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Background suppression for cloud clutter using temporal difference projection

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HIGHLIGHTS

- Removing evolving background clutter for weak target is a great challenge task for a long time.
- A temporal projection method based on temporal difference is proposed.
- We establish the proposed on the basis of obtaining optimal detection performance and practical application.
- The algorithm proposed yields a higher performance on clutter removing and enhancing target than early method.

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ABSTRACT

To remove high intensity cloud clutter in infrared image sequence containing point target with high velocity, based on the optimal log-likelihood ratio detector test (LLRDT) together with exploratory temporal data analysis, a method called standardized maximum projection of temporal difference on adjacent frames (SMPTDAF) is proposed. First, cloud scenario is classified and analysis according to temporal features. Second, mathematical difference models of adjacent frames for all regions are presented. Third, to obtain the optimal temporal performance under LLRDT operator, based on the models, projection method after differencing and its simplified method for practical application are established. Finally in the paper, we compared the proposed method against classical temporal suppression method named Moving Target Indicator (MTI) and wavelet method by test image sequence. Experimental results show that the average SCR gain exceeds 11 when the target SCR is from 1.0 and 3, which is better than results of some representative multi-frame filters mentioned above.

1. Introduction

Tracing fast motion point target is one of the key problems in Infrared Search and Track (IRST) System or other infrared detecting systems [1–3]. In these cases, the intensity of cluttered background typically due to the evolving cloud is much greater than sensor noise, even comparable to dim targets need to be detected and tracked [4]. As a result, reliable target tracking is impossible without clutter rejection. To reduce background clutter for enhancing target detectability, spatial filtering technologies were widely used to reject cloud clutter such as parametric filters [5–11], nonlinear filters [12,13], high-pass filter [14] and wavelet filters [15,16], etc. Rank-order filters, max-median filters [12], for instance were more robust than others for extracting weak targets with sharp edges, which are outstanding representatives among them. However, studying results show that even rank-order filters cannot get an acceptable performance for reserving targets energy when target signal-to-clutter ratio (SCR) less than 3 or efficient enough in unfavorable but typical conditions [20] for applications of interest. Furthermore, spatial processing on single frame cannot meet real-time requirements, and increases the complexity of detection and tracking processing at the same time (see Fig. 4, Table 2)

With the trajectory feature of targets in temporal domain, recently more approaches [17–21] have treated the clutter removing problem as extracting a known signal out of temporal noises. Moving Target Indicator (MTI) [22], Temporal Hypothesis Testing (THT) algorithm [23,24] and Adaptive Spatial–Temporal Filtering (ASTF) algorithm [25] are all quite useful temporal methods. Tzannes and Brooks [24] developed a Generalized Likelihood Ratio Test (GLRT) operator, where the target is modeled by a Fermi function and the cloud clutter is modeled by a first order Markov model. Unfortunately, THT algorithm is too complicated for real-time application, and the same question happens to ASTF algorithm.

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By projecting the spatial–temporal data into a 2-D space, MTI algorithm has been successfully used to detect satellites, meteorites and other moving targets in space. Yet the impact of evolving cloud is not considered during algorithm design, or optimized for practical application in addition.

In this paper, we focus to solve the problem of evolving cloud clutter suppression for fast moving target which has a speed more than 1 pixel/frame (p/f) on stable imaging condition using temporal methods. After establishing the temporal difference model of each part of scenario in image sequence on basis of classic temporal models, we further developed the temporal difference operator by obtaining the optimal performance of based on log-likelihood ratio detector test (LLDTR) in principle, which maximum projection of temporal difference on adjacent frames (MPTDAF) operator is proposed. Furthermore, in order to enhance the practicability under SMPTDAF operator, by using exploratory data analysis, standardized maximum projection of temporal difference on adjacent frames (SMPTDAF) is designed. Experimental results show that the proposed SMPTDAF has stronger target extraction and better background suppression ability compared to the temporal difference and other existing temporal methods.

The rest of paper is organized as follows. In Section 2, we analyze the local statistical characteristics of the IR image for cloud background components, and the temporal models are described for the targets and the clutter are described. In Section 3, we develop the OTD operator of LLDTR, the maximum projection of temporal difference on adjacent frames (MPTDAF) operator is established, and a practical method called SMPTDAF is designed with the MPTDAF operator. Section 4 contains the experiment results using the proposed method and existing representative temporal methods and conclusions further work are given in Section 5.

2. Target and clutter models

As mentioned before, the main clutter in IR image sequence is the evolving cloud. Although statistical gray-scale probability distribution is hardly to be modeled, however as seen in Fig. 1, background clutter components can be classified into three states all together [30]:

(a) Clear sky: as D region in Fig. 1, there is little cloud with gentle evolving, however, noise coming from sensor is principally the clutter source this region.
(b) Cloud: Generally speaking, cloud clutter can be divided into two parts: internal and edge, which indicate as B and D region as in Fig. 1. Because of the physical and meteorological conditions, cloud morphogenetic will be change during temporal motion.
(c) Abnormally high intensity region: Although abnormally high intensity region is a part of internal cloud, yet as A region in Fig. 1, due to the abnormal distribution of ice particles in cloud together with specific solar incidence angle [29], the region exhibits a high intensity out of normal cloud with a similar morphology to target. For that reason, we call this region as "False Target Region (FTR)" in the following parts. In addition, because of the particularity formation, FTR stays in a short duration and intensity remain unchanged basically, which is quite different from normal cloud component on intensity and morphology changing. Fig. 2 shows the spatial bar charts illustrate the textural profile in 2-D gray-scale space of four regions shown in Fig. 1, each of them is 16×16 pixels.

Specify the statistical models of clear sky, FTR, cloud and target as $s_{\text{cs}}(\mathbf{x},t)$, $s_{\text{FTR}}(\mathbf{x},t)$, $s_{\text{cld}}(\mathbf{x},t)$ and $s_{\text{tar}}(\mathbf{x},t)$ to represent their temporal

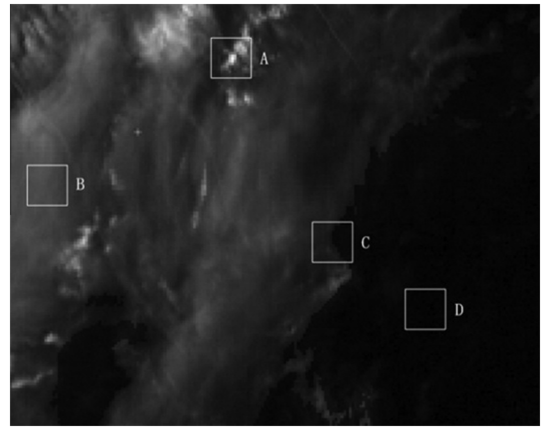

Fig. 1. A single IR grey-scale image with cloud clutter.

distribution in image sequence, where $\mathbf{x}$ represents the position on the focal plane, t denote sampling time to reflect temporal profile of the image sequence. Thus, the probability density of the clear sky region can be expressed as:

$$p_{cs}(s_{cs}(\mathbf{x},t) - C) \sim N(0,\sigma_n) \tag{1}$$

where C is constant in time domain, and $N(0,\sigma_n)$ is detector noise [24] following Gaussian distribution with the mean value of zero and the standard deviation value of σ_n. Consider FTR characteristic, the probability density can be expressed as:

$$p_{\text{FTR}}(s_{\text{FTR}}(\mathbf{x},t) - I(\mathbf{x})) \sim N(0,\sigma_n) \tag{2}$$

where $I(\mathbf{x})$ is constant in time domain. Cloud clutter pixels have temporal profiles behaving less regularly, according to the previous studies [24,26], a simple first order Markov model can be adopt:

$$p_{cld}(s_{cld}(\mathbf{x},t) - s_{cld}(\mathbf{x},t-1)) \sim N(0,\sigma_c) \tag{3}$$

where $N(0,\sigma_c)$ includes both cloud evolving and detector noise following Gaussian distribution with the mean value of zero and the standard deviation value of σ_c, which is nearly constant over all clutter pixels in a given image sequence. Denoting the characteristic variable of the target gray-scale at $t = 0$ as $\lambda_{tar}(\mathbf{x})$, for most conditions, target trajectory appears to be a streak with uniform velocity. Thus, distribution on $t \neq 0$ is represented as $\lambda_{tar}(\mathbf{x} - \mathbf{v}t)$, which is simply deformed from the initial variable, where $\mathbf{v}$ is velocity of the target in focal plane. Therefore, $s_{tar} = s_{tar}(\mathbf{x},t)$ from the target is a spatially dependent distribution expressed as [23,31,32]:

$$p_{tar}(s_{tar}) = \frac{\exp(-\lambda_{tar}(\mathbf{x} - \mathbf{v}t))[\lambda_{tar}(\mathbf{x} - \mathbf{v}t)]^{s_{tar}}}{s_{tar}!} \tag{4}$$

3. Processing of proposed method

3.1. Pixel temporal difference modeling

From Eq. (1), probability density for adjacent frame difference between clear sky is established as:

$$p'_{cs}(s_{cs}(\mathbf{x},t) - s_{cs}(\mathbf{x},t-1)) \sim N(0,\sqrt{2}\sigma_n) \tag{5}$$

and difference probability density for between FTR form Eq. (2) is:

$$p'_{\text{FTR}}(s_{\text{FTR}}(\mathbf{x},t) - s_{\text{FTR}}(\mathbf{x},t-1)) \sim N(0,\sqrt{2}\sigma_n) \tag{6}$$

Under the case in this paper or other majority applications, detector noise is independent, identically distributed (i.i.d) and its variance is much lower than the cloud clutter and FTR. Hence, the probability density distribution of difference between $s_{tar}(\mathbf{x},t)$ and $s_{cs}(\mathbf{x},t)$ can be expressed as: