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Kernel Bandwidth Adaptive Target Tracking Algorithm Based on Mean-Shift

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Abstract: The kernel bandwidth of the classical Mean-Shift tracking algorithm is fixed, and it usually results in tracking failure when the target's size changes. A kernel bandwidth adaptive Mean-Shift tracking algorithm is presented with frame difference method to solve the question in this paper. According to the targets' size obtained from the inter-frame difference method, the bandwidth matrix of kernel function can be updated. Because the improved Mean-Shift algorithm is difficult to position target while it moves fast, so a Kalman filter is put forward as auxiliary tracker further in the paper. The results of experiment show that the target's tracking accuracy of the non-rigid motion based this algorithm is improved by 3.28 % and the fast motion can be adapted to the target via the introduction of the prediction mechanism. This algorithm improved the defects on the target tracking which uses single color feature or motion information, so it is a practical tracking algorithm. *Copyright © 2013 IFSA.*

Keywords: Color feature, Motion detection, Adaptive kernel bandwidth, Mean-Shift algorithm, Kalman filter.

1. Introduction

Target tracking is widely used in areas such as video surveillance, cruise missile terminal guidance [1]. The Mean-Shift algorithm is firstly proposed by Fukunaga K. etc. [2], which is a unsupervised clustering method based on nonparametric probability density estimation of kernel function. The Mean-Shift algorithm is used in the field of target tracking [3-12].

Because of the better real-time performance and effectiveness, it is obtained to get widespread attention. However, the kernel function bandwidth of classical Mean-Shift tracking algorithm is fixed, when the target's size were increasing gradually even beyond the kernel bandwidth range, then the fixed the bounding box often lead to the loss of the tracking. Reference [4] uses plus or minus 10 % increments to correct the kernel bandwidth. When the target is narrowing, the method can obtain better tracking results. But when the target is increasing, the bounding box will usually get smaller and smaller on the contrary. A method is presented which uses SIFT algorithm to extract the target's parameters such as feature scale and the main direction of feature points in [5], then the Mean-Shift is used to position the targets, but this method has the weaknesses such as the large computation amount, poor real-time performance. It combines Gaussian scale stratification theory and Mean-Shift algorithm in [6], and its nature is the same as [5]. Reference [7] presented a backward tracking, centroid registration kernel bandwidth updating algorithm, but this algorithm is only suitable for affine motion model, unable to track non-rigid motion.

Therefore, for the shortcoming of [4-7], this paper which is based on the Mean-Shift algorithm, promote the concept of kernel bandwidth to bandwidth matrix.

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It introduces the bandwidth matrix updating mechanism, and fuses the inter-frame difference motion detection algorithm, gets the geometric dimensions of the target in the current frame from the binary image of the moving target, in order to update kernel bandwidth matrix of the Mean-Shift algorithm.

2. Adaptive Kernel Bandwidth Mean-Shift Algorithm

2.1. Expression of Target's Size

Inter-frame difference method is used to detect the change of the moving targets size in this paper firstly. It is because that the inter-frame difference method is simple, and suit to all kinds of dynamic environment, can adapt to meet the real-time requirement. Three frames difference method is used in this paper, and the Mathematical definition of three frames difference method is represented as follows:

If f_n , f_{n-1} , f_{n+1} represents the gray value of three arbitrary continuous images, then the pixel by pixel difference images D_n and D_{n+1} can be defined as formula (1):

$$\begin{aligned} D_n(i,j) &= \left| f_n(i,j) - f_{n-1}(i,j) \right| \\ D_{n+1}(i,j) &= \left| f_{n+1}(i,j) - f_n(i,j) \right| \end{aligned} \tag{1}$$

Then, the difference images D_n and D_{n+1} is binary, such as the formula (2):

$$F_t(i,j) = \begin{cases} 1 & D_t(i,j) \geq T \\ 0 & D_t(i,j) < T \end{cases}, \quad t = n, n+1 \tag{2}$$

where T is the threshold value, because of taking into account the changes of the environmental noise, it need to dynamically select the threshold value, so Ostu threshold value method is used in this paper to determine the threshold value of the D_n. Finally two binary images F_n and F_{n+1} are carried out and operation, to get the moving foreground region M_n, such as formula (3):

$$M_n(i,j) = F_n(i,j) \cap F_{n+1}(i,j) \tag{3}$$

Then the binary image M_n is operated morphological filtering, to generate new target binary image T_n. Then threshold processing will be executed according to the area of connection object, to eliminate some small, isolated noise point. The processing results are shown as Fig. 1 (a), Fig. 1 (b).

Fig. 1 (a). The original image.

Fig. 1 (b). The binary image T_n.

2.2. Kernel Bandwidth h is Extended to the Matrix H

In order to make the Mean Shift tracking algorithm suitable for the affine motion or non-rigid motion, this paper draws on the idea of reference [1, 4], the single kernel radius h is extended to the bandwidth matrix H, H is shown as (4):

$$H = \begin{bmatrix} h & 0 \\ 0 & w \end{bmatrix}, \tag{4}$$

where h and w are the length of the major axis and minor axis of the window region respectively. The improved Mean-Shift algorithm uses the formula (5-7) respectively to represent the color of the target template, the target's candidate region distribution, and the iterative formula of the target's centroid location as follows:

$$q_u = C\sum_{i=1}^{n}\left\{ k\left((x_i - x_0)^T (H^T H)^{-1} (x_i - x_0) \right) \cdot \delta(b(x_i) - u) \right\} \tag{5}$$

$$\mathrm{p}_u = C_u\sum_{i=1}^{n}\left\{ k\left((x_i - x_c)^T (H^T H)^{-1} (x_i - x_c) \right) \cdot \delta(b(x_i) - u) \right\} \tag{6}$$

$$x_c = \frac{\sum_{i=1}^{n} x_i \omega_i g\left((x_b - x_i)^T (H^T H)^{-1} (x_b - x_i)\right)}{\sum_{i=1}^{n} \omega_i g\left((x_b - x_i)^T (H^T H)^{-1} (x_b - x_i)\right)} \quad (7)$$

2.3. The Updating of Bandwidth Matrix H

The updating process of kernel bandwidth matrix H in this algorithm is shown as Fig. 2:

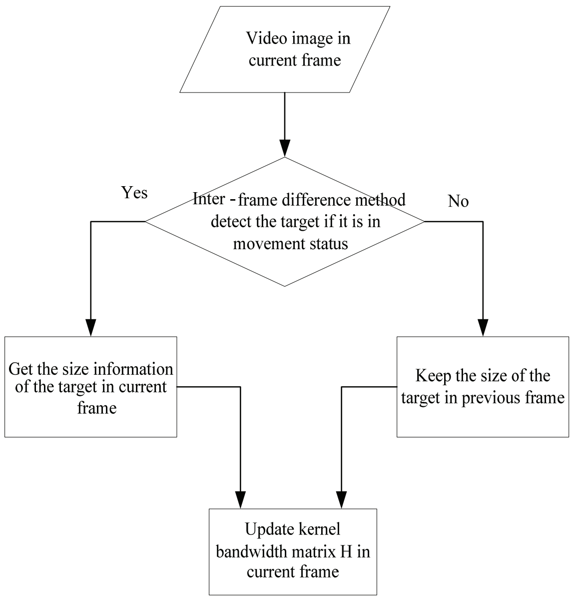

Fig. 2. The updating of bandwidth matrix H.

3. The Supplementary Improvement by Kalman Filter

Mean Shift algorithm requires that there are overlap regions between two successive frames for targets. Therefore, the Kalman filter is used as an auxiliary tracker. The Kalman filter could track the target by predicting, its principle is mainly composed through the following five equations, such as (8-12).

$$\hat{X}_{i|i-1} = A\hat{X}_{i-1} \quad (8)$$

$$P_{i|i-1} = AP_{i-1}A^T + Q \quad (9)$$

$$\hat{X}_i = \hat{X}_{i|i-1} + K_i(Z_i - H\hat{X}_{i|i-1}) \quad (10)$$

$$P_i = (I - K_i H)P_{i|i-1} \quad (11)$$

$$K_i = P_{i|i-1}H^T(HP_{i|i-1}H + R)^{-1}, \quad (12)$$

where X_i is the state vector, Z_i is the observation vector, H is the measurement matrix, W_i is the state noise, V_i is the measurement noise x_i is the position vector of the moving target, and v_i is the velocity vector.

The supplementary improved algorithm is shown as Fig. 3.

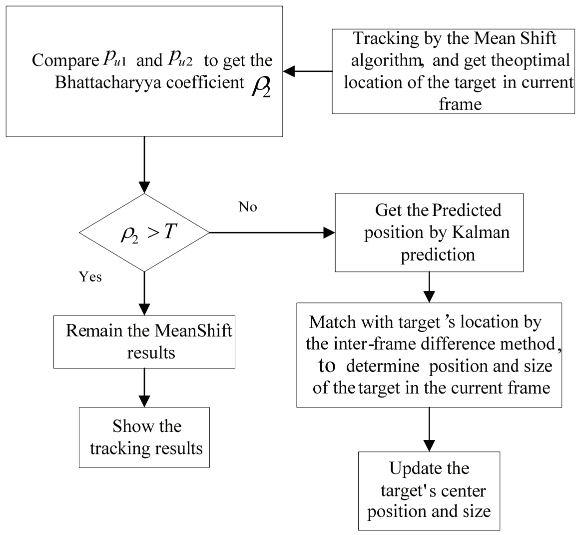

Fig. 3. The supplementary improved algorithm.

Where p_{u1} and p_{u2} respectively is the color histogram distribution of the target's candidate location in current and previous frame. In Fig. 3, the value of T influences the experimental operation speed directly. It is assigned 0.3 by experimental method, and it is used as threshold value to determine whether the target move too fast to result in no overlap between the previous frame and the current frame.

4. Experimental Results and Analysis

The development platform is Matlab 7.0. In Experiment 1, A nonrigid object is tracked by the classical Mean Shift algorithm and the improved algorithm. The processed video SampleVideo.avi is a test video sequence for target tracking. The number of frame is 80, the manual initialize size of bounding box is 137×36, Comparison of experimental results is shown as Fig. 4 (a), Fig. 4 (b):

In this video, with the dimensions of the target gradually increases. The bounding box of classic algorithm can not adaptively change its size, leading the goal with severe tracking offset; on contrast, the proposed algorithm has a good robustness for the target tracking of non-rigid motion. In 30 times comparative experiments for this video, the average processing time of classical Mean Shift algorithm is

5.26 s, and the improved algorithm is 11.62 s. The x-coordinate/y-coordinate comparison charts of the target's center obtained by these two algorithms are given in Fig. 5. It can be seen from Fig. 5, the tracking error of the improved algorithm is smaller than the classical Mean-Shift algorithm. The mean of error and the mean of relative error to x-coordinate/y-coordinate of target's center for these two algorithms are given in Table 1, in order to measure the tracking accuracy.

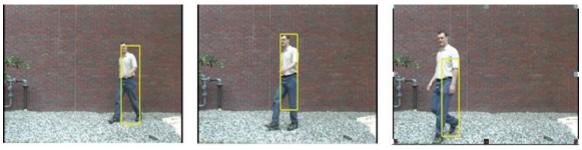

Fig. 4 (a). Tracking results of Classical Mean Shift Algorithm (Frame 20, 50, 79).

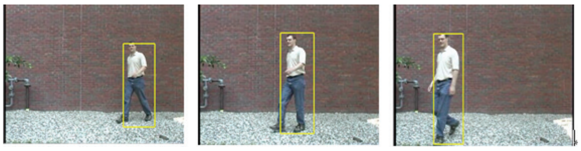

Fig. 4 (b). Tracking results of improved Algorithm in this paper (Frame 20, 50, 79).

Table 1. A comparison of tracking accuracy of the two algorithms.

Algorithm	Mean of error (Mean of relative error)	
	x-coordinate of the target's center	y-coordinate of the target's center
This algorithm	11.62 (6.76 %)	3.50 (2.56 %)
Classical Mean-Shift algorithm	14.05 (8.36 %)	8.01 (5.84 %)

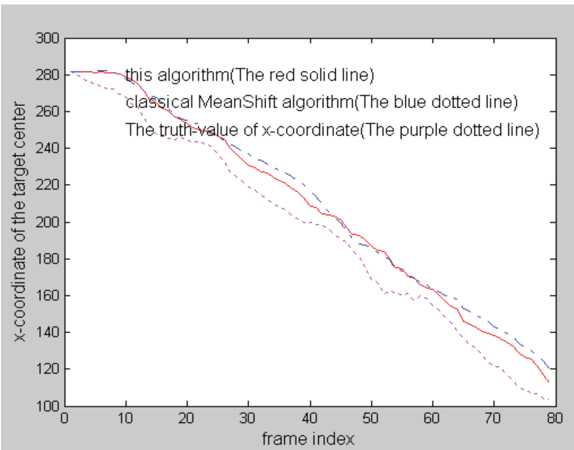

Fig. 5 (a). The comparison chart of x-coordinate.

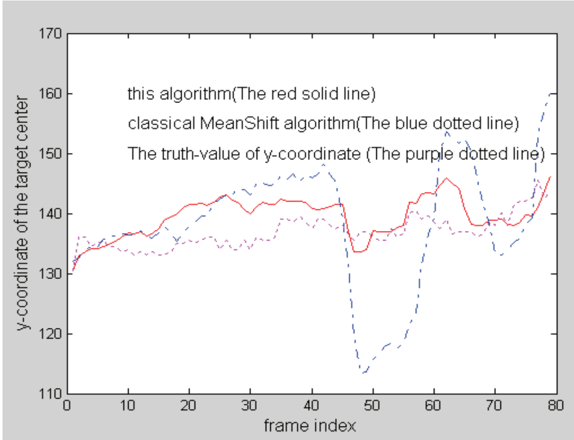

Fig. 5 (b). The comparison chart of y-coordinate.

Experiment 2 is the simulation for supplementary improved algorithm, which has been mentioned in this paper. The Video sequence processed is a sequence of image which is captured from PetsD2TeC2.avi that is provided from IBM human vision researching Center, and the time step is set 14 to simulate the rapid movement of the target. A pair of comparison charts that before and after the Kalman filter used as supplementary improvement to track the target are given by Fig. 6 (a), Fig. 6 (b).

Fig. 6 (a). The tracking results before supplementary improvement.

Fig. 6 (b). The tracking results after using Kalman filter as supplementary improvement.

It can be seen in Fig. 6 (a), when the target car is moving too fast, the Mean shift algorithm will fail since the algorithm is lack of predictive ability. It will result in bounding box retention, so it need to introduce Kalman prediction mechanism and match with the target's position detected by inter-frame difference, and meanwhile update the central location and dimensions of the target in real time. As shown in Fig. 6 (b), it can achieve accurate tracking.

5. Conclusions

As the experiment results show, the algorithm in this paper achieved two improvements as follows: First, the tracking accuracy of nonrigid motion is improved 3.28 %. Second, this algorithm has a strong adaptability for the fast motion of the target. However, this article doesn't consider the occlusion of the targets yet. The match between the targets will make mistake easily if there exists the occlusion between the targets, and these problems will be studied as a key issue in the next step of the work.

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