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A Real-time Target Detection Algorithm for Panorama Infrared Search and Track System

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Abstract

With regard to target detection in high resolution panorama images attained by circumferential scan Infrared Search and Tracking system, a rough-to-meticulous real-time target detection algorithm is proposed based on analysis of characteristics of targets and background. In the rough detection phase, it attains initial high rate target detection by quick real-time algorithm, based on the gray high frequency and movement characteristics of the target in the whole panorama image. In the meticulous detection phase, focusing on the detected suspected target sliced images, it has further delicate detection and recognition on the basis of targets' characteristics to exclude those false jamming. The detection result of the test images shows, the algorithm enables stable detection with low-rate false alarm for distant dim small targets, and has been applied to the development of engineering sample of the Panorama Infrared Search and Tracking system.

Keywords: PIRST; dim small target; target detection; real-time algorithm

1. Introduction

The Infrared Search and Tracking system (IRST) receives infrared radiation of targets and their backgrounds, realizes real-time target detection and recognition through high-speed image information processing, picks up target information and trajectory, enables 360° whole-airspace target detection. In contrast with the forward looking infrared detection system, IRST acquires images with larger data, high data rate, and extremely complex background, including various jamming elements such as land buildings,

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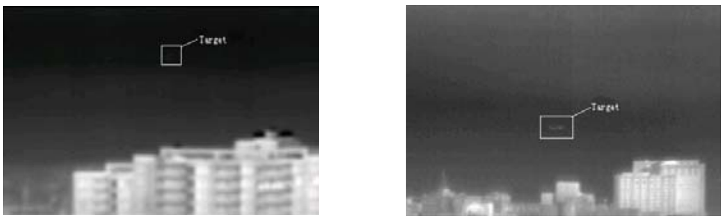
cloud layers, trees and flying birds, thus a distant aircraft behaves as a dim small target with lower signal-noise-rate (SNR) in the panorama image. How to detect and recognize small targets on line in the panorama infrared image with large-quantity data becomes the vital problem of IRST necessary to solve.

It is a widespread method now to realize IRST design by using a linear array detector with optical 360° scanning. In china, a newest high-performance early warning infrared search and tracking system, using a 576×6 long-wave linear array detector, acquires 360° panorama image by scanning of 1 rps, with 576×50000 high resolution panorama long-wave infrared image output. It is then improved to use 1152*6 long-wave linear array detector [1], with 1152×50000Byte/s data rate image output. The indicator requires stable early warning for aircrafts from more than 20km distance. With regard to the above mentioned target detection processing requirements, the paper proposes a rough detection plus meticulous recognition process flow. In the rough detection phase, it attains initial high rate target detection by quick real-time algorithm, in the meticulous detection phase, focusing on the detected suspected target sliced images, it has further delicate detection and recognition on the basis of targets' characteristics to exclude those false jamming. The test data detection examines efficiency of the algorithm, which enables stable detection with low-rate false alarm for distant smaller targets in the whole panorama image.

2. Characteristic Analysis of Target and Background and Detection Algorithm Process

The factor that impacts on performance of infrared image target detection can be classified to three kinds [2]: detector, environment and target. Given a certain detector design, the characteristics difference between target and background is the base for target detection and recognition. Fig. 1 shows the typical panorama long-wave infrared image at low altitude, four stripes each showing 90° azimuth and 4.15° elevation. Fig. 2 show locally amplified images of low-altitude long distance small targets and area targets.

Fig. 1. Typical panorama long-wave infrared image in natural environment



(1) Small target image (2) Area target image

Fig. 2. Locally amplified infrared image of aircraft target

Typical panorama infrared images of aircraft targets at low altitude is featured as follows:

1) Large-quantity data of panorama image, as high as 576×50000Byte/s;
2) A distant target shows as a dim small target with low-SNR, the target at a distance from about 10-20 km is generally sized by 2×2 to 24×24 pixel in the image;
3) As for a system at 1 frame per second, based on the difference of the moving speed of the target and the angle for observation site, the target image between two frames represents as certain pixels per second moving feature, with regular trajectory while the background is relatively static;
4) Panorama long-wave infrared images at low altitude is extremely complex, with great grey level change, including various artificial and natural jamming such as buildings, distant mountains, clouds, trees and flying birds.

Target detection and recognition algorithm is highly required for distant early-warning panorama infrared search and tracking system. There are two key requisite: the first is stable low false-warning rate detection for small targets in the complex low-altitude panorama background; the second is real-time algorithm for data quantity as high as 576×50000Byte/s. To realize the request, it is essential to take emphasis on the differences between targets and their backgrounds' features, and to optimize algorithm compatible with hardware resources. In the sequences of low-altitude background panorama infrared images, in space domain, the target represents as local high grey pixels on a single frame image; in time domain, it represents as moving feature between frames while the background remains relatively static. On the basis of above mentioned characteristics, we adopt a rough detection plus meticulous recognition process illustrated as Fig. 3. In the rough detection phase, we use the fast algorithm that can be realized rapidly by FPGA hard pipeline to attain initial high rate target detection, based on the pixels grey high frequency and moving characteristics of the target in the whole image, while the meticulous detection phase has further delicate detection and recognition to exclude those false jamming, focusing on the detected suspected target sliced images, which ensures algorithm instantaneity and also low false alarm rate stable detection of targets.

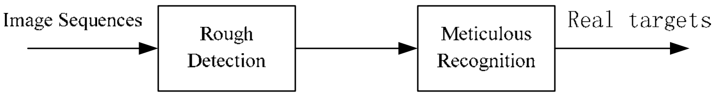


Fig. 3. Procedure of panorama infrared image processing algorithm

3. Rough Target Detection Based on Morphological Filtering and Interframe Difference

Rough detection aims at picking up suspected targets most rapidly from high resolution image in large quantity data. We adopt a kind of algorithm based on the integrating processing of morphological filtering and interframe differences. The morphological filtering put emphasis on background restrain and gray enhancement of distant small targets, while interframe differences on enhancement of moving characters. The integrating processing of the two effectively enhance the targets by highlighting differences of the target and background; and at the meantime, morphological filtering can be realized by FPGA hard pipeline and the lower computational complexity of difference processing enables real-time processing of high resolution images. The algorithm procedure is illustrated as Fig. 4. Process the image sequences by morphological filtering, calculate the interframe differences for filtered images, conduct sliced adaptive detection and clustering process for differentiated images, and finally detect suspected targets.

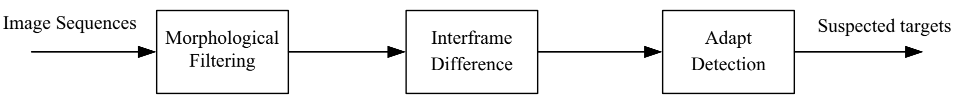


Fig. 4. Procedure of target rough detection

3.1. Morphological Filtering

The formula of morphological Hop-hat filtering is as follow:

$$g = f - (f \circ b) \tag{1}$$

f stands for input image, and b stands for structural element. $f \circ b$ stands for open operation of image f using structural element b. Open operation equates a non-linear low-connectivity filter, which can eliminate brightness details smaller than structural elements, while basically does not impact the whole grey level and bigger bright areas of the image. Leave the image with background estimate only by open operation after choosing appropriate structural elements. After subtraction, the result g is the background suppressed image.

It can retain the target in filtering only when structural element is larger than the target. Here we choose 25×25 square structure element to do Hop-hat filtering for the image. Morphological operation, a kind of convolution algorithm similarly with structural element as the template, its operation speed is proportional to size of structural element. Large-sized structural element will greatly increase computational complexity. Efficiency of morphological operation can be greatly increased by decomposition of structural element [3], i.e. a two dimensional structural element into one dimensional one and further break down a big one dimensional one into several smaller ones. As illustrated in Fig. 5, in actual hardware application[4], the 25×25 square structure element can be decomposed into 1×25 and 25×1 flat structural element, then 1×25 and 25×1 flat structural element can be decomposed into 1×3 and 3×1 small-sized one, thus it fits for hardware pipeline operation with high efficiency.

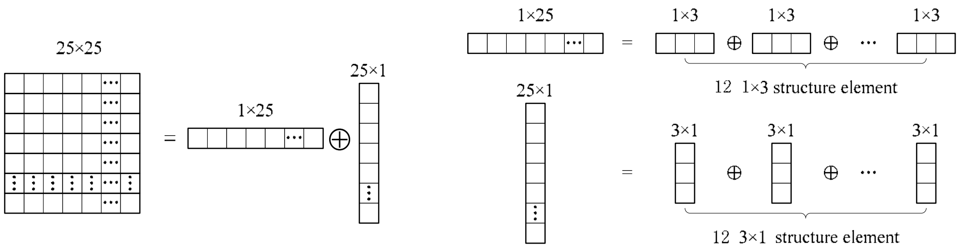


Fig. 5. 25×25 square structural element be decomposed into 1×3 and 3×1 small-sized ones

3.2. Time Domain Difference Processing

Directly using difference of the original image may result in too many false moving areas because of the high light background excursion, which may impact pickup of the real target subsequently. Nonetheless, interframe difference of image sequence after background suppression by morphological filtering may effectively avoid it. For panorama IRST with 576×50000 resolution rate, its field of view is 4.15°×360° and pixels' angle resolution is 0.13mrad. Presuming that target distance is 20km, speed of the target in cruise is 300m/s and flight height 5km, the interframe moving pixel of target is about 29 when the aircraft flying head on towards the observation spot, and about 119 when it is flying over the horizon of the detector vertically. It is thus known that the interframe moving distance is far more than the target area when the target is flying head on and abeam, which suggests interframed images of the target do not overlap, and the background may have 1-2 pixel random drift due to instability of the servo.

Therefore, we adopt a time-domain multi-frame cumulative difference algorithm [5]. A time domain multi-frame difference image can be generated by the image sequence of current frame and previous N frame:

$$F(i,j,k) = \prod_{d=1}^{N} \left[g(i,j,k) - g(i,j,k-d) \right] \times \left[\left(g(i,j,k) - g(i,j,k-d) \right) > 0 \right] \tag{2}$$

$g(i, j, k)$ stands for the morphological filtered image, due to the target in the long-wave infrared image represents as local high lightness versus background, so the only part remained is the positive value of the cumulative difference, and the assignment of the negative part is 0. Cumulative difference can more effectively enhance moving small targets and suppress random slow drift of static background in the acquired image. The more image frames involved in cumulative difference computation, the more information about the moving target, thus improving the target detection possibility. However, more frames mean more computation and storage demand. Therefore, taking account of the actual situation, number of frames needs to be compromised, generally 2 to 5. Here we choose the cumulative frame number 3.

3.3. Adaptive detection

As for 576×50000 resolution image, the partition adaptive threshold method is more appropriate instead of the single threshold segmentation method. Partition the image into 576×600 ones, and every adjacent two intervals has 100 pixel overlap, and the image can be divided into 100 interval in total. The image in every interval can be approximately seemed to consist of target signal, background single and Gaussian white noise. Signal detection with above-mentioned Gaussian white noise introduces permanent false alarm threshold detection algorithm, and judge the threshold th as:

$$th = u[F_d(i, j, k)] + th' \cdot \sigma \quad (3)$$

$u[F_d(i, j, k)]$ is mean value of current partition image $F_d(i, j, k)$, σ is standard deviation of images in current partition,. th' is an adjustment factor related to target's overall clutter ratio. Since targets cannot be omitted in the rough detection phase, th' is set lower, 3 to 5 in general. Detecting images in every partition according to threshold value gets binary-image after detection, conduct 8 neighbor clustering for targets with pixel 1 of binary-image, and then gets the suspected target sequence { PT_d }.

4. Meticulous recognition based on characteristics of the target

The suspected target sequences draw from rough detection include various false targets, such as cloud brinks, land building edges, fixed land light, detector noise and flying birds. Meticulous recognition is proposed for real target pick-up in the suspected target sequence and realizing low false alarm rate. Target meticulous recognition algorithm has a process as the following Fig. 6, which mainly consists of steps as follows:

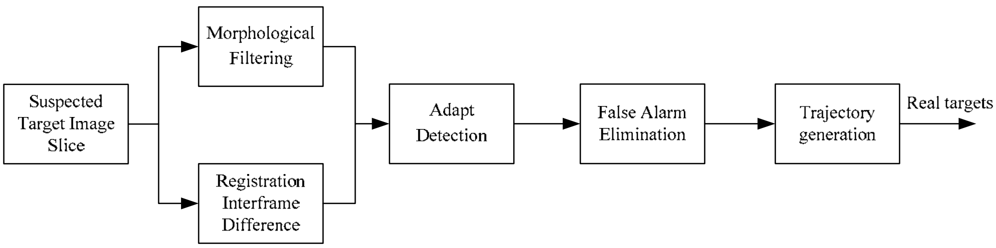


Fig. 6. Processing of target meticulous recognition

4.1. Generation of Target slices

Based on coordinates of the suspected target group { PT_d }, it can generate suspected target image slice { f_d } corresponding to the original images. The subsequent processing is all conducted in the suspected target image slice { f_d }.Before generation of target slice, we should first eliminate suspected target sized not between 2×2 and 24×24 area, while the target image slice can be sized 64×64.

4.2. Integrating target enhancement of morphological filtering and registration interframe difference

In order to weed out 1 to 2 pixel drift of image background due to instability of servo, we should firstly register the slice with the previous frame slice at the same position, and then do multiplication fusion of the results of interframe difference and sliced morphological filtering during rough detection.

4.3. Target detection

It still adopts the same permanent false alarm adaptive threshold method to divide the fusion result, but only the value of the adjustment factor th' here is relatively high, which is set value of 8. Choose closest to the slice center, 1 pixel one from binary image to do 8 neighbor clustering, and then generate the finely detected target sequences $\{ RT_d \}$.

4.4. False alarm elimination

As for finely detected target sequences, further eliminate false alarm and recognize real targets based on 5 feature factors below:

1) Target area: generally between 2×2 and 24×24 pixel.
2) Local SNR of the target: set the minimum detected local SNR is 2.
3) Local contrast of the target: set the minimum detected local contrast is 20%.
4) Detection area proportion of high and low segmentation threshold:

For the fused slice image of morphological filtering and registration interframe difference, the detect threshold is $th = u[F_d(i, j, k)] + th' \cdot \sigma$, which divides difference area of the target according to the different value of adjustment factor th'. For a real target, if th' sets a high threshold and a low one respectively, partitioned area of the real target is basically the same, but for margin of clouds, if th' sets a high threshold and a low one respectively, partitioned area associated with the false alarm of clouds margin has greater deviation, where some false alarm of clouds margin can be eliminated by setting liminal value of certain detection area proportion for high and low threshold.

5) Duty cycle of target local segmentation

It is known from the grey level distributed difference[6] of the target and clouds margin that highest grey level in the central area of the real target declines and diffuses all around gradually, while the grey level of the cloud margin is increasing from darkness to lightness. Based on above feature difference, we define area duty cycle of target local segmentation to be the ratio of target area and neighborhood size after local segmentation of certain neighborhood around the target. If the ratio is smaller than a certain threshold, it should be judged as a real target; otherwise it should be eliminated as false alarm of cloud margin.

4.5. Trajectory generation

After false alarm elimination, the next approach is to generate trajectory for the rest targets, recognize the target based on trajectory and speed of the target, and eliminate residual false alarm such as flying bird. Target trajectory generation consists of two main steps:

1) Trajectory establishment: establish trajectory based on the rule that target is in an approximate uniform rectilinear motion within adjacent frames in a short time;
2) Trajectory affirm: Identify whether the current detected targets are continuing of the established trajectory, while establish new trajectory for the residual suspected targets based on trajectory establishment rule.

5. Test and conclusion

Adopt real image sequences captured by panorama IRST to demonstrate the algorithm, Fig. 7 is the target binary image processed after rough detection with regard to the third stripe in Fig. 1, where what in the rectangle is the real target, while the rest light pixels are all false targets of noise or building margin. Fig. 8 is the target slice processing result after amplification, where (1) is the target slices picked up from suspected target sequences, (2) is the image after fusion enhancement of the slice, (3) is the images after adaptive segmentation, and (4) is the target tracking window formed after trajectory recognition. False target slices such as building margin have all been eliminated in the phase of meticulous detection and recognition. The algorithm has realized real-time processing based on hardware droved by double DSP6455 and FPGA, where morphological filtering realized in FPGA, while the rest realized in double DSP6455, which succeeded in detecting 50 groups of targets at most from 576×50000 resolution image, and at the same time processing time per frame is within 1 second.

Fig. 7. Suspected target binary images after rough detection

(1) Target slices | (2) Enhanced images after fusion | (3) Segmented images | (4) Recognized target tracking window

Fig. 8. Result of target slice processing

With regard to real-time target detection processing demand of high resolution images captured by panorama infrared search and tracking system, the paper proposes a rough detection plus meticulous recognition algorithm, which effectively ensures both real-time and low false alarm detection of small targets. The test data demonstrates that the algorithm can realize low false alarm stable detection for distant small targets and has been effectively applied to the development of the engineering sample of Panorama Infrared Search and Tracking system.

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