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Detecting and tracking dim moving point target in IR image sequence

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Abstract

This paper presents a novel algorithm for detecting and tracking dim moving point target in IR image sequence with low SNR. Original images are preprocessed using temperature non-linear elimination and Top-hat operator, and then a composite frame is obtained by reducing the three-dimensional (3D) spatio-temporal scanning for target to 2D spatial hunting. Finally the target trajectory is tracked under the condition of constant false-alarm probability (CFAR). Based on the experimental results, the algorithm can successfully detect dim moving point target and accurately estimate its trajectory. The algorithm, insensitive to the velocity mismatch and the changes of statistical distribution of background or noise, is adaptable to real-time target detection and tracking.

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1. Introduction

Dim moving point target detection and tracking in IR image sequence are currently attracting great interest in wide civil and military applications. Due to the long distance, the target appears as a dim point embedded in a heavy cluttered background in the IR image, and has no feature information like shapes and textures. Furthermore, aero-optic disturbances and air turbulence make the SNR of a single IR image very low ($SNR < 3$) in the real environments. Only available information for the detection and tracking is the target has unknown intensity and is moving at unknown velocity. All of above make the target difficulty to detect and track [1].

Recent algorithms can be categorized into two broad classes: detect-before-track (DBT), implying that target intensity is used first and target motion hypothesis used after the detection has been done, and track-before-detect (TBD), where target motion information is used first and target intensity after that.

Standard DBT techniques such as the Kalman filter [2], multiple hypothesis testing [3] and probabilistic data association [4] declare detections at each measurement time and then use these detections to estimate target trajectory. Much of the

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recent work on target tracking has focused on these approaches. While computationally simple, DBT algorithms have two fatal defects [1,3,4]. One is that they exhibit poor performance when the SNR is low, the other is that much of the information contained in the measurements is completely discarded due to the application of a detection threshold at each frame.

TBD algorithms such as dynamic programing [5], 3-D matched filtering [6], and recursive moving target indication algorithm [7] show strong advantages in the active area of detecting and tracking dim moving point target in IR image sequence under low SNR condition. Instead of applying a threshold at each measurement frame, data are processed over a number of frames before decisions on target existence are made. The estimated target track is returned simultaneously when the detection is declared. TBD techniques are especially useful for very low SNR scenarios. Latest research indicates that the performance of TBD is superior to that of DBT in almost all respects for low SNR. But ordinary TBD algorithms are often extremely sensitive to background or noise and their performance degrades in the present of a velocity mismatch or a target maneuver.

In addition, DBT and TBD algorithms usually assume background clutter and noise follow Gaussian distributions, whereas this does not adapt to most real situation. That there is no statistical prior information about the background clutter and noise is a big obstacle for target detection and tracking. This paper presents a powerful detection and tracking TBD algorithm for low SNR without the assumption about the distributions of the background clutter and noise. The algorithm is also insensitive to the velocity mismatch or a target maneuver.

The outline of this paper is organized as follows. The target and observation models are stated in Section 2. This is followed by the temperature non-linear preprocessing and cluttered background suppression in Section 3. In Section 4, a simple novel TBD algorithm under the condition of constant false alarm probability (CFAR) is proposed, and its performance is also analyzed. Experimental results are showed in Section 5. Section 6 includes concluding remarks arid further works.

2. Target and observation models

For long-range infrared detection and tracking (IRDT) applications, the target is close to a point source (several pixels) because of aero-optic disturbances and air turbulence. Target at long range can be well modeled by the following 2D IR optical blur function [8]

$$f_{\mathrm{T}}(x,y) = \tau \ * \exp\left\{-\frac{1}{2}\left[\left(\frac{x}{\delta_x}\right)^2 + \left(\frac{y}{\delta_x}\right)^2\right]\right\}, \tag{1}$$

where $f_{\mathrm{T}}(x,y)$ is the target intensity; τ is the target intensity amplitude; δ_x, δ_y are horizontal and vertical extent parameters, respectively; x, y represent the spatial coordinates of the target.

The observation of a random image sequence embedded with dim moving point target can be modeled as

$$f(x,y,k) = f_{\mathrm{T}}(x,y,k) + B(x,y,k) + N(x,y,k), \tag{2}$$

where, $B(x,y,k)$ is an exterior cluttered background; $N(x,y,k)$ represents the noise of the image; k refers to sampling time.

3. Image preprocessing

Image preprocessing consists of two steps which are eliminating the temperature non-linear distribution and suppressing complex background.

3.1. Eliminating the non-linearity of temperature distribution

The atmosphere temperature is non-linear distribution with the rise of ground height. When the target's LOS (line of sight) with respect to the horizon is small, the temperature changing is close at the same ground height. So, except the target pixels, the pixels in the same row of the image correspond to the same atmosphere temperature approximately. The intensity of a target is usually larger than the mean intensity of the corresponding row [9]. The intensity mean of ith row is given by