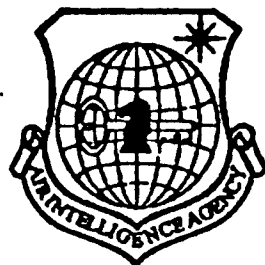


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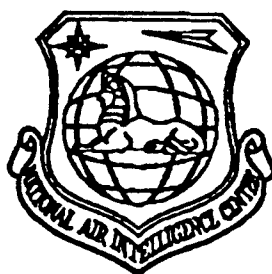


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by

Wang Tao and Lin Shangqian

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NOVEL FAST AND ACCURATE CORRELATION-TRACKING ALGORITHM

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Abstract: This paper presents a novel correlation-tracking algorithm on the basis of the Forward-Looking-Infrared-Imagery tracking work of the aiming compartment. This algorithm adopts the one-dimensional histogram quick search and two-dimension multistage sub-sample accurate positioning methods, which make it possible to realize real-time processing. It has also effectively improved the system's tracking precision by frame jump modifying of cumulative errors with a sequence of images. Finally, this paper gives some experimental results which are in accord with theoretical results.

Key words: correlation-matching, forward-looking-infrared, imaging tracking.

The correlation-tracking algorithm has many unique advantages, namely: moderate requirements for image quality and normal operation with low signal-noise ratio; simple operation not requiring complex image preprocessing; correlation operations by directly using image-element gray-scale characteristics; adaptability to a target and background with complex structure;

high anti-local jamming capabilities and insensitivity to local modification of the target and discontinuous portions of scenery. Because of the above-listed advantages, the correlation-tracking algorithm has a significant place in image-tracking technology and cannot be substituted by any other algorithm. For instance in the initial phase--the search positioning phase--of the forward-looking-infrared image tracking, the image has low contrast and it is difficult to separate man-made ground targets (such as buildings, bridges and airports, etc.) from a complex background through the image. In this case it is desirable to adopt correlation tracking as the optimal scheme, and an optimized correlation-tracking algorithm appears to be a key to realizing this scheme.

There are two major problems in realizing a general correlation-tracking algorithm in engineering projects. One of them is that it requires an excessively large computational load and time, which is unfavorable for real-time realization. The other problem is that it is accompanied with a cumulative error process, which may lead to reference-window drift and missing the target. Thus far, several practical algorithms have been created, including the SSDA method, gray scale variation correlation method, etc., which can somewhat reduce the total computational load but still cannot meet the requirements of real-time image tracking in modern weaponry.

In this paper a novel fast and accurate correlation-tracking algorithm is described, which was developed for the forward-looking-infrared image tracking system in response to the working state and tactical requirements of the aiming compartments. This algorithm uses a scheme of one-dimensional histogram quick search, and two-dimensional multistage accurate sub-sample positioning, to effectively compress image processing data and provide conditions for its real-time realization. Apart from this, the algorithm, employing the degree of correlation of the

image sequence, adopts a reference-window location frame-jump correction method to make corrections to the cumulative tracking errors and raise the tracking precision of the system.

1. One-dimensional Gray Scale Histogram Fast Rough Search Algorithm

In the initial phase of tracking, the tracking contrast appears stable and imaging conditions also remain unchanged because the target is at a short distance. It is therefore believed that the target area and its surrounding image element gray scale distribution characteristics can basically maintain unchanged in the real-time image sequence, i.e., in several frames, the reference image containing the target and the sub-image located at the matching position have a similar statistical characteristic height of the gray scale histogram. Based on this, a one-dimensional gray scale histogram can be designed to quickly screen the matching correlation points. The specified steps in realizing this algorithm are as follows:

First step: calculate the gray-scale histogram function of the reference image $H_s(x)$, where x is the gray-scale modification scope, which is evaluated as $0 < x < 255$.

Second step: select a sub-image the same size as the reference window at the real-time image search location (n, v) and calculate its histogram expressed as $H_{u,v}(x)$.

Third step: calculate the similarity between $H_s(x)$ and $H_{u,v}(x)$ simply with the one-dimensional MAD algorithm

$$D_n^0(u, v) = \sum_{x=0}^{255} |H_s(x) - H_{u,v}(x)| \quad (1)$$

For better reliability of the correlation search, a deviation of ± 1 gray scale is allowed between the real-time

pattern and the reference pattern plate. Let H_s move 1 gray scale relative to $H_{u,v}$ and conduct to subtract correlation, i.e.,

$$D_n^{+1}(u,v) = \sum_{x=0}^{254} |H_s(x+1) - H_{u,v}(x)| \quad (2)$$

$$D_n^{-1}(u,v) = \sum_{x=1}^{255} |H_s(x-1) - H_{u,v}(x)| \quad (3)$$

Then select the minimum value from the calculated values in the above three equations as the measured correlation value at that point

$$D_n(u,v) = \min [D_n^0(u,v), D_n^{+1}(u,v), D_n^{-1}(u,v)] \quad (4)$$

Fourth step: modify (n, v) , i.e., repeat the second and third steps throughout the correlation search area (for faster speed, it is possible to select only the sub-image at the lattice points) so as to acquire the histogram correlation-matching measured curved face of the reference image and real-time image throughout the search area $D_n(u,v)$.

Finally, select an area corresponding to the valley on the curved face $D_n(u,v)$ as an option area for further fine correlation-matching. To improve reliability, it would be wise to choose more areas (i.e., locations corresponding to the second and third minimum value of $D_n(u,v)$ 4:1 as possible option areas.

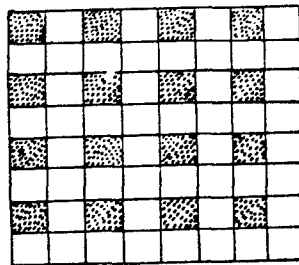


Fig. 1. 4:1 Sub-sample pattern with black-dot image elements forming pattern A

2. Multistage Sub-sample Correlation-matching Algorithm

During the tracking of ground fixed man-made targets, the imaging device moves relative to the scenery. Viewed from the filming plane, the whole scene is translational. To estimate such movement, it is sufficient to estimate the movement of some of image elements in the scene. On this basis, the multistage sub-sample correlation-matching algorithm can be adopted for the option areas determined in the rough search for faster and more accurate matching.

Structure of 4:1 sub-sample pattern:

Fig. 1 shows a 4:1 (image elements) sub-sample pattern structure, where black dots represent pattern A, while the other three 4:1 sub-sample patterns are B, C and D, which, respectively, are made up of image elements to the left, under and at the bottom right of the black-dot image elements. These four sub-sample patterns are used alternatively across the correlation area and produce a better effect than only one of them used alone. The alternation principle of the four patterns is as follows: if pattern A is used at the location (x,y) , then it should also be used at the location $(x+2i,y+2j)$ (i and j are integers); pattern B is used at $(x+2i,y+1+2j)$; pattern C is employed at $(x+1+2i,y+2j)$; and pattern D is used at $(x+1+2i,y+1+2j)$. Similarly, 16:1 and 64:1 sub-sample patterns can also be constructed, which are used alternatively at different locations and formulate a multistage sub-sample pattern.

The multistage sub-sample fast correlation-matching algorithm operates in the following steps:

First step: adopt the multistage sub-sample pattern to perform two-dimensional correlation in every correlation window for the option areas selected in the rough search algorithm as

described above. First, use a higher level (64:1) sub-sample pattern to remove most non-matching points, and those left are a new option point album. Then, use the 16:1 and 4:1 patterns to further remove non-matching points.

Second step: adopt the 1:1 sub-sample pattern to deal with the remaining few option points (usually 4), i.e., all image elements in the window are involved in the correlation operations.

Third step: from the several correlation coefficients calculated in the last step, select the locations corresponding to the maximum values as matching points.

The dimensions of the correlation-tracking reference-image window are selected based on target-background characteristics and correlation-matching performance in integration. In our experiment, the reference dimension was selected as (64x64).

Whether or not the reference image needs replacement and how to replace it depends on the confidence level of correlation tracking. In fact, correlation tracking is to realize target tracking by replacing the reference images frame by frame. If the confidence level of correlation tracking is lower than a particular threshold (T_c), it indicates that the present image is unreliable and it has to be further correlated with the original reference image or otherwise, it should be replaced with the window image at the matching location.

The confidence level signal of correlation tracking is designed on the basis of analyzing the performance of the correlation-matching algorithm as a vitally important parameter. The larger the matching peak value and the larger the difference between the peak value and the correlation measured mean values

of other non-matching points, the more reliable the tracking can be. Suppose the fourth step in the foregoing correlation-matching algorithm generates $Q+1$ measurement $\psi(J)$, where $\psi(0)$ is the measurement of a non-matching point while the rest are Q number of non-matching points, then the measured mean value of the non-matching point is calculated as follows:

$$\bar{\psi}_j = \frac{1}{Q} \sum_{j=1}^Q \psi(j) \quad (5)$$

and the tracking confidence level c is

$$c = \psi(0) \cdot [\psi(0) - \bar{\psi}_j] \quad (6)$$

3. Frame-Jump Correlation-Tracking Cumulative-Error Correction Scheme

Because each matching error in correlation tracking is more than 1 image element, the reference window may drift and miss the target if such errors accumulate during correlation tracking. To solve the problem, a frame-jump cumulative-error correction scheme was adopted in this paper. The basic philosophy of this scheme is to correct the cumulative errors generated from $(i-L)$ frame to the present frame (i -th frame) making use of the $(i-L)$ frame reference image.

Assume the corrected reference image s_{i-L} and the present reference image s_{i-j} are respectively matched with the real-time image at the locations $[x_{M_i}^{(i)}, y_{M_i}^{(i)}]$ and (x_{M_i}, y_{M_i}) ; the confidence level, respectively, is $c_i^{(i)}$ and c_i ; and the target image location deviation of the present frame i relative to the last frame $(i-1)$ and frame $(i-L)$, respectively, is $(\Delta x_i, \Delta y_i)$ and $[\Delta x_i^{(i)}, \Delta y_i^{(i)}]$, i.e.,

$$\begin{cases} \Delta x_i = x_{M_i} - x_{M_{i-1}} \\ \Delta y_i = y_{M_i} - y_{M_{i-1}} \end{cases} \quad (7)$$

$$\begin{cases} \Delta x_i^{(i)} = x_{M_i}^{(i)} - x_{M_{i-L}} \\ \Delta y_i^{(i)} = y_{M_i}^{(i)} - y_{M_{i-L}} \end{cases} \quad (8)$$

then the cumulative location deviation from the i-L frame to the i-th frame is

$$a_{x_i} = \sum_{j=0}^{i-1} \Delta x_i^{(j)} \quad , \quad a_{y_i} = \sum_{j=0}^{i-1} \Delta y_i^{(j)} \quad (9)$$

By comparing (a_{x_i}, a_{y_i}) , with $[\Delta x_i^{(i)}, \Delta y_i^{(i)}]$,
if $a_{x_i} \leq \Delta x_i^{(i)}$, and $a_{y_i} \leq \Delta y_i^{(i)}$, then the matching location of the
present frame does not need correction, or otherwise it can be
corrected with the following equation

$$\begin{aligned} x_{M_i} &= \frac{c_i}{c_i + c_i^{(i)}} a_{x_i} + \frac{c_i^{(i)}}{c_i + c_i^{(i)}} \Delta x_i^{(i)} + x_{M_{i-L}} \\ y_{M_i} &= \frac{c_i}{c_i + c_i^{(i)}} a_{y_i} + \frac{c_i^{(i)}}{c_i + c_i^{(i)}} \Delta y_i^{(i)} + y_{M_{i-L}} \end{aligned} \quad (10)$$

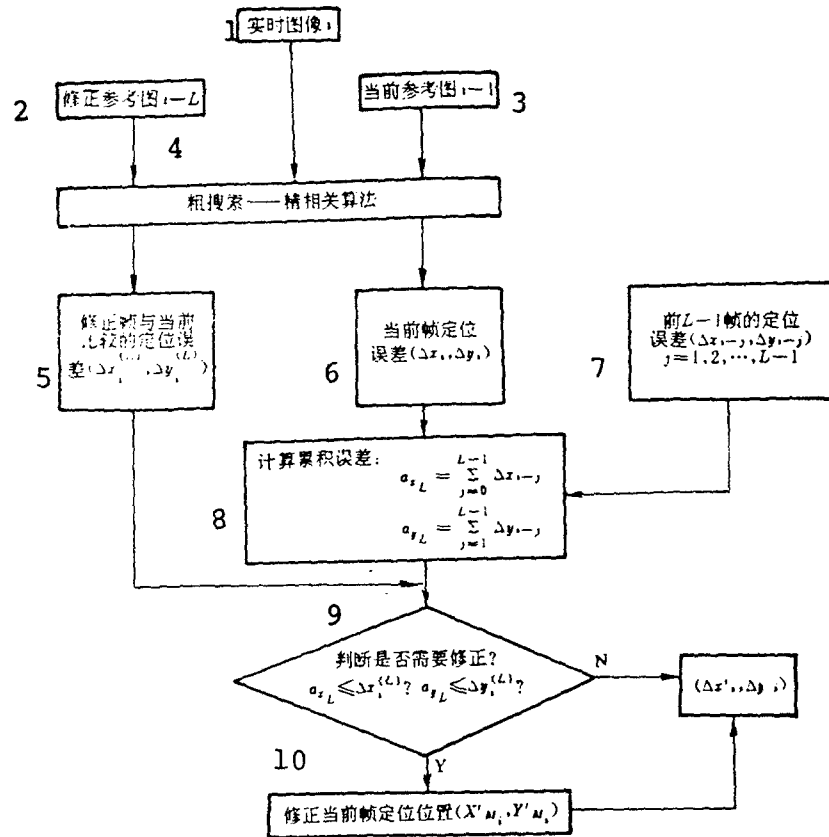


Fig. 2. Flow chart showing correction of correlation cumulative errors

- Key:
- (1) Real-time image i
 - (2) Correct reference image $i-L$
 - (3) Present reference image $i-1$
 - (4) Rough search--precise correlation algorithm
 - (5) Positioning error of corrected frame compared with present frame
 - (6) Positioning error of present frame
 - (7) Positioning error of last $L-1$ frame
 - (8) Calculate cumulative errors
 - (9) Judge if correction is needed
 - (10) Correct positioning location of present frame

where L is the number of corrected frames, which is determined from the variation of target dimensions, other distortions and precision requirements of the correlation tracking system. In our experiment, $L=5$.

Fig. 2 is a flow chart showing the process of correlating the cumulative errors of the correlation-tracking system.

4. Experimental Results and Conclusions

A simulation experiment was conducted by the author of the novel algorithm proposed in this paper by using the video pictures of the forward-looking-infrared image filmed on the spot.

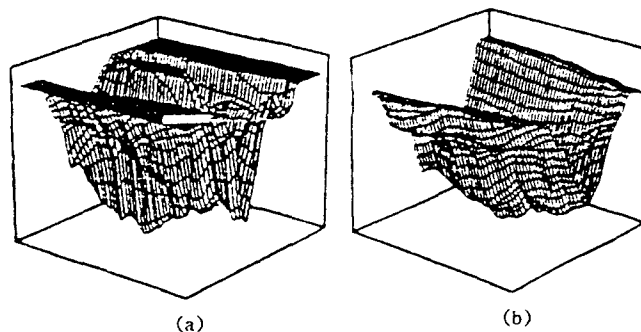


Fig. 3. Correlation measured curved face

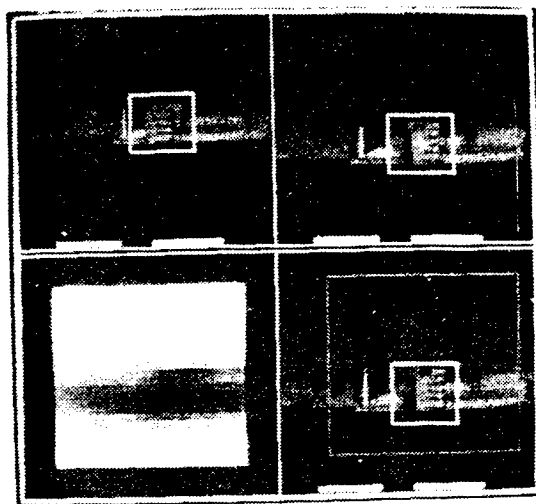


Fig. 4. Photographs of rapid and precise correlation-tracking (positioning) experiment

Fig. 3 shows correlation curved face photographs of images filmed on the spot, where (a) is the MAD two-dimensional curved face of an input image; and (b) is the histogram one-dimensional MAD correlation curved face of the same input image. It is known through a comparison between the two photographs that they are extremely similar in shape, although (b) is less fine than (a). This suggests that the scheme of conducting a one-dimensional histogram correlation quick search of the lattice is feasible.

Fig. 4 shows the multistage sub-sample quick and precise correlation positioning photographs. The one on the top left is a reference image, from which the image in the window is selected as a reference image. The matching location is searched in the second image (bottom right) filmed 0.5s later with its reference image window dimensions 64×64 , while the large window is the search area. The photograph on the bottom left is a histogram one-dimensional MAD rough search correlation curved face. In the top right photograph, the cross marks the location of precise correlation-matching. The experimental results indicate that although the target image has a complex structure and there is a

certain modification of the perspective angle between the two images, the above-described fast correlation algorithm still can realize precise target positioning to confirm the effectiveness of this algorithm.

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