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A Multiple Object Tracking Method Using Kalman Filter

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***Abstract* –It is important to maintain the identity of multiple targets while tracking them in some applications such as behavior understanding. However, unsatisfying tracking results may be produced due to different real-time conditions. These conditions include: inter-object occlusion, occlusion of the ocjects by background obstacles, splits and merges, which are observed when objects are being tracked in real-time. In this paper, an algorithm of feature-based using Kalman filter motion to handle multiple objects tracking is proposed. The system is fully automatic and requires no manual input of any kind for initialization of tracking. Through establishing Kalman filter motion model with the features centroid and area of moving objects in a single fixed camera monitoring scene, using information obtained by detection to judge whether merge or split occurred, the calculation of the cost function can be used to solve the problems of correspondence after split happened. The algorithm proposed is validated on human and vehicle image sequence.** The results shows that the **algorithm proposed achieves efficient tracking of multiple moving objects under the confusing situations.**

Index Terms - Kalam filter, motion model, multi-object tracking , Occlusion

I. INTRODUCTION

Moving object tracking of video image sequences is one of the most important subjects in computer vision. It has already been applied in many computer vision field, such as video surveillance, artificial intelligence, military guidance, safety detection, and robot navigation, medical and biological application etc..[1]. In recent years, a number of successful single-object tracking system appeared, but In the presence of several objects, the problem is one of multiple object tracking where targets and observations need to be matched from frame to frame in a video sequence. The multiple object tracking is still a challenging, and it will be harder especially in the case of that the objects have a similar appearance [2].

To deal with these problems, researchers did a lot of works.and gained many good achievements. Nguyen et al. [3] used Kalman filter in distributed tracking system for tracking multiple moving people in a room using multiple cameras. Whereas Chang et al. [4] use both Bayesian network and Kalman filtering to solve the correspondence problem between multiple objects. In [5], a video surveillance system is proposed where detection, recognition and tracking of object is carried out. However, multiple objects are tracked by using the c-constant velocity Kalman algorithm. The performance of the approach is dependent on the proposed detection and recognition algorithms. In another work [6], vector Kalman is proposed for tracking objects. In this paper, separate methods for occlusion and merge are applied to handle the confusing situations. Further states of the corresponding moving objects are searched using spiral searching prior to tracking. Medioni *et al.* [7] proposed an approach based on graph theory for tracking multiple targets. Their algorithm considered splits only, and they used gray level correlation between objects and segmented blobs to detect and handle splits. Recently Czyzewski and Dalka [8] used Kalman filter with RGB color-based approach to measure the similarity between moving objects. A threshold is applied to measure the similarity between the detected regions which fails in fully occluded scenarios.

In this paper, we use Kalman filter to establish object motion model, using the current object's information to predict object's position, so that we can reduce the search scope and search time of moving object to achieve fast tracking. Establishing corresponding relationship through moving object features matching to deal with separation after objects merged.

Experimental results show the proposed method is able to ensure an efficient and robust tracking with merge and split of multi-object.

II. OBJECT TRACKING USING KALMAN FILTER

A. *Typical Kalman filter*

Mathematically, Kalman filer is an estimator that predicts and corrects the states of wide range of linear processes[9]. It is not only efficient practically but attractive theoretically as well Precisely, the optimal state is found with smallest possible variance error, recursively. However, an accurate model is an essential requirement.

In Kalman filer, we consider a tracking system where x_k is the state vector which represents the dynamic behaviour of the object, where subscript k indicate the discrete time. The objective is to estimate x_k from the measurement z_k . Following is the mathematical description of Kalman filer, which for understanding we have sectioned into four phases.

1) *Process equation*

$$x_k = \mathbf{A}x_{k-1} + w_{k-1} \quad (1)$$

Where A represents the transition matrix and x_k the state at time $k-1$ to k. Vector w_{k-1} is the Gassian process noise $N(.)$ With following normal probability distribution $p(w)$.

$$p(w) \sim N(0,Q) \tag{2}$$

2) Measurement equation

$$z_k = Hx_k + v_k \tag{3}$$

Where H is the measurement matrix and z_k is the measurement observed at time $k-1$ to k respectively. v_k is the Gaussian measurement noise $N(.)$ with normal probability distribution $p(v)$.

$$p(v) \sim N(0,R) \tag{4}$$

3) Time update equations

Equation (1) and (3) describes a linear model at time k. As x_k is not measured directly, therefore the information provided by measured z_k is used to update the unknown states x_k .Apriori estimate of state $\hat{x}_k^-$ and covariance error $\hat{x}_k$ estimate is obtained for the next time step k.

$$\hat{x}_k^- = A\hat{x}_{k-1} + w_k \tag{5}$$

$$P_k^- = AP_{k-1}A^T + Q \tag{6}$$

4) Measurement update equations

These equations are associated with the feedback of the system. The objective is to estimate aposteriori estimating $\hat{x}_k$ which is a linear combination of the apriori estimate and the new measurement z_k .These equations are given below:

$$K_k = P_k^- H^T (HP_k^- H^T + R)^{-1} \tag{7}$$

$$\hat{x}_k = \hat{x}_k^- + K_k(z_k - H\hat{x}_k^-) \tag{8}$$

$$P_k = (1 - K_k H)P_k^- \tag{9}$$

K_k is the Kalman gain which is computed by above the measurement update equations. After that aposterior state estimate $\hat{x}_k$ and aposterior error estimate P_k is computed by the measurement z_k .The time and measurement equations are calculated recursively with previous aposterior estimates to predict new aprior estimate. This recursive behaviour of estimating the states is one of the highlights of the Kalman filter.

B. *Kalman Filter for Multi-object Tracking*

Describing the object's geometric features can include location, shape and center of mass (centroid)[10], etc.. The camera we used in this paper sampling time is 30fps, so there is relatively little changed of moving object in two adjacent frames, so we can consider that the size of tracking window and cetroid position of moving target in the adjacent two frames are little changed, that is said, moving target in the adjacent two frames of the movement is continuously. Therefore, we choose centroid and size of tracking window as the feature value to describe moving object. After the moving objects have been segmented, some process preparations for the subsequent moving object tracking is needed. First to assign a tracking window for each moving object in the scene, in order to prevent a lot of noise easy to come in, tracking window should not be too large. We make the tracking window size slightly larger than the object image size, so that it not only can reduce the noise interference, but also can reduce image processing time and increase speed of operation. Kalman filter tracking model can be divided into three sub-modules which are :motion model, feature matching, model update[11].

1) Motion Estimation Model

Kalman filter used for tracking is defined in terms of its states, motion model, and measurement equations matrix X_k is an eight-dimensional system state vector, which can be expressed as:

$$x_k = [x_{0,k}, y_{0,k}, l_k, h_k, v_{x,k}, v_{y,k}, v_{l,k} v_{h,k}]^T \tag{10}$$

Where, $x_{0,k}$, $y_{0,k}$ represent horizontal and vertical centroid coordinate, l_k , h_k represent half-width and half-height of the tracking window, $v_{x,k}$, $v_{y,k}$, $v_{l,k}$, $v_{h,k}$ represents their speed respectively.

The measurement vector of the system adopts the ollowing from:

$$z_k = [x_{0,k}, y_{0,k}, l_k, h_k]^T \tag{11}$$

In the following, A is the transition matrix and H is the measurement matrix of our tracking system along with the Gaussian process w_k and measurement v_k. These noise values are entirely dependent on the system that is being tracked and adjusted empirically.

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 & \Delta t & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & \Delta t & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & \Delta t & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & \Delta t \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Observation matrix H can be described as:

$$H = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

After the state equation and measurement equation of motion model are defined, in the next frame, Kalman filter can be used to estimate the object's location and size in a small range, and to gain trajectories of moving objects.

2) Feature matching

Each moving object is described by its centroid and tracking window, the horizontal and vertical centroid coordinates and the area of the i^{th} object in the k^{th} frame were respectively described as x_k^i , y_k^i and S_k^i.

First, centroid distance function between the i^{th} object in the k^{th} frame and the j^{th} object in the $k+1^{th}$ frame is defined as:

$$D(i,j) = \frac{\left|\sqrt{(x_k^i - x_{k+1}^j)^2 + (y_k^i - y_{k+1}^j)^2}\right|}{Max_n \left|\sqrt{(x_k^i - x_{k+1}^n)^2 + (y_k^i - y_{k+1}^n)^2}\right|} \tag{12}$$

Scend, the area difference between the i^{th} object in the k frame and the j^{th} object in the k+1th frame is defined as:

$$A(i,j)=\frac{\left|S_k^i-S_{k+1}^i\right|}{Max_n\left|S_k^n-S_{k+1}^n\right|} \tag{13}$$

Where, $S_k^i=4l_k^ih_k^i$, which represents the area of tracking window. It reflects the degree of deformation of the window, the smaller the value is, the closer description of the two objects's shape is.

With these definitions we define cost function is:

$$V(i,j)=\alpha D(i,j)+\beta A(i,j) \tag{14}$$

Where, $\alpha+\beta=1$, we can make $\alpha=0.8$, $\beta=0.2$ here. The smaller the cost function's value is, the two objects are more likely have correspondence.

3) Model Update

When the minimum value of cost function is found, we use the $k+1^{th}$ frame features to update parameters of kalman filter motion model, and use them as the input in the next frame. Repeatedly doing this to finish the model update until the moving objects disappeared.

III. Occlusion problem

In this paper, we use background subtraction method to detect and extract moving objects, through detection results to determine whether there has a occlusion or split between multiple objects.

When we found by detection that multiple objects's region connected together, we believe that the objects' region have merged, to make the multiple objects as a whole object to track, and to establish a new eigenvalue for object matching. When a object contains more than one moving object split into several independent moving objects, first to judge whether merge occurred before, if it happend, matching the split objects' with objects' feature before splitting. If not, we consider the objects are news by splitting, new eigenvalues will be established and new tracking windows will be assigned for moving objects tracking.

The Figure. 1 gives a two moving objects example for illustration.

As shown in Figure 1, two moving objects T_A and T_B occlusion occurred in time k_1, they merged into to one object T in time k_2. Starting from time k_2, objcet T will be tracked as a new moving object. During time k_2 to time k_3, object T_A

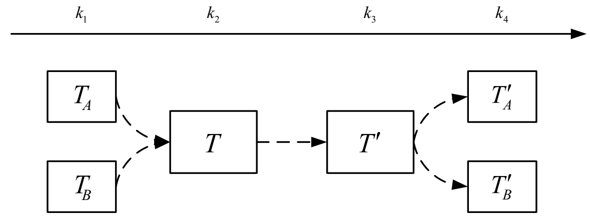


Figure 1 Illustration for merge and split

and T_B also will be updated as well while updating object T.

When the update has finished, object T turns to object $T^{'}$. Object $T^{'}$ starts to split in time k_3, during time k_3 to time k_4 .object $T^{'}$ splits into two objects, $T_A^{'}$ and $T_B^{'}$. Then we make a judgement whether the object is T or not, if it is, we believe that the moving object is the one which has merged before, then we matching $T_A^{'}$ and $T_B^{'}$ with T_A and T_B in a certain range of objects' locations, establishing and updating the correspondence, then delete object T. If it is not, the splitted out object is a new, to establish a new Kalman filter motion model for the objects respectively.

The algorithm steps are as follows:

1 If the current image is the first frame, establishing motion model and assigning tracking window for each moving object in the scene. If the current image is the k^{th} frame, and the moving object do not fall into any of those eatablished tracking windows, we consider it is a new object, establishing a new Kalman filter motion model, initializing the model for tracking.

2. Searching features for each object near the tracking window in the scene, calculate the value of the cost function, the minimum value is the best match.

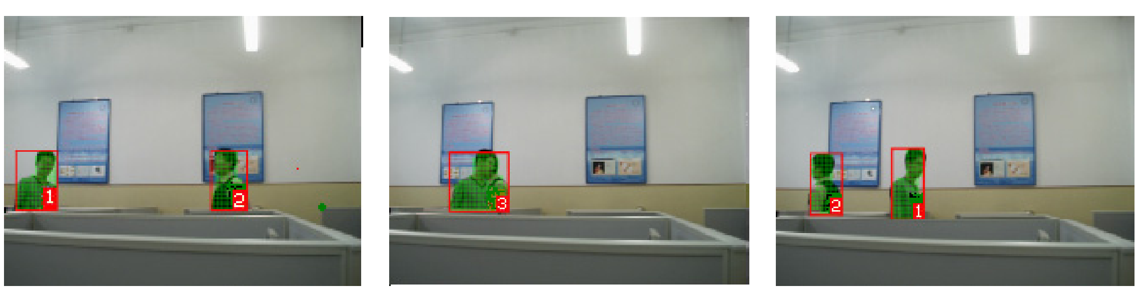
3. To judge whether there is a occlusion happened, if it happened, go to the merge or split treatment. If not, keep tracking the object until it disappeared.

4 Turning to the handling of the next frame until the object disappeared, the tracking is complete.

IV. Experimental results and analysis

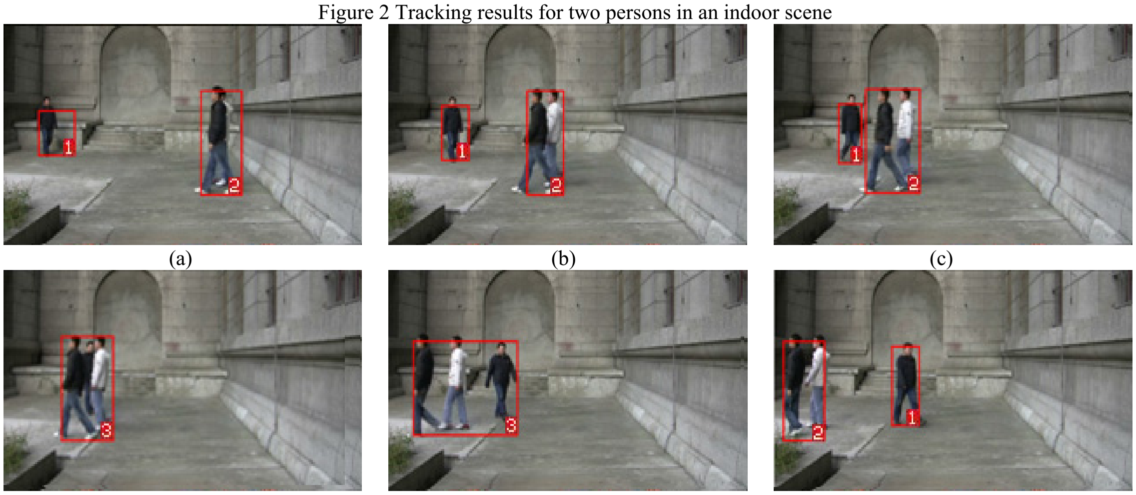
A. Indoor moving human body tracking

Figure. 2 shows the tracking results for a video of moving human bodies in an indoor scene, the two persons are exchanging positions and both of them have been tracked properly in spite of the merge that occurs due to occlusion. In Figure 2(a), these two persons are initialized and assigned a tracking window and ID reapectively when they come into this



(a) (b) (c)

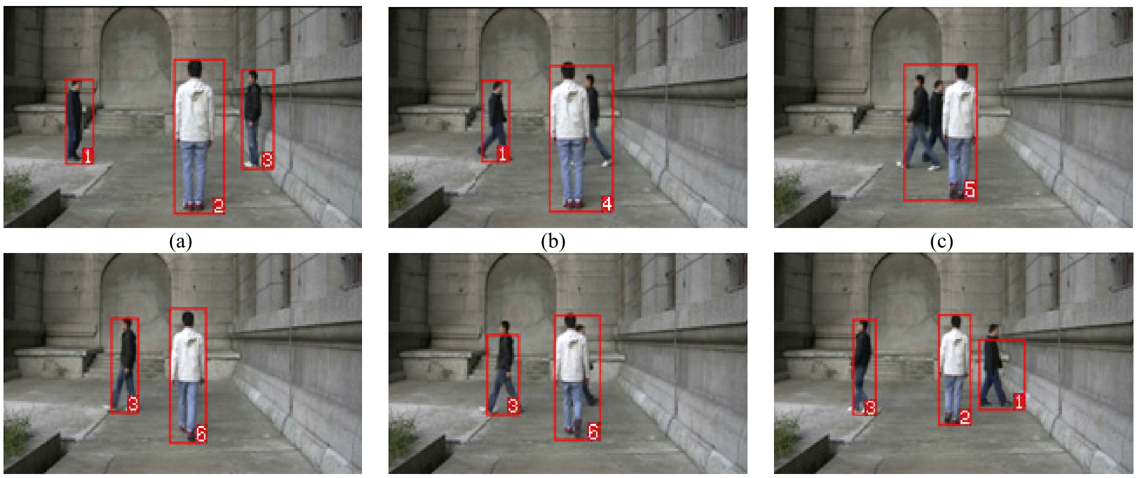
Figure 2 Tracking results for two persons in an indoor scene



(a) (b) (c)

(d) (e) (f)

Figure 3 Tracking results for three persons in an outdoor scene A



(a) (b) (c)

(d) (e) (f)

Figure 4 Tracking results for three persons in an outdoor scene B

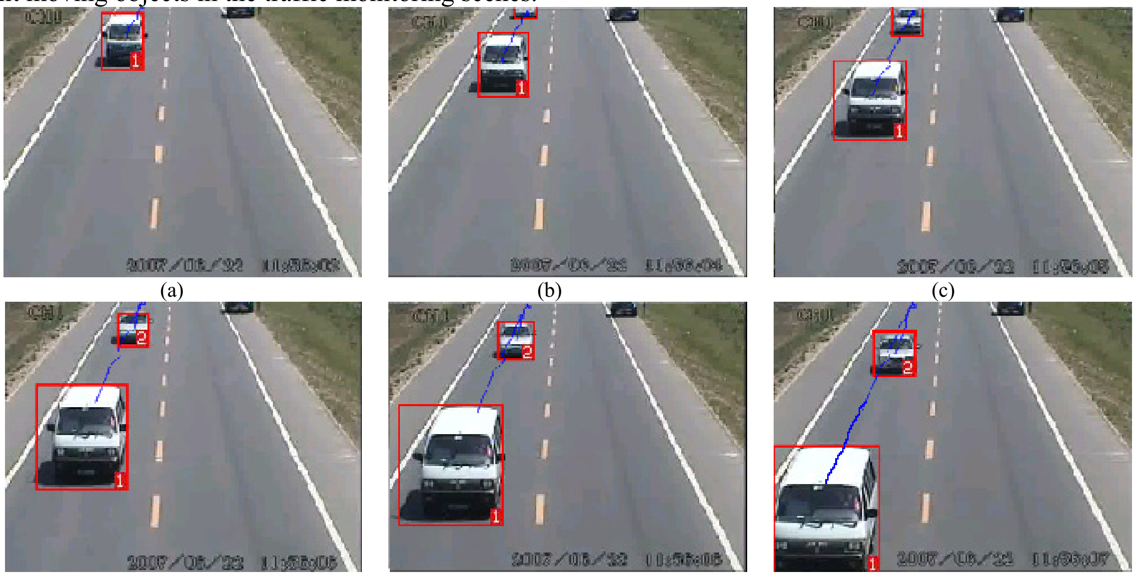
field of view, and the shape of the two person is filled with green so that we can easy to see the changes during the Figure 2(b), occlusion occurs of the two persons, so we merge them into one object, seeing it as a new object for tracking, simultaneously assigning a new ID for it. In figure 2(c), the moving object occurs separation, the splitted objects maintain their IDs correctly by using feature matching of Kalman filter motion. It is difficult to track moving human bodies because their shape change is difficult to track and their motion is difficult to learn and predict. However, here also we have been able to track multiple persons.correctly after they merge and separate.

B. Outdoor moving human body tracking

Figure. 3 and Figure. 4 show the tracking results for a video of moving human bodies in an outdoor scene. The situation in fiure 3 is similar with figure 2, there are two moving objects in the scene, and both occured occlusion, but the diffirence of the two experiences is that the second object with two persons and they been seen as one whole identity, the correctly after multi-object splitted, see figure. 3(f).In figure 4, the situation for tracking is more complex, each of the person is a indepent object, not only the Kalman motion models are need to be established for every object, but also the judgement is needed whether any of these objects merged together or split from a muti-person object. The information is sent to their associated trackers to maintain correct ID for tracking after multi-person object separated. The tracking results show that the Kalman filter based tracker does a good job of tracking the human bodies when they get partially or completely occluded, even in the difficult case of simultaneous merge and split.

C. Vehicle Tracking

We use traffic sequences to verify the tracking method based on Kalman filter, with the tracking results as shown in Figure4, we can see that the method has a good tracking speed and it can track fast moving object such as vehichles as well. When a car come into the scene, it is be seen as a new tracking object, to distribute a new nember and to initialize tracking window for that car. The tracking results of vehicles show the tracking method is able to correctly handle the new entry and exit moving objects in the traffic monitoring scenes.



(a) (b) (c)

(d) (e) (f)

Figure 5 Tracking results for vehicles

V. CONCLUSION

In this paper, we researched multi-target tracking algorithm based on Kalman filter. First to establish Kalman filter motion model, to choose centroid and tracking window as the features. Selecting the center of mass moving targets and tracking of the window as the feature. Through feature matching to establish information links. The use of matching results update the model of moving objects. using the updated model as the next frame of the input parameters. So that can be achieved continuous tracking of objects. combining with obtained detection information to judge whether there is a block between objects. the establishment of motion model to the emerged object. establishing motion model to the separation of blocked moving objects. And using the prediction of Kalman filter matching and tracking. Experimental selected different scenes and objects, and effectiveness and robustness of the algorithm have been proved

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