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New Approach in Processing of the Infrared Image Sequence for Moving Dim Point Targets Detection

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ABSTRACT

The development of an efficient moving target detection algorithm in IR-image sequence is considered one of the most critical research fields in modern IRST (Infrared Search and Track) systems, especially when dealing with moving dim point targets. In this paper we propose a new approach in processing of the Infrared image sequence for moving dim point targets detection built on the transformation of the IR-image sequence into 4-vectors for each frame in the sequence. The results of testing the proposed approach on a set of frames having a simple single pixel target performing a different motion patterns show the validity of the approach for detecting the motion, with simplicity in calculation and low time consumption.

Keywords: IR Image Sequence Processing; Statistical Processing; Dim Point Target Detection

1. Introduction

The detection and tracking of pixel-size moving targets in optical or infrared images have been an active research area for a many years. The pixel-size target is produced when distance between target and imaging system (visual camera or forward looking infrared—FLIR) is long enough. In these circumstances, the target in each frame of images only occupies several pixels, even one pixel.

Early work in IR search and tracking systems utilized algorithms that initially attempted to detect the target spatially in each image, and then used temporal associations for target tracking. Such as the unified framework for IR target detection [1], the correlation based algorithm [2], wavelet based algorithm [3], mathematical morphology based algorithm [4], image processing techniques [5], maximum local contrast [6] and pattern analysis [7], etc. These algorithms are also known as "detect before track" algorithms. Although the "detect before track" algorithms were adequate for applications where the targets were bright compared with the background, they performed poorly with dim targets in severe clutter. In long range surveillance, the target occupies few pixels or even single pixel, and it can be easily contaminated by noise and evolving clutter.

As for the case of the detection of moving dim point target in images is quite difficult because the target intensity in images is low due to the energy transmission loss through long distance, that is, the signal-to-noise ratio (SNR) is low. Another difficulty of detecting moving dim point target in low SNR images is that it is not easy to accumulate the target energy due to the small size and the motion of the target. Because of these reasons, it has been realized that moving dim point target cannot be detected on the basis of single frame image (DBT algorithms). We have to deal with image sequence processing instead of single frame image processing to get better detection results. Thus the "track before detect" algorithms were proposed. The "track before detect" algorithm is a temporal based algorithm which uses multiple frames to incorporate temporal as well as spatial information. A lot of techniques and algorithms was developed within this concept of processing as 3-D matched filtering [8,9], Velocity filter banks [10,11], multistage IIR filter [12,13], Temporal Profile Based detection [14], Temporal filters [15,16], triple temporal filter (TTF) [17], bilateral TTF [18], dynamic programming [19, 20], sequential detection [21], parallel spatial and temporal filtering [4,22] and Probabilistic data association (PDA) [23], etc.

The main problem that faces any of these algorithms is caused from the huge number of data handling which cause either the computational complexity or the time consumption which for the realization and implementation for real time processing it either cost money or for compensation it comes on the expense of the accuracy.

This paper is organized as follows. In Section 2, we outline temporal profile of IR image sequence and it's constitutes. In Section 3, we introduce the proposed new approach and describe its basic steps. In Section 4, a simple practical example of the approach implementation is presented. These results allow us to evaluate the performance of the validity of the approach. Finally the conclusion and plans for future work are outlined in Section 5.

2. Temporal Profile Model

By using a focal plane array (FPA) detector to constantly monitor a scene, each pixel will produce a temporal profile over a short period of time. The temporal profile indicates the variation of the pixel values in this period of time. When a target moves across the pixel, a pulse-like shape disturbance is created on the temporal profile. The width of the pulse will be inversely proportional to the target velocity. Its height above (or depth below) the background depends on its differential intensity with respect to the background.

The pixels that see clear sky or other features constant in time will have temporal profiles that usually behave like a constant mean value plus white noise. Stationary or very large slow moving clutter will also appear as a slowly varying mean plus the same random noise process. Pixels affected by cloud edges or other difficult clutter features will have less regular temporal behaviors. A pixel affected by a small moving target will have a pulse-like shape on the temporal profile, which is distinct from that of the cloud clutter and clear sky [14, 18, 24].

2.1. Static Background

Pixels seeing static background or slow moving objects such as clear sky and the inner portions of cloud have approximately constant intensities. Intensity variation is often caused by random noise. Therefore, the temporal profile of pixels seeing a static background can be modeled as a constant plus a low level of random noise. The random noise can be effectively modeled by a Gaussian distribution.

$$I(t) = C + w(t) \tag{1}$$

where x(t) is the intensity value of pixel at time t, C is the constant value, w(t) is the random noise assumed to be Gaussian with zero mean and variance σ_s^2.

2.2. Cloud Edge

Pixels seeing a cloud edge have the temporal profile modeled by a first-order Markov model.

$$I(t) = I(t-1) + n(t) \tag{2}$$

where n(t) is assumed independent with normal density, zero mean, and variance σ_c^2.

2.3. Target

Pixels that see a target have intensities that are distinct from those of the cloud clutter and clear sky. The intensities temporal profile of small targets and the background are different: either colder or hotter than the surroundings. As the target moves across these pixels, there will be a disturbance signal on the temporal profile. The width and height of the disturbance signal is related to the target velocity and intensity respectively. Therefore, the temporal profile of the target can be modeled by super-imposing a disturbance signal on the background.

$$I(t) = B(t) + T(t) \tag{3}$$

where T(t) is the disturbance signal generated when target move across the starring pixel. B(t) is the background intensity related to the position where the target is located. If the target appears on a static background, then B(t) is the intensity of the static background, else it is cloud edge.

T(t) can be modeled as an independent Gaussian signal with higher variance and mean value reflecting the temperature of the target and can be represented as follows:

$$T(\Delta t) = c + x(\Delta t) \tag{4}$$

where, c is the background intensity, Δt is time of target entering and exit the starring pixel, x(Δt) is normal Gaussian function which exists during Δt, with mean μ and variance σ_t^2. f(t) has a constant value of c when the target does not exist. The value of mean μ is either higher or lower relative to background intensity c to reflect the temperature difference between target and the surroundings. The variance σ_t^2 is higher than the process noise variance for static object to reflect the disturbance signal caused by target moving across the starring pixel.

So in general the observation model of infrared image sequence can be described as follows:

$$f(x,y,k) = \begin{cases} B(x,y,k) + T(x,y,k) + N(x,y,k) & \text{with target} \\ B(x,y,k) + N(x,y,k) & \text{without target} \end{cases} \tag{5}$$

where $f(x,y,k)$ represents the intensity of infrared image sequences, $B(x,y,k)$ is intensity of background clutter, which is the main component in sequences, $N(x,y,k)$ is the intensity of noise generating in focal plane, and $T(x,y,k)$ is the target components when it appears. x,y in above expressions respectively represent the spatial coordinate in focal plane (x=l,2,…,M, y=l,2,…,N for an image of size MxN) and k is temporal coordinate in frames (k=l,2,..,K).

3. The Proposed Approach

A single IR-image frame contains N rows, M columns and D Diagonals (same for both right and left diagonals), Where D is the number of diagonals in a single frame (**Figure**), which can be simply calculated by

$$D=(M+N)-1 \quad (6)$$

The proposed approach mainly perform a transformation of the every single IR-image frame of N rows by M columns pixels is converted into 4-vectors, Horizontal Vector with (1xM) cells, Vertical Vector with (1xN) cells, Right Diagonal Vector with (1xD) and the Left Diagonal Vector with (1XD) cells. Each cell of those vectors is the standard deviation value of the corresponding vertical columns pixel, horizontal row pixels, Left Diagonal pixels and Left Diagonal pixels respectively. **Figure** and **Figure** shows an illustration for the process of creating the 4-vectors (Horizontal - Vertical – Right Diagonal – Left Diagonal).

The standard deviation values are calculated using the population standard deviation

$$\sigma = \sqrt{\frac{\sum_{v=1}^{V}\left(I(x,y,v)-\mu\right)^2}{V}} \quad (7)$$

where the $I(x,y,v)$ is the pixel intensity, x, y are the pixel position, v is the pixel frame number, V is the total number of pixels (V=N for rows and diagonals, M for columns), μ is the average of the pixels to have their standard deviation calculated.

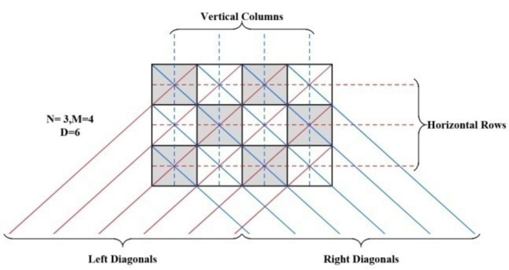

Figure 1. Sample of FPA Pixels and the description of the Columns, Rows, Left Diagonals and Right Diagonals.

During the calculation of the Diagonals standard deviation some diagonals will contain less number or pixels, so to normalize the standard deviation value for all diagonals we perform zeroing for shorter diagonals as explained in **Table** (**Figure**), where the Added Zeroing pixels number different from diagonal to another according to the number of existing diagonal pixels.

Table 1. Diagonal Standard deviation calculation.

	# of pixels	Population standard deviation	
		Before Zeroing	After Zeroing
shortest diagonal	1	$\sqrt{\frac{\sum_{v=1}^{1}\left(I(x,y,v)-\mu\right)^2}{1}}$	$\sqrt{\frac{\sum_{v=1}^{N}\left(I(x,y,v)-\mu\right)^2}{N}}$
longest diagonal	N	$\sqrt{\frac{\sum_{v=1}^{1}\left(I(x,y,v)-\mu\right)^2}{N}}$	$\sqrt{\frac{\sum_{v=1}^{N}\left(I(x,y,v)-\mu\right)^2}{N}}$

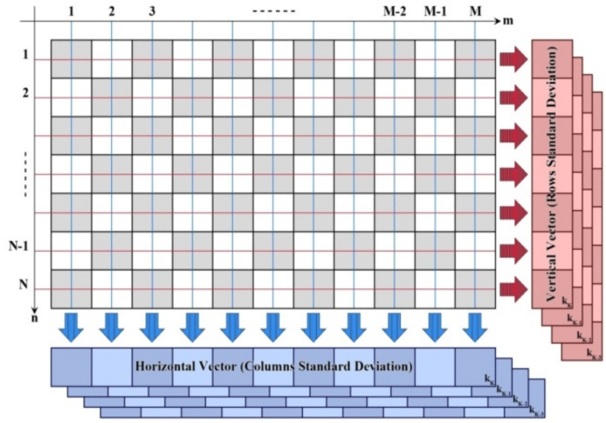

Figure 2. Illustration of Horizontal/Vertical Vectors creation process.

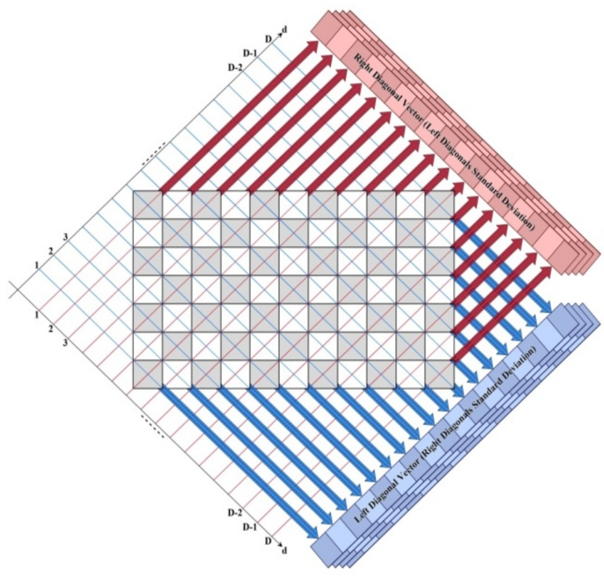

Figure 3. Illustration of Right/Left Diagonal Vectors creation process.

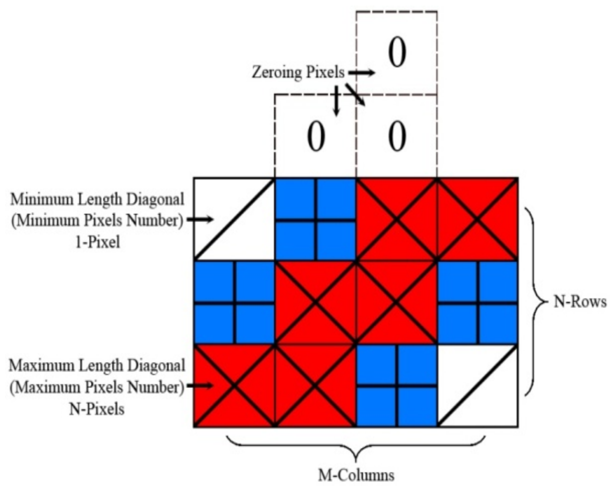

Figure 4. Diagonals Zeroing.

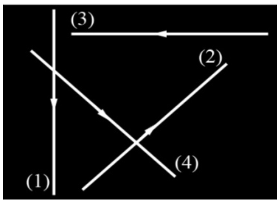

Figure 5. Testing Target Paths.

4. Experimental Results

We applied the proposed new approach on a 95 frames each of (15x20) pixels, where a target is moving across the frames a linear motion through four paths vertical (path 1) , horizontal (path 3), and two diagonal (path 2-4) as shown in **Figure**. It was clear that the Motion of the target will be recognized in at least three of the 4-vectors corresponding to the frame. This change in the 4-vectors will correspond to the disturbance created by the target passing through the corresponding column/row/diagonal. The effect of motion is shown in **Figure** , **Figure** , **Figure** and **Figure** , it's also very noticeable that the target motion disturbance will only be fixed in the case of target motion in a path normal to the vector (marked with (X) on the figures).

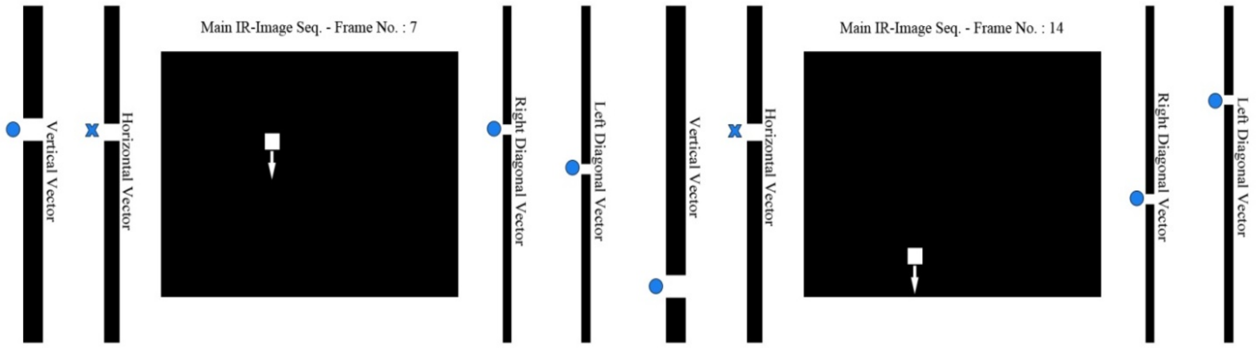

Figure 6. Target moving in a vertical path (normal to the Horizontal Vector).

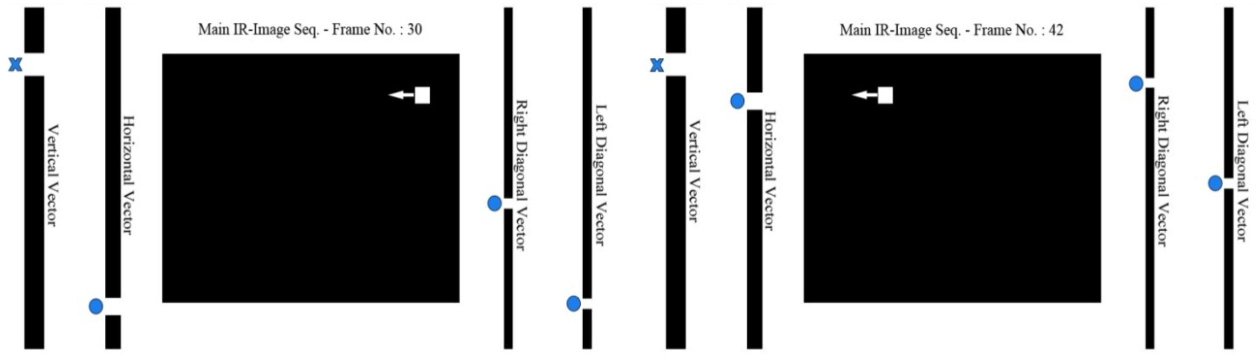

Figure 7. Target moving in a Horizontal path (normal to the Vertical Vector).

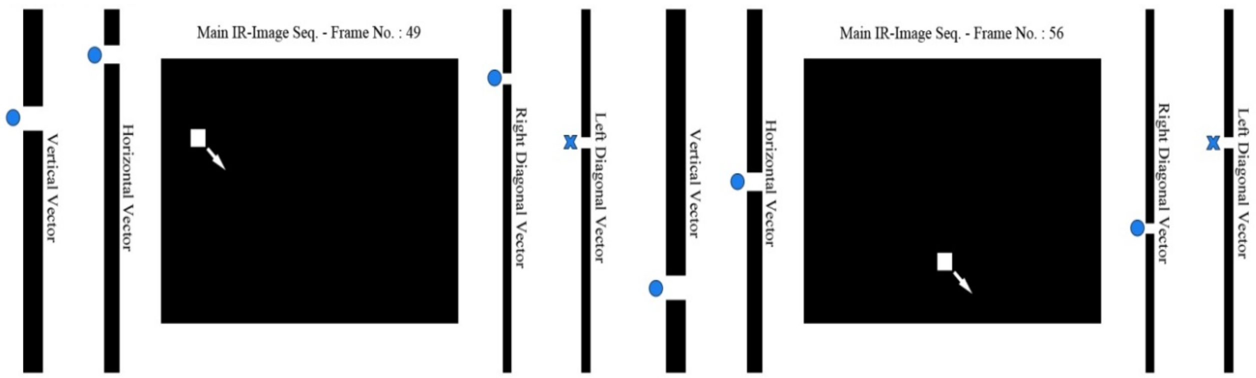

Figure 8. Target moving in a right diagonal path (normal to the left Diagonal Vector).

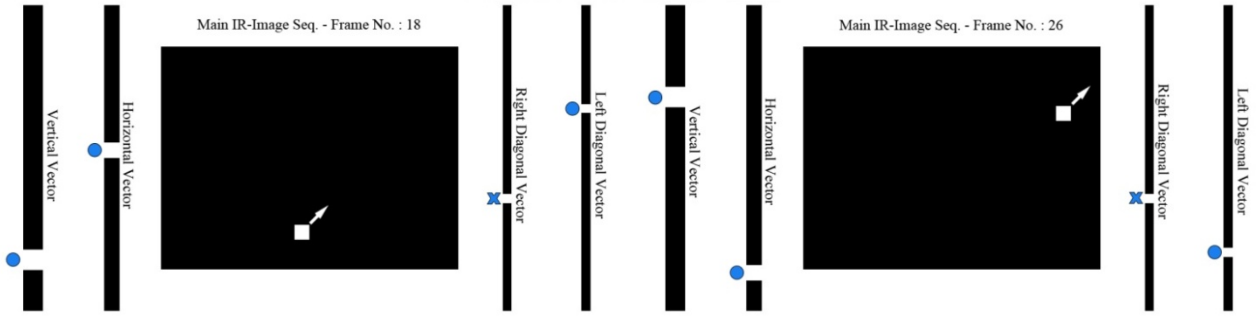

Figure 9. Target moving in a left diagonal path (normal to the right Diagonal Vector).

5. Conclusions

In this paper we propose a new approach in processing the of the Infrared image sequence for moving Dim Point targets detection built on the transformation of the IR-image sequence into 4-vectors for each frame in the sequence. Where these 4-vectors represent that standard deviation of columns, vectors and two diagonals of each image frame pixels. Thus any point on the IR-image can be presented by two different pairs of coordinate either axial or diagonal. We tested the proposed approach on a set of 100 frames with different moving target's behavior to prove the ability of it to adapt and response to different dim small targets motion patterns. The test results show a great performance beside its calculations and low time consumption which make them valid to be used in real time detection.

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