Magnetic Resonance Image Segmentation and Heart Motion Tracking with an Active Mesh Based System

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Abstract

The work presented here relates to a method for motion tracking in sequences of medical images. The purpose is to quantify the general motions and the local deformations of a beating heart during a cardiac cycle.

In order to achieve this goal, we first tessellate the first image of the sequence into triangular patches. A Delaunay triangulation is applied to find the optimal set of triangles describing this image, giving a mesh covering the organs. One imposes the contours of the organs to correspond to edges of triangles so that each part of the heart (left ventricle, right ventricle, myocardium) can be described as a different set of triangles, each set indicated by a different color. We then track the nodes of the mesh on the image sequence while imposing them to remain on the edges of the different parts of the heart

1.   Introduction

Medical images permit now to obtain more and more detailed anatomical pieces of information about patients. They are used for diagnostic purposes by doctors, but they may also be used for simulation, control and therapeutic validation. However automatic diagnosis is difficult to achieve, on static images but even more on dynamic images.

Tracking and quantification of object motion in images sequences is a growing research area. In medicine, the performance of the developed algorithms are closely related to the quality of the image sequences. Such techniques as block matching [1] and optical flow [2] have been developed these last years to help solve these problems. They don't give good enough results alone and other techniques as the ones based on mesh tracking have been introduced.

Active mesh is one of the geometric possible solutions capable of representing deformable surfaces

[3]. Its goal is to partition an original image into polygonal elements in order to obtain an approximated image. The result is a reduced representation based on the homogeneous characteristics of the original image [4].

In medicine, the automatic tracking of the heart beatings is of great interest, as the observation of the motion of the heart walls give much information about cardiac pathologies. This work begins with the segmentation of the heart on MRI image sequences. A triangular mesh is then computed, and a color is given to the triangles depending on the area they represent. Finally, the mesh is deformed all along the image sequence according to the motion of the underlying area.

2.   Initial processing

In the first image of the sequence, the contours of the organs in the image have to be found in order to place the nodes of the first mesh. A filter is applied to each image of the sequence in order to reduce the noise, then the contours of the organs are detected.

For this purpose, the SUSAN algorithm [5] is used : it incorporates a Gaussian median filter the degree of smoothing of which may be tuned. Then it detects the contours while distinguishing contours with a strong curvature, where more nodes will be placed, from those with less curvature where there will be less nodes.

The precision of the mesh relies on the precision of the segmentation of the first image. Therefore the first mesh is refined in order to match the underlying organs and then displayed.

3.   Triangulation

The mesh we use in this project is a Delaunay triangulation [6] without constraints, a well-known

triangular mesh technique. Only the position of the nodes are imposed. The lack of constraint on the edges allows more flexibility in the mesh realization. The interest of such a partitioning is that it relies on a set of nodes that can be positioned almost everywhere on the image.

The Delaunay triangulation has been chosen for its easiness of use and for its properties. It allows to obtain a regular triangular mesh that has the characteristic of being unique for a given set of points. It has two other particularities :

• it takes all the given points into account

• the circle that touches the three apexes of a triangle does not contain any other point.

These two properties will be useful when deforming the mesh during the motion tracking step.

4. Initial segmentation

The goal of this initial segmentation step is to assign a different color to all the triangles identifying each organ, or each distinct part of an organ, in the MRI image. The purpose of this coloration is to visually evaluate the accuracy of the segmentation and its tracking along the image sequence.

The contour detection which is done for the initial positioning of the nodes of the mesh is nevertheless able to separate the myocardium and the liver which have almost the same grey level. Therefore we first rely on binary images only containing the image contours in order to determine the boarders of different regions.

Some outlines are present but badly delimited, which make them difficult to use for allocating the colors. They are then combined with an analysis of the grey levels. We consider an interval of plus or minus 15% around the median value grey level values of the triangles. This permits to take into account the luminance homogeneity. Indeed, the more the grey levels are uniform, the smaller is the interval. Conversely, the more the grey levels are numerous, the bigger the interval is.

In order to avoid grouping together triangles belonging to a gradation of grey levels, we also take into account the luminance of triangles which have been grouped together. For this purpose, as one goes along the grouping, the program computes the mean of the median values of the different regions and their combined intervals.

5. Motion tracking

5.1. Mesh tracking

Mesh tracking is realized with the block matching method. The general idea of this widespread motion estimation method is to admit that a set of image pixels has a local motion assimilated to a translation.

In order to avoid a sliding of the nodes along the contours, an index of confidence is computed [7]. The nodes that satisfy the two following criteria are considered as already well-positioned :

• nodes for which the nodes that are in a fixed area and that did not move

• the similarity criterion of the block matching algorithm gave good results [8]

Once these well-positioned nodes have been determined, the positioning of the other nodes begins by minimizing the energy E of the mesh (1) at every non-fixed node.

$$E = \sum_{l_{ij} \neq l_{ji}} \left(l_{ij} - l_{ij}^0 \right)^2 \qquad (1)$$

$$\text{with } l_{ij} = \frac{\|a_{ij}\|}{L_{gr(f_i)}} \quad l_{ji} = \frac{\|a_{ji}\|}{L_{gr(f_j)}}$$

$$\text{and } L_k = \sum_{\substack{gr(f_i) \neq gr(f_j) \\ gr(f_i) = k}} \|a_{ij}\|$$

where f_i is the face of the triangle i, a_{ij} (i≠j) the segment separating face f_i and face f_j, l_{ij} and l_{ji} the lengths of a_{ij} and a_{ji}, $gr(f_i)$ the set face i belongs to.

5.2. Tracking of the segmented areas

At this stage, the nodes of the mesh are on the contours and the boarders of the different areas of the heart correspond, in the initial image, to a side of a triangle of the mesh. The segmented image distinguishes the different regions of the heart. If needed, the program allows to manually group some triangles together with sets of triangles different from those they were automatically linked with.

The aim is now to follow the segmentation, that is to say the colored mesh, all along the image sequence. It will allow us to track the deformation of the ventricles and of the myocardium, and to evaluate their areas for diagnostic purposes.

The optical flow [9] is therefore computed for each image of the sequence. It consists in extracting a velocity vector field or a displacement vector field from

the image sequence by assuming that the grey level of pixels do not change from one image to the following. The algorithm used is the one of Horn and Schunck.

The initial mesh is already well segmented in areas. It is represented with differently colored sets of triangles. As the positioning of the nodes on the contours of the organs is effective, each triangle corresponds to only one organ all along the image sequence. We pay now a particular attention to track each organ along the image sequence by considering the initial mesh, the initial colors and the displacement vector field.

For this purpose, we look for the group each triangle belonged to in the previous image. Let v_i be the displacement vector of face i, let f_i^{j+1} be the face number i of the mesh of image j+1 and let $gr(f_i^j)$ be the group face f_i^j belongs to

$$f_n^j = f_m^{j+1} - v_n \qquad (2)$$

$$gr\left(f_m^{j+1}\right) = gr\left(f_n^j\right) \qquad (3)$$

It is like making a translation of a vector ($-v_i$) to each face of the current image (2). We obtain the position of this face in the previous image and we are therefore able to retrieve its group (3) from this position.

However this method can lead to certain malfunctions, especially for small triangles at the border of groups. In this case, as the coordinates of the vertexes of these small triangles are very close to those of the connected triangles, the translation can assign the triangle to the next group. Globally, this method allows to suppress areas vanishing along the image sequence.

6. Results

The results of the automatic segmentation on the first image usually present too many regions (figure 1).
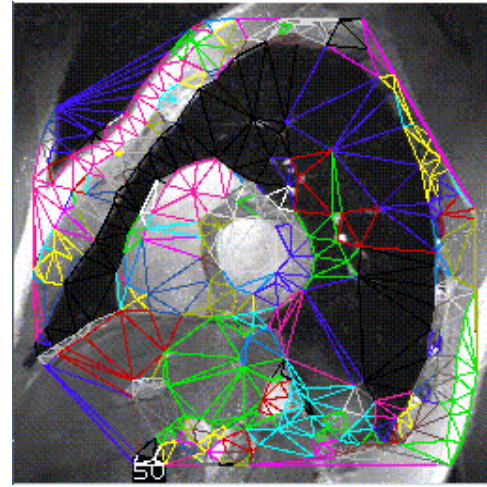

Figure 1 : Automatic triangulation – first image

These regions are too numerous as an organ can be described by many sets of triangles. This is due to the wide extent of grey levels representing a given organ. In spite of that, the myocardium and the liver, which have very close grey levels, are well identified and separated. Nevertheless, the user has often to manually group some regions together in order that each interesting part of organ be described by only one colored set of triangles in the first image (figure 2). After that, we obtain a good description of the different parts of the first MR image.
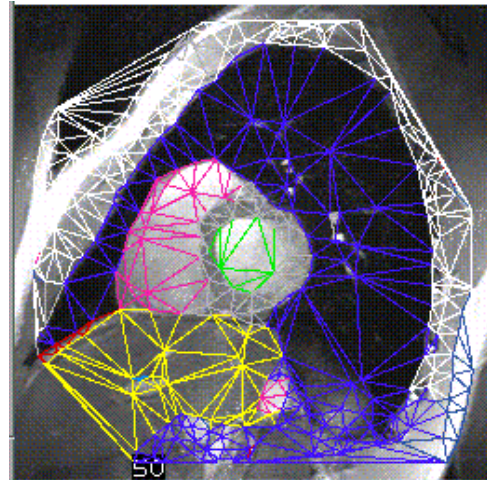

Figure 2 : less areas – first image

Once this first mesh has been constituted, occasionally with the intervention of the operator, the problem is now to automatically track the regions of the mesh. On figure 2, one can see the result of the tracking of the first mesh in an image sequence where the heart is contracting. There are six images in this example, but the program works with longer sequences. One can note

that the colored sets of triangles still correspond to the organs they were affected to in the first image.
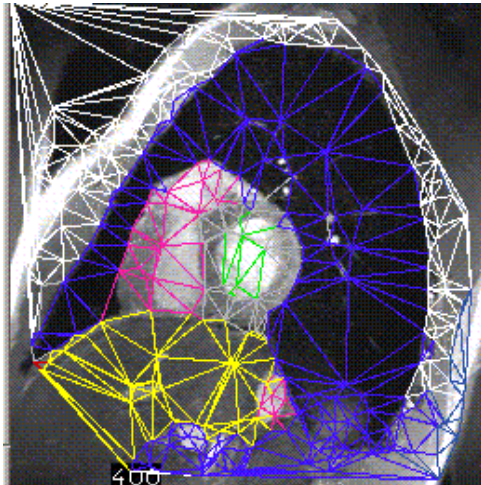

Figure 3 : Mesh tracking after 6 images

The method has been used for computing surfaces by adding the surfaces of the triangles describing parts of the heart. The differences between surfaces measured with hand-drawn contours, which are not very accurate, and those computed by summing the surfaces of the triangles having the same color is less than 10%.

7.   Conclusion

MRI image processing is often difficult to carry out, especially if one is interested in motion detection and tracking. The work presented here aimed to quantify general motions and even local deformations of a beating heart during a cardiac cycle.

The method has been applied to many magnetic resonance image sequences. The segmentation obtained on the first image is visually good as each organ corresponds to one or more differently colored set of triangles. Once these sets are reduced to one for every part of the heart in study, the tracking of the nodes of the mesh along the whole sequence is very satisfying.

Finally, the proposed method can be considered as a virtual tagging method that has the advantage of not producing a thick square grid that hides parts of the image and that vanishes with time.

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