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Spatial and temporal bilateral filter for infrared small target enhancement

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HIGHLIGHTS

- Small target detection algorithm is essential technique for IRCM and DIRCM.
- This paper presents a spatial and temporal bilateral filter for target trajectory detection.
- Target information is extracted using spatial and temporal bilateral filter.
- The proposed method enforces weak points of previous spatial- or temporal-based methods.
- The proposed method will be applied to IR images obtained from various IR wavelength-bands.

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ABSTRACT

This paper presents a spatial and temporal bilateral filter (BF) to detect target trajectories, by extracting spatial target information using a spatial BF and temporal target information using a temporal BF. Background prediction when it is covered by targets is the key to small target detection. In order to apply the BF to a small target detection field for this purpose, this paper presents a novel spatial and temporal BF with an adaptive standard deviation to predict spatial background and temporal background profiles, based on analysis of the blocks surrounding a spatial and temporal filter window. In order to discriminate between the edge or object regions with a flat background and the target region spatially and temporally, spatial and temporal variances of the blocks surrounding the filter window are calculated in a spatial infrared (IR) image and temporal profile. The spatial and temporal variances adjust standard deviations of the spatial and temporal BF. Through this procedure, spatial background and temporal background profiles are predicted, and then small targets can be detected by subtracting the predicted spatial background (and temporal background profile) from the original IR image (and original temporal profile) and multiplying spatial and temporal target information. To compare existing target detection methods and the proposed method, signal-to-clutter ratio gain (SCRG) and background suppression factor (BSF) are employed for spatial performance comparison and receiver operating characteristics (ROC) is used for detection-performance comparison of the target trajectory. Experimental results show that the proposed method has a superior target detection rate and a lower false-alarm rate.

1. Introduction

Infrared (IR) electro-optical sensors have been used for seeking, tracking, or identifying small moving targets. In particular, an infrared search and track (IRST) system is the essential defense technique against an attack by cruise missiles or infiltration by low-flying objects [1,2]. The IR image is obtained from difference in natural IR radiant energy, in other words, IR contrast or temperature difference between targets and backgrounds. Based on the features, targets can be observed, detected, and recognized by radiant features that differ from backgrounds. However, IR images generally have a very low signal-to-noise ratio (SNR) from various optical factors such as target sources, background radiation, transmission properties of the atmosphere, and limitation in IR sensor. Moreover, small targets appear as a dim point embedded in heavy cluttered background owing to the long distances between the IR sensor and the targets [2]. Since these factors bring about a lot of clutters and false target detection, it is very challenging work to detect and track dim, small, moving targets. Nevertheless, a target-detection algorithm is an essential technique for IR countermeasures (IRCM) and directed IRCM (DIRCM), which protect friendly aircrafts or ground vehicles from enemy missiles or aircrafts. IRCM can use either the flare method or the jammer method [3–5]. The flare method emits high radiation energy which includes the IR band of protective objects. The jammer method is

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either omni-directional or directed. Since the omni-directional jammer method emits the IR source in all directions, it has greater power consumption and does not inject a strong jamming signal into missile seeker [4]. In order to address this weak point, the DIRCM, directed jammer method was developed [5]. Because the directed jammer method uses higher luminance lamps or a laser to concentrate jamming energy into a missile seeker, it consumes less power and can continuously emit a jamming source. For development of these IRCM or DIRCM systems, small target detection techniques must come first.

Recently, many researchers have developed several spatial-based methods [6–14], morphology-based methods [15,16], and temporal-based methods [17–19] to detect moving targets in IR image sequences. First, representative spatial-based methods are introduced. In spatial-based methods, background prediction when it is covered by targets is the key to small target detection [20]. Deshpande et al. suggested Max-mean and Max-median filters for preserving structural backgrounds, such as clouds in an IR image [6]. This method uses anti-mean (or -median) filter in order to detect small targets against moving clutter. Max-mean (or -median) represents a maximum value among respective mean (or median) pixel values of horizontal, vertical, and diagonal directions in the local filter window. Clutter on an IR background can be eliminated by subtraction of an original image and a filtered image using the Max-mean (or -median). Then, a threshold process is applied to the subtracted image. The threshold is calculated with a sum of means and standard-deviations over a small window in the subtracted image. And the proportionality constant of standard deviations depends on the probability of a false alarm. However, this method is not effective for dim target detection in IR sequences with low contrast. Zhang et al. presented a target detection method using top-hat for tracking dim moving-point targets in IR sequences [7]. The procedure consists of two steps. In the first step, non-linearity of temperature distribution is eliminated through difference of row-mean value and pixel values in the original IR image. And, in the second step, a top-hat operator is utilized to transform the input IR sequence into a new sequence so that the background is eliminated and small targets are preserved. Then, a projection operation is performed by projecting a three-dimensional spatial–temporal scanning of the target trajectory to two-dimensional (2D) space, during a short integration time for the output IR sequence via image preprocessing. For this projected image, respective pixel energies are calculated along four directions in the local window. The threshold is based on the sum of mean and standard deviations of an accumulation image of three consecutive energy images. And the proportionality constant of standard deviations depends on the probability of a false alarm, like the Max-mean (or -median) method by Deshpande et al. [6]. Then, a target trajectory is detected under conditions of a constant false-alarm probability. Though this method is useful for detecting small targets with various velocities, it has a high false-alarm rate due to inaccurate detection of target surroundings. Cao et al. proposed a target detection method using a 2D least mean square (LMS) based on neighborhood analysis for the local filter [14]. This method uses four surrounding blocks (windows) of the filter window to predict backgrounds covered by small targets. These four blocks share the same weight-matrix, and each block windows generates its own predicted pixel values. The predicted IR background could be more precise than one predicted by a basic 2D LMS filter, but it still incurs a prediction error. Step size (controlling coefficients of the weight matrix) is adaptively adjusted through variance of the predicted pixel values for the surrounding blocks. The target detection performance is superior for constant backgrounds; however, it is limited in cloudy regions including strong edges. In the spatial-based methods mentioned above, those methods assume that a small target has a brighter intensity from higher temperatures, compared to the background region. However, it is difficult to identify the real target region precisely in cases where many non-target objects have bright gray levels in the IR images.

For parallel processing and easy implementation in a real-time system, a morphology-based method [15,16], especially top-hat transform, is widely used to enhance small targets. Bai et al. proposed a new white top-hat transform for small target application, modifying the basic white top-hat transform [15]. Because of its structuring-element structure, it has better target enhancement performance, compared to the basic white top-hat transform. However, its performance is still affected by structuring-element size. Besides, the user must set the structuring element size with prior information of the actual target size. Recently, in order to solve this problem, Bae et al. proposed an automatic decision mechanism for the structuring-element size with a top-hat based algorithm in a target-detection application [16]. The method detects small targets by updating structuring element sizes of the hierarchy structure until the processed image has the best target-to-clutter ratio gain. Though the method is superior than previous top-hat based methods, it is time consuming to process one IR image, and its target detection rate is very low when many objects exist in an IR image.

The temporal-based method uses the variation of a pixel value over a short period of IR sequences. Tzannes et al. proposed temporal filters using the Mexican hat continuous wavelet transform (CWT) to identify temporal pixel profile in IR image sequences [17,18]. This method constructs a set of filters that are matched to a point spread function (PSF) at different scales by selecting a mother wavelet function that is similar to the PSF shape. It classifies target and clutter by applying Mexican hat CWT of different scales to a time profile of pixels. This method assumes that target pixels exhibit higher response at the large scale than they do at the small scale, and vice versa for clutter pixels. Though this method detects the exact target trajectory comparatively, it is time consuming and still has a high false-alarm rate. Bae et al. proposed a small target detection method using a cross product based on a temporal profile [19]. The method classifies target pixels and background pixels through hypothesis testing using the cross product of pixels on a temporal profile and predicts temporal backgrounds, and then detects target trajectory through differences between the original temporal profile and the predicted background profile. These temporal-based methods assumed that small targets are moving in a specific direction with an arbitrary velocity. In other words, temporal-based methods could find it difficult to detect a target trajectory in cases of a non-moving target.

In order to be applicable to practical military purposes, target detection methods must detect a target's position per frame as well as track a target trajectory per arbitrary sequences. However, since many spatial-based methods detect a target using just 1 frame with a mainly monotonous background, it is not applicable to a ground IR background with many objects. On the other hand, since temporal-based methods need an accumulation of frames to track a target trajectory, they cannot detect a target per frame and are not efficient under IR images including non-moving targets.

In order to solve weaknesses in previous spatial- and temporal-based methods, we propose a spatial and temporal target detection method based on a spatial (2D) and temporal (1D) bilateral filter (BF) to reinforce the weak points of previous spatial- or temporal-based target detection methods. The proposed method predicts spatial IR background using a spatial BF, and a temporal background profile using a temporal BF, and then extracts a trajectory for small targets based on the differences between an original IR image and a predicted IR background, as well as an original temporal profile and a temporal background profile. The proposed spatial bilateral method is compared with conventional methods by using signal-to-clutter ratio gain (SCRG) and background suppression