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Non-local and nonlinear background suppression method controlled by multi-scale clutter metric

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HIGHLIGHTS

- Background suppression method for multi-scale small target in cloud clutter is essential technique in target detection.
- We proposed clutter metric for controlling background suppression method.
- A non-local and nonlinear approach is designed based on physical properties of cloud clutter.
- Out method yields an outstanding performance over classical methods.

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ABSTRACT

To improve the detection performance for non-morphological multi-scale target in IR image containing complex cloud clutter, on basis of cloud scenario self-similarity feature, a non-local and nonlinear background suppression algorithm controlled by multi-scale clutter metric is presented. According to the classical achievements on cloud structure, self-similarity and relativity of cloud clutter on image for target detection is deeply analyzed by classical indicators firstly. Then we establish multi-scale clutter metric method based on *LoG* operator to describe scenes feature for controlled suppression method. After that, non-local means based on optimal strength similarity metric as non-local processing, and multi-scale median filter and on minimum gradient direction as local processing are set up. Finally linear fusing principle adopting clutter metric for local and non-local processing is put forward. Experimental results by two kinds of infrared imageries show that compared with classical and similar methods, the proposed method solves the existing problems of targets energy attenuation and suppression degradation in strongly evolving regions in previous methods. By evaluating indicators, the proposed method has a superior background suppression performance by increasing the BSF and ISCR 2 times at least.

1. Introduction

The detection small scale target under cloud clutter is the key problem in IRST system [1–3]. Due to extremely long detecting range, target on focal plane can be seen as a spot with small scale, without texture, structure or other characteristics. Compared with heavy evolving cloud clutter, the energy of target may too weak for directly segmenting [4,5]. As former research, cloud scenario has self-similarity and relativity physically [19], and target physical shape and radiation intensity are unrelated with scenarios, for these reasons, the core idea of classical methods on single frame based target detection is to remove relative background [1,2,6,7], which is cloud clutter actually. Then due to irrelevance between the target and background, target is highlighted in the image with clutter removed which makes it easier to be detected. It is obvious that in order to obtain a better detection performance, suppression method needs to be designed to ensure that target energy would not significantly attenuated, and the background should be estimated accurately.

In field of background suppression, until today, a lot of effective and meaningful achievements have been proposed by researchers. In processing domain, suppression algorithms can be divided into two sorts, the transformation domain methods [4,5,8–13] and the spatial domain methods [14–23]. Generally speaking, for the transformation domain methods, imagery containing cloud clutter and target is firstly converted into transform domain by using Fourier [9], Wavelet [10], SVM [4,11] or other transformation, then on the basis of differential features between cloud clutter and target, filters are designed for removing clutter composition and protecting targets morphology and energy at the same time. Finally with inverse transformation, the suppression operation is complete with targets

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raised from the background. Although transformation methods have advantages of accessing global resources, yet its poor real-time capability, complex and difficult to filter design and large amount of computations in transformations processing should not be ignored.

Unlike transform domain methods, spatial methods are generally operated on pixels in sliding window, which seems more accessible and understandable than transform methods. Spatial algorithms can be classified into linear mode [14–20] and nonlinear [22,23] mode according to different calculation pattern. Linear methods, such as mean filter, 2D least mean squares filter [12,16,17] or bidirectional filter [15] are firstly assume that background is homogeneous or linear evolve. Then, as the core idea, the liner operations, which their essences are various kinds of weighted averaging methods, are adopted to suppress background. Nonlinear methods, in the meantime, use maximum, median, logical and other nonlinear mathematical operations as the core procedure of background suppression. During designing process of nonlinear filter, directional factor is often added in sliding window to rank background energy, whose rank-order filter is formed [22]. To be more specific, max-median filter, max-mean filter and other rank-order filters are robust and particularly useful for removing sharp edges. In general, spatial background suppression algorithms have advantage of complete theoretical to make it to perform relatively. However, for linear methods, due to the weighted average operating, the performance will be declined in cloud edge or other strong fluctuation region; and for nonlinear methods, although it has a better performance for removing clutter, yet reserve target energy is less than linear methods during processing. To sum up, spatial background suppression method can't get an acceptable performance for reserving targets energy and the result is not accurate enough to remove clutter at the same time.

In order to achieve better background suppression performance, hybrid suppression methods, which fuse linear and nonlinear process structure, have been proposed in recent years. Bae, Tae-Wuk et al. [15] proposed a 2D LMS filter with directional weights and nonlinear step length selection strategy. The method used nonlinear order structure to deal with cloud edge and inherited adaptive updating iteration in meantime. Wei-ke, Dong et al. [18] studied a simply hybrid method which extract cloud edge by canny operator, then use nonlinear and linear methods in edge area and other scenario. However, these hybrid methods simply added up different traditional methods, which made it impossible to have breakthrough, led to a limited performance improvement.

Based on the physical features of the cloud scenario, cloud scenario can be divided into homogeneous region and fluctuation region qualitatively. In homogeneous region, scenario has an obvious feature of self-similarity, while a clear directional distribution reveals a low level of self-similarity. In view of this characteristic, to improve the performance of background suppression, for homogeneous region, non-local approach to maximize sample capacity for enhancing accuracy of estimation is chosen, which would be a breakthrough against local processing strategy in traditional methods. And for fluctuation region, process on directional rank-order would be considered seriously.

According to the analysis above, we propose a non-local and nonlinear background suppression method. After quantitatively analyzing the cloud scenario as clutter which is associated with background suppression method's primary goal in infrared imagery, since cloud scenario continuously vary physically, evaluating 'approaching level' is more appropriate than directly segment, multi-scale clutter metric method based on multi-scale *LoG* operator is put forward. Then local processing of directional rank-order filter called multi-scale median filter on minimum gradient direction, and non-local processing of non-local mean with optimal similarity measurement are designed respectively. Finally fusion mode of linear and nonlinear filters is put forward based on clutters metric. Experimental results show that the proposed algorithm has a better target extraction and better background suppression ability compared to the classical methods.

The rest of the paper is organized as follows. In Section 2, quantitative characteristics analysis cloud scenario as clutter in infrared imageries based on a variety of evaluation indicators is carried out. In Section 3 multi-scale clutter metric based on *LoG* operator for controlling the proposed method is established. In Section 4 multi-scale median filter on minimum gradient direction and non-local mean filter with optimal similarity measurement are designed. Before filters being designed, clutter fluctuation metric is built. Finally fusion strategy in non-local and nonlinear filters is established. Section 5 gives experimental results and performance analysis using the proposed method and other methods, finally conclusions are given in Section 6.

2. Brief analysis on apparent features for cloud clutter in image

Generally, infrared image for target detection can be expressed as [26]:

$$\begin{cases} f(x,y) = b(x,y) + n(x,y) & \text{target absent} \\ f(x,y) = b(x,y) + n(x,y) + t(x,y) & \text{target present} \end{cases} \tag{1}$$

where x, y are horizontal and vertical coordinate of image respectively, $f(x, y)$ represents intensity in (x, y), $b(x, y)$ and $n(x, y)$ refer background and noise intensity generating in detecting chain separately. $t(x, y)$ is the target exceed intensity over $b(x, y)$ when target present. It is known by researches that b is the major part in infrared images, which is cloud scenario and being treated as clutter under our study condition. Since cloud are constituted by similar components such as dust nuclei, water particles and ice particles, which the infrared intensity mainly depends on refraction and reflection from solar radiation [24]. Thus from the view of cloud formation, cloud scenario on infrared image appears to exhibit a certain level self-similarity qualitatively, which has already confirmed by former researchers [19]. Since processes of background removing and target detection operate in image local area, such global inherent attribute of cloud structure's self-similarity cannot directly adopt in background suppression method design. Moreover, infrared image containing cloud scenario is mixed with types of noises, which cause characteristic of background beyond the classical conclusion. In order to obtain applicable priori information for background suppression based on existing research results, analysis on imagery using various types of classical similarity metrics is executed. As discussed above, the local features, specially neighboring relativity and structure & intensity similar feature on non-local blocks are mainly concerned. Besides, the global self-similar feature is also a major consideration as the core of fundamental characteristics. Here, two quantitative indicators are picked to analysis features mentioned above, respectively:

(1) Normalized Kullback-Leible (KL) distance [25]. KL distance is a classical measure for locally structural relativity by measuring probability density distance the between two image regions. For discrete distribution data, KL distance can be expressed as:

$$Kl(X_j|X_i) = \frac{1}{N}\sum_{N} \log\frac{X_i\{x_n\}}{X_j\{x_n\}} X_i\{x_n\} \tag{2}$$

where $kl(X_j|X_i)$ is unidirectional KL distance, $X_i\{x_n\}$, $X_j\{x_n\}$ are the density probability of blocks in image, and N is the number of pixels in block. Obviously, $kl(X_j|X_i) \neq kl(X_i|X_j)$. To make the measure symmetry, define KL distance as:

$$\mathrm{KL}(X_i, X_j) = KL(X_j, X_i) = \frac{K(X_j|X_i) + K(X_i|X_j)}{N} \tag{3}$$