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A Loop-Template Matching Algorithm for Target Tracking Based on Kalman Filter*

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Abstract: The global searching method is adopted in the traditional correlation algorithms in target tracking system, resulting in the large amounts of calculation, the difficulty of real-time implementation and even the loss of the tracking target when the target is partially shaded or in sharp attitude variation. To solve the problems, an improved approach based on the loop correlation template matching and Kalman filter is proposed to realize target tracking. Kalman filter, to make the tracking more active, estimates the possible region of the target in the next frame at first, and finds the best matching points by the loop correlation matching in the aforementioned region while the loop-template matching overcomes the loss of the horizontal matching points caused by the sharp attitude variation. So the algorithm has strong robustness, and is of translation and rotation invariance. In the experiments, the proposed algorithm is applied to the tracking of a main battle tank partially shaded and a jet with "Viktor Pugachev's Cobra". Compared with the traditional algorithms, the algorithm herein can steadily track the targets in less time without losing them.

Key words: Target tracking; Kalman filter; Template; Loop matching; Horizontal matching; Correlation tracking

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0 Introduction

Correlation tracking, also known as matching tracking, is based on image similar measure, whose aim is to find the most similar image to the template in the real-time process. It does not need image segmentation and feature extraction. And the operation is only based on the original image data so that it can preserve all the information. So it is a practical tracking method. But in the global search and matching process, the algorithm has a huge quantity of calculation and high cost, and hence is difficult to be realized real-timely. At the same time, the global situation anti-disturbance capability is not satisfying in practice. Especially when the template and a certain part of background are similar and the target is in high maneuvering or the target attitude variation is sharp, it is easily lost, which make the robustness necessary for the new algorithms. To solve these problems, a loop-template matching algorithm for target tracking based on Kalman filter is proposed in this paper. The searching area can be determined by Kalman estimation, so the searching area and the computation complexity decrease greatly, and the anti-disturbance capability enhances significantly. When the target is partially shaded or in sharp attitude variation, the estimation by last frame can be used in loop matching calculation to replace the best matching point. The loss of the target by traditional horizontal matching will not occur in the improved algorithm. It can keep response of the target maneuverability rapidly.

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1 Algorithm description

1.1 Kalman filter formulas

In the system of target tracking, the track can be considered as a discrete-time dynamic system described by the following vector difference equations

$$\boldsymbol{X}(n+1)=\boldsymbol{\Phi X}(n)+\boldsymbol{G}_w(n) \quad (1)$$

$$y(n+1)=\boldsymbol{HX}(n)+v(n) \quad (2)$$

In the case where $\boldsymbol{Q}$ and $\boldsymbol{R}$ are completely known, the solution is provided by the steady state filter[2] (estimate the value of the next time by the value of present time)

$$\hat{\boldsymbol{X}}(n+1|n)=\boldsymbol{\Phi}\hat{\boldsymbol{X}}(n|n) \quad (3)$$

$$\hat{\boldsymbol{X}}(n|n)=\hat{\boldsymbol{X}}(n|n-1)+\boldsymbol{K}_n[y(n|n-1)-$$

$$\boldsymbol{H}\hat{\boldsymbol{X}}(n|n-1)] \quad (4)$$

$$\boldsymbol{K}_n = \boldsymbol{P}(n|n-1)\boldsymbol{H}^{\mathrm{T}}[\boldsymbol{H}\boldsymbol{P}(n|n-1)\boldsymbol{H}^{\mathrm{T}}+\boldsymbol{R}]^{-1} \quad (5)$$

$$\boldsymbol{P}(n|n-1) = \boldsymbol{\Phi}\boldsymbol{P}(n-1|n-1)\boldsymbol{\Phi}^{\mathrm{T}}+Q \quad (6)$$

$$\boldsymbol{P}(n|n) = (\boldsymbol{I}-\boldsymbol{K}_n\boldsymbol{H})\boldsymbol{P}(n|n-1) \quad (7)$$

In which, $\boldsymbol{\Phi}$ refers to state the transition matrix. $\boldsymbol{R}$ refers to the measurement noise variance-covariance matrix and $\boldsymbol{Q}$ to the system noise variance-covariance matrix. $\boldsymbol{H}$ is measurement matrix. And $\boldsymbol{K}_n$ refers to the Kalman gain.

So we can find out in the recursion equations (3)~(7), they are easy to be realized by computer programs.

1.2 Limitations of traditional horizontal matching algorithm

The principle of correlation matching[3] is that the template in the target image slides in the tracking window. The correlation value between the template and its coverage region is calculated in accordance with a certain criterion. The center of the best matching region is regarded as the target center. Low computational complexity in correlation matching is necessary for the high real-time performance. The traditional algorithm (the Mean Absolute Difference, MAD algorithm) with low computational complexity is used to measure the matching degree between two images by calculating their mean absolute value of the gray level difference.

Let the size of template be $M \times N$. Then thedistance between the same size images D and Cin tracking window[5] is

$$d(C,D) = \frac{1}{c}\sum_{i=1}^{M}\sum_{j=1}^{N}|C_{i,j}-D_{i,j}| \quad (8)$$

Where $c = M \times N$. The region with the minimum d is the matching region. From equation (8), it is easily found out that d increases rapidly with the target in a rotary motion or a sharp attitude variation. The template is a rectangular region, and the gray level difference of the same size of the region in the matching image is statistically analyzed from left to the right. The center in the image of the same size of the rectangular region with the minimum d is regarded as the center of the target. When the target is in rotary motion or in sharp attitude variation, the value of the real target region statistics will increase rapidly under the condition of statistical analysis from left to right. Then the target will be regarded as the background by mistake. So the traditional algorithm is not effective for motion in sharp attitude variation but only for translational motion. If the target is partially shaded, it will be lost too.

To solve the problems caused by the limitations, a loop-template matching algorithm for target tracking based on Kalman filter is proposed in the paper.

1.3 An improved loop-template matching algorithm for target tracking

Regions in tracking window the size of template are arranged to form into loop, whose center (it can be regarded as the first loop) are set to estimated matching point by last frame. The second loop contains eight regions whose size is the same with that of the template around the center of the first loop. The algorithm is used to match the center and the eight neighborhood regions extended outward. As a result eight matching values are obtained, in which the region with the maximum value is as the best matching region. The obtained best matching region is used as the new center to match the new eight neighborhood regions with loop template. After similar recursion a loop-template matching algorithm for target tracking is proposed.

The principle is shown in Fig. 1. Let the center be A, which is the estimated matching region by last frame. It matches 8 neighborhood regions around the center F, E, D, C, B, I, H and G, respectively in anticlockwise order. The matching path is shown in Fig. 2. After finding out the best matching region (let it be H), the matching is finished in current frame. Regard H as the region in practical measurement to correct the estimation by last frame. And the result is used as the estimation basis in next frame.

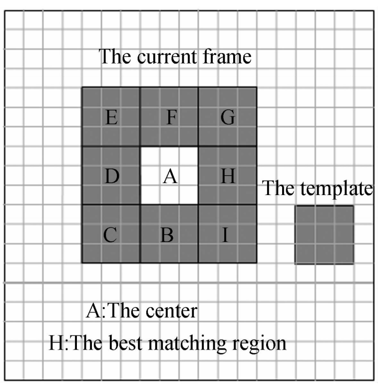

Fig. 1　Eight neighborhood regions for loop matching

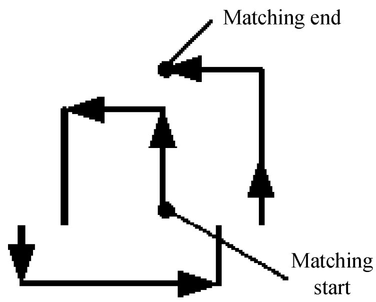

Fig. 2 Matching path

To realize the estimation algorithm, we should build two standard Kalman estimators (estimator in x coordinate and in y coordinate) for every best matching region from the first frame on.

Let $\boldsymbol{X}$ refer to the status vector of an estimator. Where

$$\boldsymbol{X}(n)=\begin{bmatrix}x_1(n)\\x_2(n)\\x_3(n)\end{bmatrix}$$

$x_1(n)$ refers to the position of the best matching region in the n-th frame; $x_2(n)$ refers to the velocity of the best matching region in the n-th frame; $x_3(n)$ refers to the acceleration of the best matching region in the n-th frame. And the state transition matrix and measurement matrix are

$$\boldsymbol{\Phi}=\begin{bmatrix}1 & T & T^2/2\\0 & 1 & T\\0 & 0 & 1\end{bmatrix}\quad \boldsymbol{H}=[1\quad 0\quad 0]$$

In which T is the interval time in interframe. The variance of measurement noise is $\boldsymbol{R}=\sigma_r^2$. The covariance matrix of system noise is

$$\boldsymbol{Q}=\begin{bmatrix}0 & 0 & 0\\0 & 0 & 0\\0 & 0 & \sigma_q^2\end{bmatrix}$$

The improved loop-template matching algorithm is designed to solve the problem of partial occlusion, high maneuverability or sharp attitude variation. In case of Gaussian white noise some parameters have been given, in which $\sigma_r^2=0.94$, $\sigma_q^2=0.96$.

The correction coefficient matrix $\boldsymbol{K}_n$ is very important. We must match in loop neighborhood region in the first frame, the second frame and the third frame to obtain the position of the best matching region. Then we should obtain the mean square error $\boldsymbol{P}(n|n-1)$. And the calculated vector estimation matrix is

$$\hat{\boldsymbol{X}}(3)=\begin{bmatrix}x_1(3)\\ [x_1(3)-x_1(2)]/T^2\\ [x_1(3)-2x_1(3)+x_1(1)]/T^2\end{bmatrix}$$

The MSEM is

$$\boldsymbol{P}(3)=\begin{bmatrix}\sigma_r^2 & \sigma_r^2/T & \sigma_r^2/T^2\\ \sigma_r^2/T & 2\sigma_r^2/T^2 & 3\sigma_r^2/T^3\\ \sigma_r^2/T^2 & 3\sigma_r^2/T^3 & \sigma_q^2+6\sigma_r^2/T^4\end{bmatrix}$$

According to the estimation equations (3)～(7), we can obtain $\boldsymbol{K}_3$, $\boldsymbol{X}_3(4)$, $\boldsymbol{P}_3(4)$. Then let the first element of $\boldsymbol{X}_3(4)$ be as the estimated position in the next frame, shown as B in Fig. 5. Let the first element of $\boldsymbol{P}_3(4)$ be as the mean square error of the estimation in the next frame. The searching region is decided with them. Fig. 3 shows that the X coordinate of the searching start is the difference of the X estimation and the value $\boldsymbol{K}$ times of the interval error ρ_x (according to actual condition adopt corresponding empirical value). The Y coordinate is the difference of the X estimation and the value K times of the interval error ρ_y. By experience when K is $1\sim2$, stable tracking can be realized. The searching width in X direction of the searching region is two times of the sum of $K\rho_x$ and the X-width of the template, and the searching width in Y direction of the searching region is two times of the sum of $K\rho_y$ and the Y-width of the template.

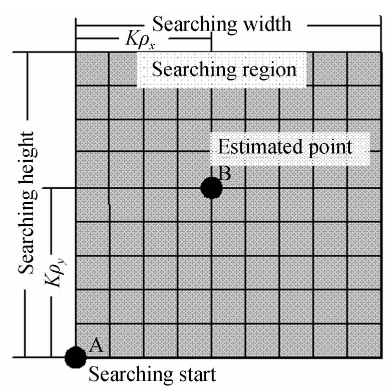

Fig. 3 Searching region

Then above process is repeated in the next frame, and $\boldsymbol{K}_4$, $\boldsymbol{X}_4(5)$, $\boldsymbol{P}_4(5)$ are obtained. Estimations in every frame are calculated with recursion equations. When the target is in partial occlusion, high maneuverability or sharp attitude variation, the better loop-template matching algorithm can be used to track the target accurately. Even if the target is lost, the previous estimations are used as the best matching region to match again. So the better loop-template matching algorithm is designed to solve the problem caused by the aforementioned limitations.

If we consider some other factors such as the unknown variance caused by the colored noise surrounding, we can treat them as followes

From equations (5) and (6), we can find

$$\boldsymbol{K}_n=\boldsymbol{P}(n|n-1)\boldsymbol{H}^{\mathrm{T}}[\boldsymbol{HP}(n|n-1)\boldsymbol{H}^{\mathrm{T}}+\boldsymbol{R}_{n-1}]^{-1}\quad(9)$$

$$\boldsymbol{P}(n|n-1)=\boldsymbol{\Phi}\boldsymbol{P}(n-1|n-1)\boldsymbol{\Phi}^{\mathrm{T}}+\boldsymbol{Q}_{n-1} \tag{10}$$

And we can estimate the $\boldsymbol{R}_n$ and $\boldsymbol{Q}_n$ by the following recursion equations

$$\tilde{\boldsymbol{y}}(n)=\boldsymbol{H}\hat{\boldsymbol{X}}(n|n-1)-\boldsymbol{y}(n) \tag{11}$$

$$\tilde{\boldsymbol{x}}(n)=\hat{\boldsymbol{X}}(n|n)-\hat{\boldsymbol{X}}(n|n-1) \tag{12}$$

We can obtain the measurement noise mean matrix r_n and the system noise mean matrix q_n by follows

$$\boldsymbol{r}_n=1/n[(n-1)\boldsymbol{r}_{n-1}+\tilde{\boldsymbol{y}}(n)] \tag{13}$$

$$\boldsymbol{q}_n=1/n[(n-1)\boldsymbol{q}_{n-1}+\tilde{\boldsymbol{x}}(n)] \tag{14}$$

And the measurement noise mean matrix $\boldsymbol{R}_n$ and the system noise mean matrix $\boldsymbol{Q}_n$ are computed by follows

$$\boldsymbol{R}_n=1/n[(n-1)\boldsymbol{R}_{n-1}+(\tilde{\boldsymbol{y}}(n)-\boldsymbol{r}_n)(\tilde{\boldsymbol{y}}^{\mathrm{T}}(\boldsymbol{n})-\boldsymbol{r}_n)^{\mathrm{T}}] \tag{15}$$

$$\boldsymbol{Q}_n=1/n[(n-1)\boldsymbol{Q}_{n-1}+(\tilde{\boldsymbol{x}}(n)-\boldsymbol{q}_n)(\tilde{\boldsymbol{x}}(n)-\boldsymbol{q}_n)^{\mathrm{T}}] \tag{16}$$

Then the adaptive ability can be increased by the obtained $\boldsymbol{R}_n$ and $\boldsymbol{Q}_n$.

2　Experiment results analysis

The algorithm is realized on the hardware platform: CPU memory to 1 GHz and CPU to 2.8 GHz and in the software environment: Windows XP operating system and Visual C++ 7.0 integrated development environment. The results are as follows:

1) Dealing with the problem of sharp attitude variation.

"Viktor Pugachev's Cobra" makes the jet reach post-stall state, so it's too sharp is difficult to be tracked for the target.

100 frame image sequences of the jet with "Viktor Pugachev's Cobra" are used for target tracking. The results of the better loop-template matching algorithm for target tracking based on Kalman filter are shown respectively in Fig. 4. (a) shows the template; The results are shown in the 6th frame, in the 12th frame, in the 17th frame, in the 20th frame, in the 28th frame, in the 35th frame, in the 49th frame and in the 54th frame are respectively shown in (b)～(i). We can find out in the Fig. 5 that the jet is in sharp attitude variation. The traditional algorithm[11] can't be used to track stably, and the target will be lost. But stable tracking is always in the 100 frame image sequences with the algorithm given in the paper. The better tracking effect shows strong Robustness. The tracking time in the experiment is 8 ms. It meets the requirement of real-time tracking (processing rate >25 frames/s).

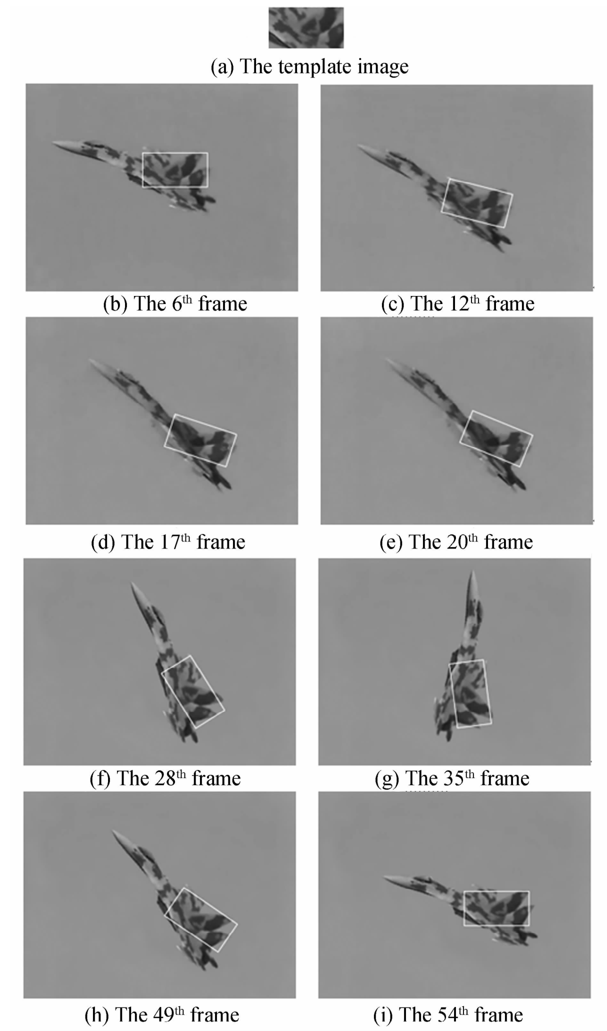

Fig. 4　The tracking results of image sequences with sharp attitude variation by the improved algorithm

2) Dealing with the target partially shaded.

100 frame image sequences of a main battle with the max image resolution which is 256×128 are used for target tracking. When the target (the tank) is partially shaded, some characteristics are lost. The results of the better loop-template matching algorithm for target tracking based on Kalman filter are shown respectively in Fig. 5. (a) shows the template; (b) and (c) show the image respectively in the 17th frame and in the 24th frame before being shaded; (d) and (e) show the image respectively in the 25th frame and in the 27th frame being shaded. (f) and (g) show the image respectively in the 30th frame and in the 34th frame after being shaded; It is obvious that the proposed algorithm is very effective when the target is being shaded in the 24th frame and in the 27th frame. And it is strongly robust because stable tracking is always in the 100 frame image sequences. But with the traditional algorithm[10], the target will be lost in the 24th frame and in the 27th frame and be tracked in the 3 1th again . The target is often lost

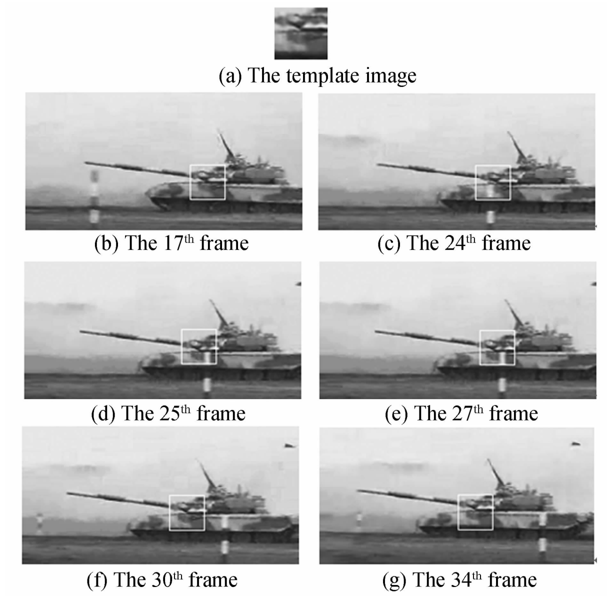

Fig. 5 The tracking results of image sequences with partial shaded by the improved algorithm

for disturbance in all the 100 frame image sequences.

In process of the tracking, the traditional method needs 80 ms, but the matching time is only 3 ms in the better loop-matching algorithm. It is much faster than real-time processing rate (25 frames/second). The results have been more fully explains the advantages of this method.

3 Conclusion

The algorithm is simple but effective. The experiment proves its superior performance and robustness in real-time signal processing. And it is suitable to be realized on the hardware platform. Given a coarse-to-fine matching strategy or some other optimization algorithms is used, the filtering result is more perfect. Then if the algorithm is ported to the hardware system, and accelerated by FPGA or DSP, the Real-time performance is further improved and it can be applied on the cruise and guidance effectively.

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一种基于 Kalman 滤波的环形模板匹配相关跟踪算法

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摘　要: 为了解决在目标跟踪系统中,传统相关算法在目标发生目标局部遮挡或旋转等姿态变化较大的情况时容易跟踪丢失的问题,提出一种改进的基于卡尔曼预测器的环形模板匹配相关跟踪的算法. 利用卡尔曼预测器来预测下一帧目标可能出现的区域,然后在较小的预测区域中进行环形相关匹配运算,找到最佳相关匹配点,使跟踪更具主动性。环形匹配还可以克服由于姿态变化而引起的横向匹配点丢失,从而可以跟踪各种姿态运动的机动目标. 实验中,利用改进算法对出现局部遮挡情况的姿态变化大的运动目标进行跟踪,传统算法处理此类情况容易跑飞,而本文算法不受这两种跟踪局限性的干扰,始终稳定跟踪机动目标且耗时大幅减少.

关键词: 目标跟踪; 卡尔曼预测; 模板; 环形匹配; 横向匹配; 相关跟踪

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