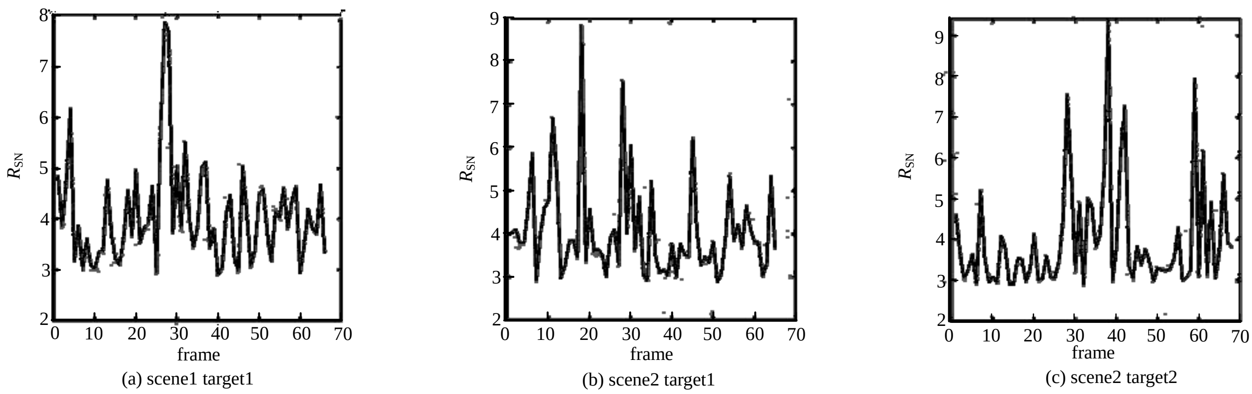


Fig.6 SNR of multi-frame confirmation target

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基于时域信噪比的红外弱小目标检测

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摘　要：复杂背景下红外弱小目标检测与追踪技术一直是遥感成像应用领域一项复杂而艰巨的课题。利用高帧频红外面阵成像系统采集到图像的强帧间相关性特征，设计了一种多帧累加的时域信噪比的弱小目标检测方案。同时利用目标运动的连续性，采用多帧确认的方法关联目标，输出真实目标运动轨迹。实验结果表明，算法在 vs2013 上运行的平均运算时间为 23 ms，检测到的目标最低信噪比为 2.91，同时对多目标的检测具有较强的适应性。

关键词：时域信噪比；多帧累加；红外弱小目标检测；多帧确认