Shape-Based Approach for Pointwise Tracking of Contours

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Abstract

For several applications in Medicine, it is fundamental to determine the temporal tracking of structure points such as the apex of heart. This tracking can provide important information of effective movement and contraction of muscles. The objective of this work is to present an alternative methodology for pointwise tracking of contours based on intermediary contours.

Given two closed contours (c(0) and c(t)) derived from two consecutive image frames, the basic idea is to estimate intermediary contours based on shape and then track prominent points of c(0) up to c(t) considering all contours. For each step, an optimum mapping is obtained taking into account closeness, curvature similarity and displacement on the contours.

Evaluation with simulated contours showed that using interpolated contours improves the tracking. An increased number of intermediary contours improves slightly the results as well.

1. Introduction

Temporal tracking of medical structures is a fundamental step for several important applications in Medicine. The tracking of heart wall, for instance, can provide important information such as effective movement and contraction of cardiac muscles, allowing more objective assessment of left ventricle (LV) functions.

From the standpoint of computer science, measuring the LV motion is a challenging problem mainly because the motion is non-rigid and there are, in general, no markers.

An effective approach for tracking should take into account closeness and similarity [1]. It should also support tri-dimensional and deformable structures and be independent of image modality.

MR tagging is an important technique for tracking, however it applies only for Magnetic Resonance images [2], it presents high cost and is difficult to use in clinic routine.

Geiger [3] investigated the use of dynamic programming with search restrictions in order to get the mapping of bi-dimensional closed contours.

Cohen [1] proposed use of geodesic paths applied to distance transforms of the given contours. The paths were obtained by following the opposite direction of the gradient of distance transform sum.

Recently Papademetris [4] proposed bayesian optimization for the tracking in Ecocardiography. He used "a priori" model of the muscle fibers for the orientation of tracking and a noise model based on curvature similarity. However, a more extensive evaluation is necessary and the processing time should be reduced for clinical applications.

The objective of this work is to present an alternative methodology for pointwise tracking of contours based on intermediary contours. The hypothesis is that shape-based interpolation of the contours will allow more robust pointwise tracking. As Cohen´s work, the method is based on the minimization of a cost function which tends to preserve the matching of high curvature points, while ensuring a smooth field of displacement vectors, but considering all intermediary contours.

2. Methodology

Given two closed contours (**c(0)** and **c(t)**) derived from two consecutive image frames (bi or tri-dimensional), the basic idea is to estimate intermediary contours based on shape [5] and then track prominent points of **c(0)** up to **c(t)** considering all intermediary contours. Therefore, the technique is comprised of two steps: a) intermediary contours estimation; b) strategy for tracking points.

2.1. Intermediary contours estimation

Given a closed contour c(t), we can associate a level set function Ψ(r,t) such that its zero level set corresponds to the contour c(t) [6]:

$$\Psi : R^N -> R$$

$\Psi(c(t),t)=0$

Signed distance transform of a contour is one of those functions and will be used in this work to create intermediary contours which encompass similarity and closeness. The intensities on figure 2 represents the signed distance transform of the inner contour and were obtained using Chamfer distance [5,7].

For a pair of contours (c(i),c(j)), the intermediary contour can be obtained by adding the corresponding distance transforms (level sets) and looking for zero-crossing points, since these are the points that have the same distance to the contours with opposite signs. By construction, this new contour (c(k)) points are closest to both contours and c(k) tries to keep a compromise between the parents contour morphology:

$$c(k)=\{r \mid \Psi_i+\Psi_j=0\}$$

Two new intermediary contours can be obtained using c(k), namely the contour between (c(i),c(k)) and the other between (c(k),c(j)). This procedure can be repeated up to the required level of "closeness" . Calculation of distance transform for each new contour is time consuming. A rough estimation of intermediary contours distance transform can be obtained by averaging the parent (pair) distance transforms, allowing a faster approach.

2.2. Optimum tracking of points

The tracking, for the set of prominent points of contour c(0), consists of looking for a global optimum mapping in relation to the next contour considering a defined cost function. The proposed cost function takes into account closeness, similar curvature and displacement smoothness. For the case of point **n** of contour **i** evolving to point **m** of contour **j**, we have (figure 1):

$$f(n,m)=w_1.|\vec{r}_m-\vec{r}_0|+w_2.|curv_m-curv_n|+w_3.|disp|$$

$$disp=|\vec{r}_n-\vec{r}_{n-1}|/P_i-|\vec{r}_m-\vec{r}_q|/P_j$$

where:

r: position vector

r_0 represents the closest point of c(j) to node n;

curv: curvature

w_1, w_2, w_3 : weights

P_i e P_j: perimeters of contours i and j.

r_q : match for the previous point (n-1)

The curvature for each point was calculated as cosine of the change of direction at that point.

Let m=M(n) be a mapping function for the prominent points of c(i). The optimum configuration can be attained by dynamic programming [8], minimizing the total cost:

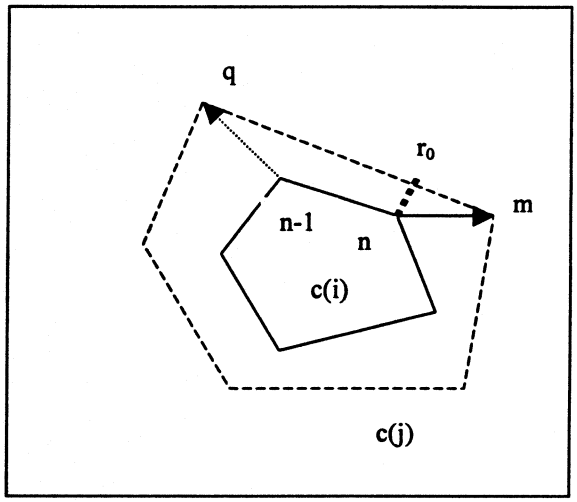

Figure 1. Scheme used for definition of cost function

$$\min_M\left(\sum_n f(n,m)\right)$$

In order to speed up the search, it is reasonable to restrict the range of search around each r_0. We have used 10% of the perimeter.

2.3. Algorithm

a) Given the contours c(i) and c(j), calculate the signed distance transforms Ψ_i and Ψ_j
b) Push the pair (Ψ_i ,Ψ_j) in the queue Q
c) While Q is not empty, do:
c.1) Remove a pair (Ψ_p, Ψ_q) and calculate $\Psi_a=(\Psi_p+\Psi_q)/2$
c.2) Get the contour associated to zero level set of Ψ_a
c.3) If more interpolation is needed, push the pairs (Ψ_p , Ψ_a) e (Ψ_a , Ψ_q) in Q
d) For each pair of contours, find out the global optimum mapping for the initial set of prominent points considering the cost function f() via dynamic programming.

3. Results

In order to evaluate the proposed approach, we simulated several evolving contours and applied different techniques, such as geodesic[1] and Geiger's approach [3]. We also investigated the effect of number of intermediary contours, considering 1, 3 and 7 intermediary contours.

An initial contour c(0) was generated as a regular

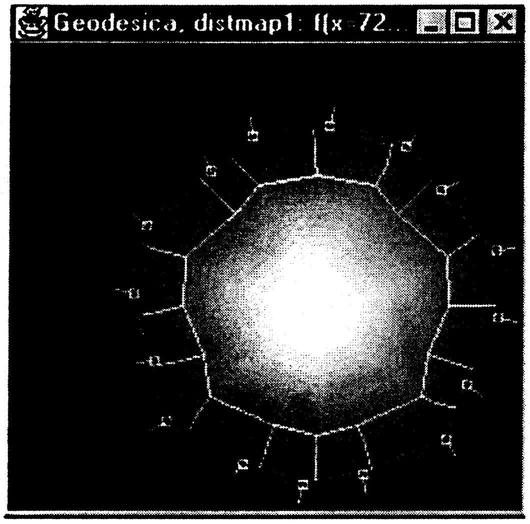

Figure 2. An example of tracking using geodesic approach. Small squares indicate the expected matches.

polygon with 16 nodes of radius 64 pixels, centered at (148,128) in a image of size 256 x 256 pixels. Several random contours c(t) were generated as follows: a) regular expansion of c(0) with velocity 25 pixels/unit; b) uniform distributed (-4, 4) random noise is added to each node position in x and y.

Figure 2 depicts one result based on geodesic technique and figure 3 using Geiger's approach (parameters μ=1 and η=0.1). The small squares indicate the expected matches. The geodesic paths were calculated using the sum of distance transforms. The markers on the outer contours indicate the true matching positions.

In figure 4 we illustrate a case of shape-based tracking with 3 interpolations (intermediary contours). The intensities of the image represent the approximated signed distance transform of the first interpolation (middle contour), that was calculated as average of parents distance transform. The weights for optimization w_1, w_2 and w_3 were set to 1.0, 10.0 and 5.0, respectively.

Table 1 shows the average and standard deviation of mean square error for position tracking on the case of 10 random simulations. The proposed approach presented better results (average and standard deviation) compared to the other two techniques. Moreover, the number of interpolations improved slightly the tracking.

Simulations with several other polygons and associated distorted polygons showed similar results. For instance, for 10 prominent points (nodes) and distortion of 15° plus 20% of expansion, in a 400 x 400 pixels image, the mean distance (city-block) error was below 1.8 pixels.

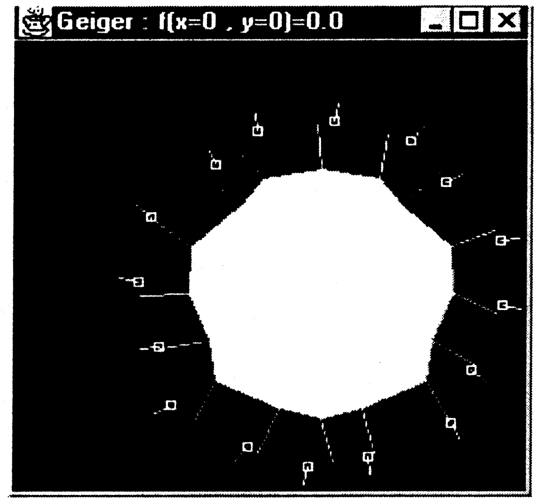

Figure 3. Results of pointwise tracking based on Geiger's technique. Small squares indicate the expected matches.

Table 1. Average and standard deviation for mismatches (mean square error in pixels) for tracking using geodesic, Geiger's and shape-based tracking approaches (three levels of interpolation) on a random set of ten cases.

	Geodesic	Geiger	Shape-based tracking		
			1 interp	3 interp	7 interp.
Average	3.77	5.74	2.19	2.08	1.96
St.dev.	0.74	1.41	0.55	0.29	0.41

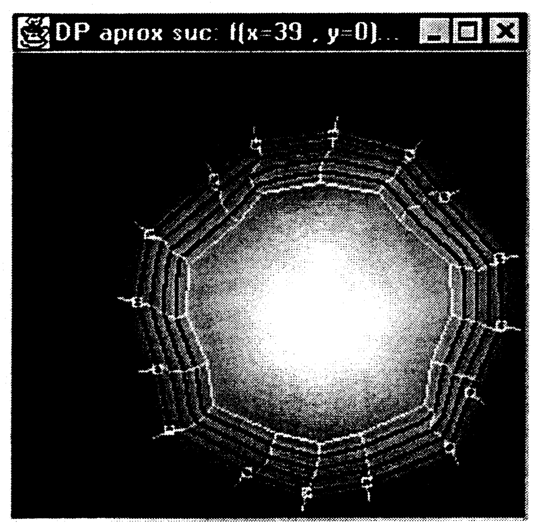

Figure 4. Pointwise tracking via shape-based interpolations for the case of 3 intermediary contours (w_1=1.0, w_2 =10.0, w_3=5.0). Small squares indicate the expected matches.

4. Discussion and conclusions

The proposed approach is simple, optimized in the discrete domain, it can be applied to tri-dimensional structures and does not assume presence of markers. It also support topological changes since it is based on level sets.

The used cost function considers closeness, curvature similarity and smooth displacement. Further investigation should be carried out to study the influence of the weights, new cost functions and the evaluation of the proposed approach on actual walls of heart.

Acknowledgements

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