Study on correlation-tracking method based on edge detection in long-wave infrared image

Wei Hao (郝 伟)[1*], Kun Zhang (张 坤)[1,2], and Zhenhuan Zhan (詹振环)[1,2]

[1] *Xi'an Institute of Optics and Precision Mechanics of Chinese Academy of Sciences, Xi'an 710119, China*

[2] *Graduate University of Chinese Academy of Sciences, Beijing 100049, China*

[*] *Corresponding author: chinaren009@163.com*

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This letter presents a correlation tracking algorithm based on edge detection, in allusion to the phenomenon that the target is susceptible to interference in long-wave infrared image. Firstly, the collected imageis processed by median filtering to remove the defects in the detector. Then thegradient information of the background is filtered out by edge detection method. Secondly, to enhance the edge information, the image is dealt with mathematical morphology (MM). And finally, the correlation matching method is done to acquire the miss-distance information of the target in the image. Through theoretical simulation and practical verification, it is proved that the algorithm has a better effect on inhibiting most of the background information, protecting the target's information effectively, enlarging the weight of the target's information in the correlation operation and improving stability of the detector.

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The visible detector mainly receivesenergy reflected by the target from the light source. As the detector imaging, there must be light source such as sun, lamps or the target lights itself. Infrared (IR) detector is a radiant energy converter. By way of receiving IR energy from the target, IR detector can detect fine temperature difference between the target surface and the background. The visible light and near IR rays can be absorbed by the atmosphere and the smoke cloud. But IR radiation is 'transparent' in the wavelength regions lying from 3 to 5 μm and 8 to 14 μm. So the two wavelength regions are called atmospheric window. With the atmospheric window, people can make clear observation of the conditions in the front, even in totally dark night or on a battlefield densely covered with smoke cloud. Thus, the thermal imaging technology is very popular in military applications.

The infrared radiation is divided into mid-wavelength infrared(MWIR)(3–5μm) and long-wavelength IR (LWIR)(8–14 μm)by the wave band of the detector . MWIR has strong response ability with the target whose temperature is above 600 K, while LWIR is suitable for observing the room temperature materials with a surface temperature about 300 K. So MWIR has a better effect on detecting high temperature flame, and LWIR on imaging the target ontology. Speaking based on the background, long-wave infrared image have a strong sense of layers in infrared image with rich background scene. The distribution of the scenes is of obvious bright-dark layers, and the boundaries between different scenes are clear. Speaking based on the targets, as most of the scenes with low temperature, the boundaries and details of the scenes in the background and targets are clear. Above all, long-wave IR image is beneficial to target recognition and correlation matching. But easily interfered by the room environment causes the long–wave IR tracker less stable than the mid-wave IR tracker. This letter focuses on the long-wave IR tracking technique.

According to the characteristics of the IR video image, the flowchart of the tracking algorithm is shown as Fig. 1.

Firstly, process the acquired long-wave IR image by median filtering, and remove hot pixels; Secondly, extract the target's contour while edge detecting and inhibit the background information; Then, enhance the information of the target's contour by dilation operation of morphology. Finally, get the miss distance of the target by correlation matching operation and generate template for correlation matching in the next frame.

Due to the higher sensibility and gray scale, it is not likely to control the consistency of the pixels in a reasonable range. The pixels with big difference are called 'defect', which increase with time. So preprocessing the acquired image is necessary to filter out the information of defects. In this case, the median filtering method is commonly used to remove the isolated hot pixels.

The median filtering method is a nonlinear digital filtering technique. The main idea is to run through the signal pixel by pixel, replacing each pixel with the median neighboring pixels. The principle of median filtering method is replacing the value of a point with the median value of points in the neighboring region, thus removing isolated hot pixels. The pixels in the two-dimensional (2D)-sliding template are ranged by the value to generate data series increasing monotonically. The 2D median-filtering output is

$$g(x,y) = \mathrm{med}\{f(x-k,\ y-l), k, l \in W\}, \qquad (1)$$

where $f(x,y)$ is the original image,and $g(x,y)$ is the processed image. W is the 2D pattern, usually 2×2, 3×3 region or other shapes such as line, circle, crisscross. The median filtering is a classical method to smooth noise with advantages of removing salt and pepper noise and protecting the edge information effectively.

As shown in Fig. 2, the isolated defects are filtered out effectively.

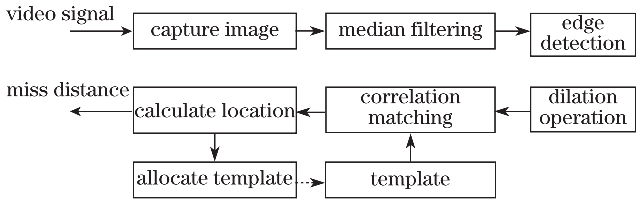
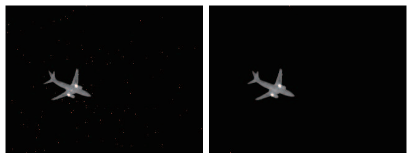


Fig. 1. Flow chart of the tracking algorithm.



(a) Original image (b) Processed image by median filtering

Fig. 2. The contrast image.

The edge detection is mainly applied to extract the feature of the target's contour and filter out background information such as the cloud, stray light in the long-wave infrared tracker. In the neighboring region of the long-wave infrared image, the IR radiation intensity of the target is generally higher than the intensity of the natural background. Thus the features of the target can be observed clearly in a small distance, which is beneficial for extracting the information of the contour's feature. In a long distance, the image of the target is small enough to take the target as an isolated bright spot with constant gray value. Because of the large-scale continuous distribution of background in space and the gradually-changed transitional distribution of background in IR radiation intensity, they have high correlation in image gray space. But the thermal radiation difference reflected by infrared image is extremely sensitive to temperature. The nonlinear distribution of atmospheric temperature field, caused by the climate change and air movement, and the effect of air scattering and absorbing the thermal radiation result in halation in IR image, low contrast between the target and background, and obscure edge of the target. Besides, extracting features of contour in long-wave IR image is harder than in visible-light image. But the contour edge of continuous-distribution background cannot be extracted either. Therefore, filtering out the background information with edge detection is reasonable and feasible.

Edge detection extracts the boundary line between the target and background by some algorithm. The changes of image greyscale are reflected by the gradient of image greyscale distribution. So, we can get edge detection operator by partial-image differential technique. The classical edge detector method is detecting the edge by structuring edge detection operator in some small neighboring region of pixels in original image. The commonly-used operators are Roberts Cross Operator, Prewitt Operator, Sobel Operator, and Kirsch Operator and so on.

As shown in Fig. 3, to short-distance target, Robert Operator and Sobel Operator can extract the edge fairly well. But, to long-distance target, the effect of Robert Operator is obviously better than Sobel Operator.

In the edge detected IR image, the filtered-out continuous background information, the target's information which only reserves the edge contour and the in continuous contour line, as a result of the interference from the background and stray light, make it necessary to strengthen the contour line. The strengthened contour line will have more information in the later correlate matching resulting in a stable tracking. Through some operations of the interaction of the body and structure element, the mathematical morphological algorithm, acquiring the topology and structure information, can get the basic shape of the body. So we can strengthen the target's contour edge information with mathematical morphology.

In mathematical morphology, Erosion Operator, Dilation Operator, Opening Operator and Closing Operator are foundational.

For simplicity, Erosion Operator and Dilation Operator are explained as follows.

ξ is 2D discrete Euclidean Space. Image A, structuring element B and point b are subsets of ξ. A_b and $\tilde{A}$ are defined by

$$A_b = \{a + b | a \in A\}, \tag{2}$$

where A_b is the translation of A by b. The elements in image A_b is the corresponding to the elements in image A translated to the coordinate oriented from b.

$$\widetilde{A} = \{-a | a \in A\}, \tag{3}$$

where $\tilde{A}$ is the reflection of the image origin.
According to Eqs. 1 and 2, Erosion and Dilation are defined by

$$A \odot B = \{x | b + x \cap A, b \in B\}, \tag{4}$$

$$A \oplus B = \{a + b | a \in A, b \in B\} \cup A_b. \tag{5}$$

Through erosion operation, the thicker edge contour lines can connect and strengthen the edge contour. As shown in Fig. 4, all the contour lines processed by dual erosion operation are strengthened fairly well and the information of contour lines increases.

Image matching technique is widely used in modern

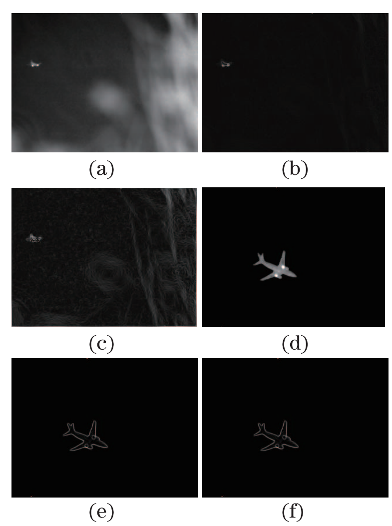


Fig. 3. Edge-detecting image. (a), (b), (c) are the long-distance-target image without background information and (d), (e), (f) are the short-distance-target images with background information.

space technology, military and medical area. It is also applied to real-time tracking system, which is called correlation tracking. Due to a small influence from noise and precise identification in complex ground environment, the correlation matching technique is absolutely necessary in real-time tracking system.

Correlation matching is at the very core of correlation tracking. The preselected target or the specific part on preselected target is regarded as correlation pattern. Whether the pattern-selected target image is in input image and the location of the target image are determined by the value and location of the peak of correlation function of correlation template and input image. There are three kinds of correlation algorithm, the target contour matching, binary image matching and greyscale correlation matching.

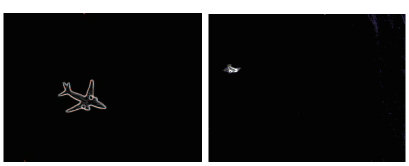
$$C(u,v) = \frac{\iint S(x,y)R(x+u,y+v)\mathrm{d}x\mathrm{d}y}{\left[\iint R^2(x+u,y+v)\mathrm{d}x\mathrm{d}y\right]^{1/2}}, \quad (6)$$

where C is the normalized correlation function, R is the input image, S is the pattern, u and v is the offset.

In spite of the large calculation, this correlation matching algorithm is effective to identify and track the target or, when the target is larger than the window, the specific part of the target.

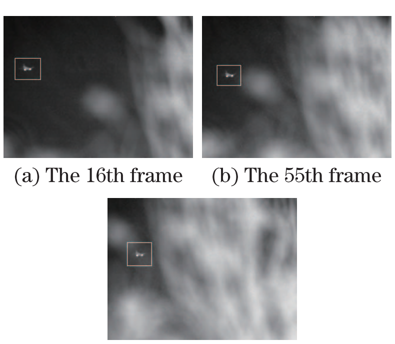
Under many circumstances, the reference image, prestored or manual selected, is the previous tracking-target frame. In the target location, the value of $C(x,y)$, the correlation function of the reference image $S(u,v)$ and the received image $R(u,v)$, is the largest. Sequence similarity detection method is commonly used. The size of digital reference image $S(i,j)$ with k level gray scale on each pixel is $M\times M$, while the receive image $R(m+i,n+j)$ containing S is $L\times L(L>M)$. So the image standard difference function is

$$E(m,n) = \sum_{i=1}^{m}\sum_{j=1}^{n} |r(m+i,n+j) - s(i,j)|. \quad (7)$$



(a) (b)

Fig. 4. Processed image by dilation operator.



(a) The 16th frame (b) The 55th frame

(c) The 112th frame

Fig. 5. Correlation tracking image.

In theory, if $R(m,n)$ is corresponding to $S(m,n)$, $E(m,n)$=0; otherwise $E(m,n)>0$.

In practice, (m,n) can be regarded as the coordinate of the target location when $E(m,n)$ is less than some threshold.

Generally there are three kinds of the existing strategies for updating the target pattern. Firstly, match the image in the best matching location of the current image with the next frame as target template. Secondly, with a constant weight, weigh the image in the best location with the old template to generate a new template. Thirdly, generate a weight according to the tracking quality in the current frame, and then generate a new template by weighing the image in the best matching location with the old template. In application, we use the matching value in the current frame as the weight to weigh the old template and the image in the best matching location, generating a new template. The weighing method is

$$M_{\mathrm{new}} = aM_{\mathrm{old}} + (1-a)M_{\mathrm{curr}}, \quad (8)$$

where M_{new} is the new template, M_{old} is the old template used now, M_{curr} is the image in the best matching location, and a is the weight namely the correlation coefficient.

It has been proved that this strategy can inhibit accumulation of the tracking difference and the drift of the tracking target effectively. Besides, even the tracking effect is awful in some frame, the next frame will return to the correct location. As verified in Fig. 5, with this algorithm, the target can avoid the interference from the background in complex background environment and be extracted and tracked steadily.

In conclusion, the correlation tracking algorithm in this letter can inhibit the interference from the background, extract and enhance the contour information effectively. Besides, the target's information in correlation operation is increased greatly, resulting in the improvement of the tracker's real-time performance and matching accuracy, more importantly, the improvement of the ability to inhibit the interference from the background. And now this algorithm is applied in real-time target's tracking system. The result shows that this algorithm can meet the real-time demand of the target's tracking system with fast calculating speed, high accuracy and well stability.

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