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Small dim object tracking using frequency and spatial domain information

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ABSTRACT

Small dim target tracking is an active and important research area in image processing and pattern recognition. Recently, there has been an emphasis on the development of algorithms based on spatial domain Constant False Alarm Rate (CFAR) detection. This paper presents a novel algorithm for detecting and tracking small dim targets in Infrared (IR) image sequences with low Signal to Noise Ratio (SNR) based on the frequency and spatial domain information. Using a Dual-Tree Complex Wavelet Transform (DT-CWT), a CFAR detector is applied in the frequency domain to find potential positions of objects in a frame. Following this step, a Support Vector Machine (SVM) classification is applied to accept or reject each potential point based on the spatial domain information of the frame. The combination of the frequency and spatial domain information demonstrates the high efficiency and accuracy of the proposed method which is supported by the experimental results.

1. Introduction

The detection and tracking of small dim targets in Infrared (IR) images plays a key role in video surveillance and military image guidance. The development of small dim object tracking is of interest in situations where the objects being tracked are a great distance from the imaging equipment causing the objects to appear small and dim in the image plane. In addition, IR images have a low Signal to Noise Ratio (SNR), usually less than 3 dB, which causes the background of these images to be noisy, complicated and chaotic. The development of a novel detection and tracking methodology that can more efficiently identify small dim objects is the interest of this paper.

Generally speaking, dim object tracking algorithms can be classified into two categories: *spatial* and *frequency* domain algorithms. Common techniques used in the first category of domain algorithms detect the objects in each frame based on the spatial information within the frame. Kalman filters [1], Particle Filter (PF) [2], Genetic Algorithms (GA) [3,4], Human Visual Systems (HVS) [5], Multiple Hypothesis Testing (MHT) [6], and Support Vector Machine (SVM) [7,8] methods are common techniques used that focus on the *spatial* features of the shapeless targets in the tracking systems. In addition, due to the lack of object features in small point-sized targets, other methods attempt to track dim objects by exploring *frequency* domain information. Morphological object tracking methods [9,10] and wavelet based tracking methods [11] are approaches for dim object tracking that utilizes *frequency* domain information. The basic concept behind these methods is the difference between the frequency contents of the target and the background. Targets are considered to have higher frequency contents than the background, and as a result, a high frequency filter can be used to segment the image into target and background categories.

Most spatial based Infrared Search and Track (IRST) systems assume a Gaussian distribution for the target region [12]. In addition, they usually assume that the target intensity is either higher or lower than the background. These two assumptions restrict the functionality of tracking systems in the real world [11]. Also, clutter in the background can cause unexpected changes in intensities. In order to deal with this issue, a temporal decomposition wavelet that can detect multiple targets in the presence of clutter using a change detection map is applied. The output at this stage in the tracking process is to provide a list of candidate targets. The wavelet-based temporal detection approach provides a practical solution but only for the detection of single-pixel targets. In the real world, the target size may greatly vary from one point to several points in an image sequence. In order to overcome this limitation, morphological operations that use frequency domain information are widely used. These methods suppress the background clutter by applying a mathematical morphology which

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enhances target intensity values. High frequency areas commonly provide features used in these algorithms, however, there is a risk of background edge misdetection. Therefore, the detection of a point target requires the integration of target intensity values over multiple frames [13,14].

In this paper, a Dual-Tree Complex Wavelet Transform (DT-CWT) is applied to each frame to obtain high frequency sub-bands in six different directions. The Constant False Alarm Rate (CFAR) detection is then applied to the high frequency sub-bands to identify potential target areas. The high frequency areas that surpass the threshold are identified as potential blocks that could be small targets (hit) or the edge points of the background (false alarm). Therefore, these potential blocks will pass through a SVM classifier for a final decision. Through the use of this method, the SVM classifier will separate the targets from the non-targets based on features in the spatial domain. The main contribution of this paper is the integration of both spatial and frequency domain features in order to more accurately locate the position of the targets without any specific assumption.

The organization of this paper is as follows: Section 2 describes the proposed method along with DT-CWT, CFAR detection, SVM classification, and multi-frame trajectory construction method overviews. In Section 3, an analysis of the model and its parameters is illustrated through relevant graphs and tables. Moreover, a comparison of the proposed method with other related dim object tracking algorithms is shown in this section. Finally, the conclusion with a summary of the proposed method and its advantages is presented in the last section.

2. Proposed tracking method using DT-CWT and SVM

The proposed method is designed to detect small and dim objects in a cluttered background. The small dim object is defined to be close to a point source (or several pixel sizes) that concentrates itself in a relatively small region with higher density at the center [15]. The proposed method consists of three steps. First, a DT-CWT of each frame in the image sequence is obtained. The targets (hit) and edge area of the background (false alarm) are identified in six high frequency sub-bands. In the second step, the variance of a small window in the neighborhood of each coefficient is calculated in high-frequency sub-bands. The CFAR detection module selects points with higher variance values. In the third step, a small block for each of the selected points in the previous step is provided to a SVM classifier. The SVM module will then decide whether a given block belongs to a target or to a background region. Note, CFAR is applied to the frequency domain, while SVM classifies potential areas based on the spatial domain information in order to achieve a consolidation of the frequency and spatial domain information. Fig. 1 shows the flowchart of the proposed model.

In summary, the proposed method is expressed as follows:

- *Find high frequency sub-bands using DT-CWT.*
- *Detect potential targets in high-frequency sub-bands using the CFAR detection module.*
- *Refine potential targets using SVM in the spatial domain.*

2.1. Find high frequency sub-bands using DT-CWT

The wavelet transform has been widely used with great success in many signal processing applications [16–18]. However, discrete wavelet transforms suffer from some serious disadvantages, including shift sensitivity and poor directionality. DT-CWT is a relatively recent enhancement to the discrete wavelet transform (DWT) which has some significant added properties: namely, it is shift invariant with added directional selectivity in two or more dimensions. Small object tracking requires a feature that remains invariant by translation and rotation because different video frames may contain a translated and rotated version of a moving object. Therefore, DT-CWT is an ideal candidate for dim object tracking [19,20].

Given a filter bank of a complex-valued band-pass wavelet $\psi_c(t)$ and a complex-valued low-pass scaling function $\varphi_c(t)$, the complex

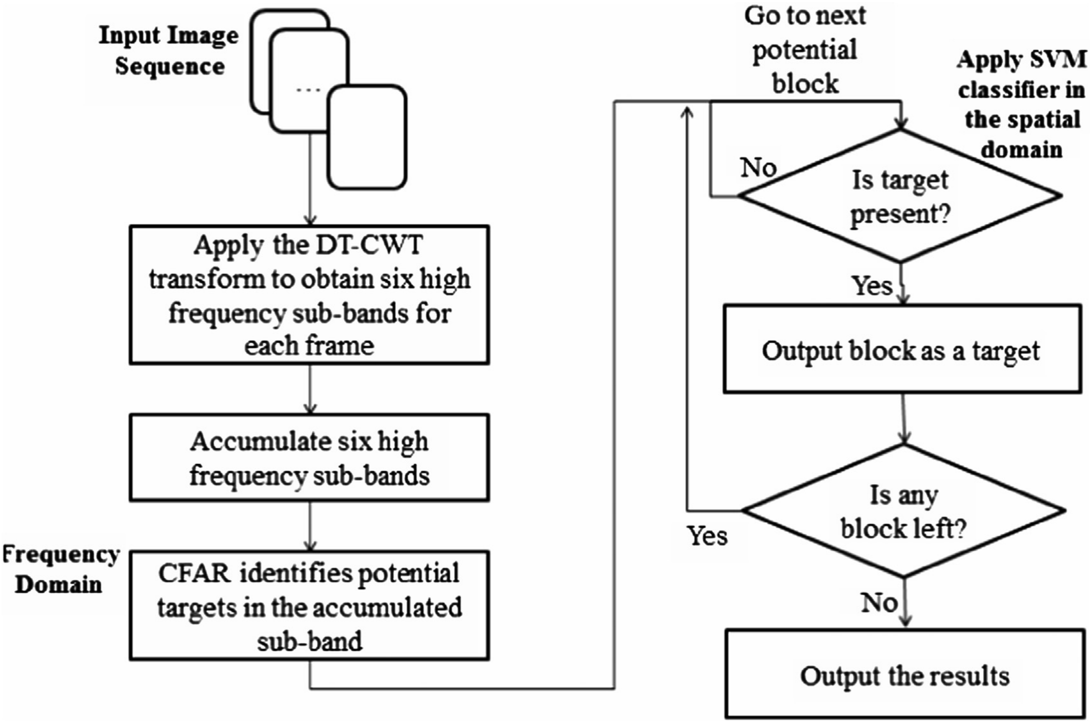

Fig. 1. Flowchart of the proposed model.