Exploiting the Temporal Coherence of Motion for Linking Partial Spatiotemporal Trajectories *

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Abstract

We address in this paper the problem of establishing trajectories of objects in a long image sequence, in the case of occlusion, disocclusion of objects, and crossing trajectories and junctions. Two complementary criteria have been investigated to come to the decision of linking two partial pieces of trajectory, that could come from a single object in motion : the continuity of the global trajectory, and the continuity of the velocity of the moving object. Experiments have been conducted on long sequences of real images. Complete trajectories are successfully recovered.

1 Introduction

The major contribution of this work is to explore, and propose an original solution, to the problem of establishing trajectories of objects from an image sequence, in the case of occlusion, disocclusion of objects, and crossing trajectories and junctions. In contrast to classic tracking algorithms, our method relies on more complex primitives, such as regions, and exploits a robust motion information, directly extracted from the sequence of images. A full description of the work is available in [1].

2 Birth, maintenance, and death of trajectories

Instantaneous measurements of the region position and shape are provided by a motion-based segmentation algorithm. Let $\mathbf{x}(t) = [x_1, y_1, \ldots, x_n, y_n]^T$ be the set of vertices of the convex hull of a polygonal approximation of the region. An affine transform characterizes the dynamic evolution of this region descriptor between t and $t+1$ [2] :

$$\mathbf{x}(t+1) = \mathbf{A}(t)\mathbf{x}(t) + \mathbf{b}(t) + \xi(t) \quad (1)$$

$\boldsymbol{\xi}(t)$ is a sequence of zero-mean Gaussian white noise. Let us note $\mathbf{a}(t) = (\mathbf{A}(t), \mathbf{b}(t))$, the affine transform. It depends only on the six parameters of an affine model of the 2-D motion field within the region, which are estimated with a multiresolution estimation scheme [1]. A Kalman filter generates the *optimal filtered estimate* [3] : $\hat{\mathbf{a}}(t) = (\hat{\mathbf{A}}(t), \hat{\mathbf{b}}(t))$, given the instantaneous measurements : $\tilde{\mathbf{a}}(0), \ldots, \tilde{\mathbf{a}}(t)$ [1].

Each time a new moving object appears in the field of view, a new tentative trajectory is initiated. Incoming measurements are used to update the established trajectories. In a multiple object tracking environment, associating measurements and trajectories becomes a complicated problem. Therefore a gate, or validation zone, where the measurements will be found with some high probability, is defined [1].

If a region corresponding to an established trajectory disappears in one or more frames, the trajectory is not immediately dropped. At each instant we obtain the *optimal predicted estimate* [3] until we find a frame where an association can be achieved with a new starting trajectory. The decision of associating such a new trajectory with the established one will be deferred until enough information can be gained from the new trajectory as explained in the following. However, if too much a long time elapses without measurement we will decide to drop the trajectory [1].

3 The deferred linking technique

We discuss here the procedure designed to associate an existing trajectory for which we have no more measurement for one or more frames, with a new starting trajectory. We consider a region represented by its state vector $\mathbf{x}^0$, that has been tracked from time t_0 until time t_j. At time t_j the region totally disappears and we do not have any more measurement since that time. At time t_k a region, represented by its state vector $\mathbf{x}^1$, appears within the validation gate. A new trajectory is started for this new region, and is considered as established at time $T > t_k$. Our problem is the following - could the new trajectory :$\{\hat{\mathbf{x}}^1(t_k), \ldots, \hat{\mathbf{x}}^1(T)\}$ and the previously existing trajectory :$\{\hat{\mathbf{x}}^0(t_0), \ldots, \hat{\mathbf{x}}^0(t_k)\}$

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be interpreted as a single object in motion ?

Let $\mathbf{a}^i(t)$, $i = 0, 1$, be the affine transform characterizing the dynamic evolution, given by (1), of each region. Let $\hat{\mathbf{a}}^0(t_k|t_j)$ be the *optimal predicted estimate* of $\mathbf{a}^0(t_k)$ given the measurements $\tilde{\mathbf{a}}^0(t_0), .., \tilde{\mathbf{a}}^0(t_j)$. And let $\hat{\mathbf{a}}^1(t_k|T)$ be the *optimal smoothed estimate* of $\mathbf{a}^1(t_k)$ given the measurements $\tilde{\mathbf{a}}^1(t_k), .., \tilde{\mathbf{a}}^1(T)$. Both estimates can be obtained using efficient recursive algorithms [3]. We accept the hypothesis that both partial trajectories come from a single object in motion if the following criteria are satisfied :

(i) From the instant the new region first appeared in the validation gate of the existing trajectory, it should remain consecutively present within this gate during a short fixed time interval,

(ii) the squared difference of $\hat{\mathbf{a}}^0(t_k|t_j)$ and $\hat{\mathbf{a}}^1(t_k|T)$ normalized by the covariance (which is a χ^2 distributed random variable [1]) should be "small".

The criterion (ii) requires the system model after time t_k to be the continuation of the system model before time t_k. Because $\mathbf{a}^i(t)$ depends only on the parameters of the affine model of 2-D motion field, (ii) requires the motion along the global trajectory to be continuous. On the other hand (i) requires the complete trajectory, composed of the two partial trajectories to be spatially continuous. Our approach allows to consider multiple hypotheses for the association of partial trajectories. As opposed to classic branching or splitting techniques our method is not combinatorially explosive [1].

4 Experiments

We present in Fig. 1 two sequences with junctions of trajectories and long occlusions. The tracked regions are presented in Fig 1 (a,c). We notice in Fig. 1.b, and Fig. 1.d that the reappearing regions (solid lines) fall within the gate (dashed lines) of the corresponding previously tracked regions, thus the first criterion (i) is satisfied. Criterion (ii) is also satisfied [1], and the complete trajectories are successfully recovered.

References

[1] F.G. Meyer and P. Bouthemy. Exploiting the temporal coherence of motion for linking partial spatiotemporal trajectories. 1993. to appear as Research Report IRISA/INRIA.

[2] F. Meyer and P. Bouthemy. Region-based tracking in an image sequence. In G. Sandini, editor, *Proc. of 2nd ECCV-92*, pages 476–484, Springer-Verlag, 1992.

[3] J.S. Meditch. *Stochastic Optimal Linear Estimation and Control*. McGraw-Hill, 1969.

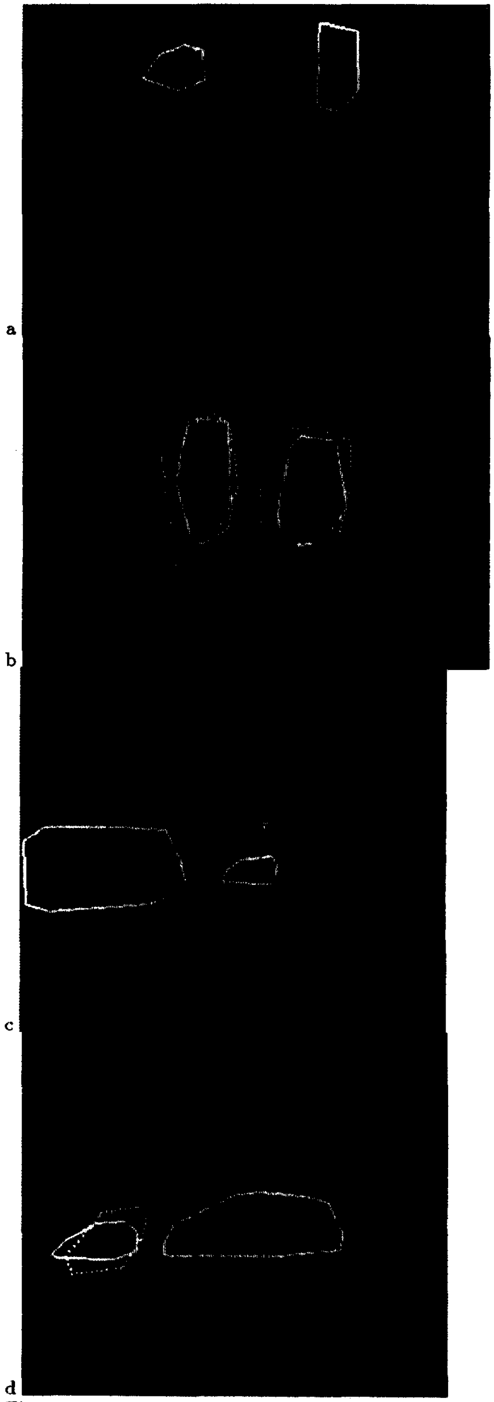

Figure 1 : (a,b) : sequence *breakfast* t_1, t_{26}
(c,d) : sequence *van* t_{30}, t_{62}