Three-Dimensional Annulus Segmentation and Hybrid Visualisation in Echocardiography

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Abstract

Changes in mitral annular shape and dynamics are associated with mitral regurgitation without valvular disease. Therefore, it is interesting to visualise the annulus together with the regurgitant flow patterns.

A prerequisite for a clear visualisation is the segmentation of the annulus. We present a specialised method for annular segmentation in rotational acquired three-dimensional transesophageal echocardiographic data.

For visualisation, a surface model of the annulus is constructed, while we use a volume rendering method for flow patterns, which allows the display in the original colour coding from two-dimensional echocardiography. A hybrid visualisation technique enables a simultaneous display of surface rendered annulus together with volume rendered flow patterns and/or the morphology.

1. Introduction

Size, shape and dynamics of atrioventricular annuli yield important diagnostic information about dilatation, heart valve insufficiencies and myocardial function. Moreover, knowledge about annuli form can be used in computer assisted operation planning of heart valve reconstruction and to design annuli prostheses guided by the individual anatomy.

Information about pathologic blood flow patterns is another valuable clue for diagnosis. Functional mitral regurgitation, i.e. mitral regurgitation in the absence of structural mitral valvular abnormalities, is associated with changes in mitral annular shape and dynamics [1]. A combined visualisation of the blood flow with the annular motion may be helpful to further elucidate this phenomenon.

Three-dimensional transesophageal echocardiography optimally assesses annuli structure as well as blood flow. The segmentation of the annulus is necessary to extract diagnostic valuable information. This is a very time-consuming step if performed manually.

We have developed a nearly automatic method for annulus segmentation, reducing the time necessary for user interaction.

The described methods facilitate the use of annulus shape and dynamics for diagnosis and therapy planning by reducing segmentation time and by enhancing visualisation.

2. Data acquisition

For data acquisition we use a Sonos 2500DSR/Sonos 5500DSR ultrasound system (Agilent, Andover, Mass, USA) with a transesophageal multiplane probe, which allows digital storage. The morphology and Doppler data are stored separately. Four-dimensional data sets are acquired by the built-in rotational controller, which is triggered by ECG and respiratory gating [2,3]. After acquisition, the data are either stored on a magneto-optical disc for transfer to our processing system EchoAnalyzer® [4] or transferred using the optional LAN interface.

3. Segmentation

The segmentation procedure for the detection of the annulus consists of two major steps. First, one of the cavities adjacent to the annulus is segmented. Usually, we use the atrium for this purpose, because its contour is often better visible than the contour of the ventricle. The second step, based on the result of the first step, is the actual annulus segmentation.

3.1. Segmentation of heart cavities

Starting from a seed point close to the centre of the cavity, the image is scanned for potential edge points, which subsequently are connected by means of minimising a cost-functional yielding contour fragments. This process is based on different criteria like smoothness of the contour fragment, visibility and local wall thickness.

Figure 1 shows an example for some of the criteria. All black points are "preliminary candidates", extracted by low-level image processing. The local wall thickness $th(p_i)$ is the distance from p_i to the next point on the scan ray that is *not* a preliminary candidate (white in the example). The thicker a boundary the more probable it is a real edge and not noise. The visibility $vi(p_i)$ is defined as the sum of the $th(p_j)$s of all candidate points p_j on the scan ray that lie closer to the seed point than p_i itself. The

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greater $vi(p_i)$, the *worse* is the visibility of p_i from the origin. The better the visibility of p_i, the more likely p_i is a point of the *desired* cavity's boundary. $bp(p_i)$ is a Boolean value, which is *true*, if p_i is a point of the imaging area's border and *not* a preliminary candidate. Points with $bp(p_i)$=*true* are considered unreliable but have to be taken into account, because the cavity to be segmented often lies partly outside the imaging area. Further criteria are the local orientation of the image's edges calculated by a structure tensor method on the gray level data and the distance to the boundary on the previous slice, if available.

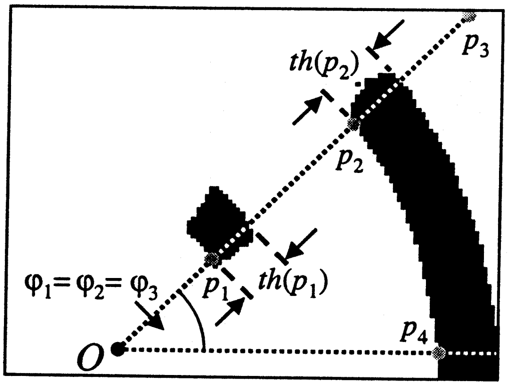

Figure 1. The feature values are $vi(p_1)=0$, $vi(p_2)=th(p_1)$, $vi(p_3)=th(p_1)+th(p_2)$, $th(p_3)=0$, $bp(p_3)=true$, $bp(p_1)=bp(p_2)=bp(p_4)=false$. The border pixel on the lower ray is not accepted. O is the seed point.

After building up the contour fragments, a subgroup of all contour fragments is selected by using a second cost function, which generates the final closed contour. The plausibility of the result is checked and, if needed, the contour is corrected and/or refined by searching for additional candidate points [5].

Segmentation of three- and four-dimensional data set is done by propagating the centre of mass of the current segmentation result as seed point to the next slice in spatial as well as temporal direction.

3.2. Annulus segmentation

The approach to segment the annulus nearly automatically is based on the fact that the heart valve is much thinner than the myocardium. Thus, the valve can be detected as the part of the cavity's contour that is considerably thinner than the adjacent parts. After the detection of the contour with the method described in the last section, the discontinuities in wall thickness along this contour on either side of the valve define the position of the annulus.

A point on the valve is required to reliable detect the discontinuities in wall thickness belonging to the transition from the valve to the myocardium, because otherwise the septum could be mistaken for a valve. In the case of imaging from the transesophageal position – in contrast to the transgastric –, the sequence of structures in the image starting from the transducer location is atrium, valve, ventricle. The intersection of the vertical line through the centre of mass of the segmented area of the cavity with its contour yields two points. The one farther away from the transducer is probably a point of the valve (see Figure 2). This point is presented to the user as default, but can be changed manually.

Starting from that point the contour is searched in either direction for a rapid change in local wall thickness. The wall thickness should be calculated perpendicular to the contour. Due to the locally noise nature of the contour, the normal direction would considerably fluctuate, which would result in erratic changes in wall thickness. Smoothing of the contour would separate the border line from the actual atria wall. Instead of smoothing the contour itself, it is better to smooth the normals of the contour. In the simples version, the centre of mass can be used as the seed point of a new scan according to section 3.1 using the scan rays as directions of the normals and calculating $th(p_j)$ as described above (see Figure 2).

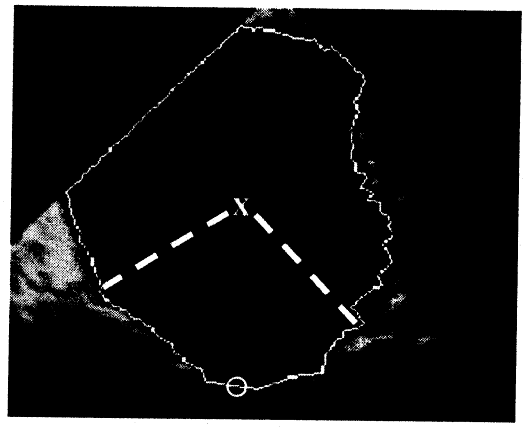

Figure 2. Solid line: contour of the atrium. X: Centre of mass of the atrium in this slice. Circle: Point used as a start point for searching wall thickness discontinuities. Dashed lines: Directions of discontinuities of the wall thickness.

4. Hybrid visualisation

The annulus segmentation process as described in the previous section yields a three-dimensional polygon in cylindrical co-ordinates, the latter due to the rotational data acquisition method. After transformation in a Cartesian co-ordinate system, a surface model of a tube is constructed around the detected points. Additional points are added by spline interpolation to achieve a smoother visualisation.

A hybrid visualisation technique allows for visualising the constructed surface model of the annulus together with a volume rendered 3D (over time) reconstruction of

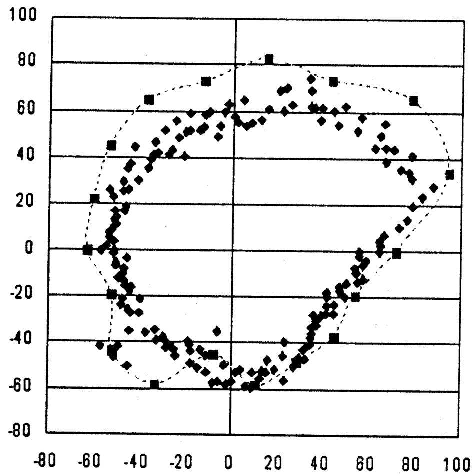

Figure 3. Result of annulus segmentation procedure. Squares: Manual segmentation in 9 slices.

Figure 5. Hybrid visualisation of annulus surface model combined with colour Doppler signal.

either backscatter and Doppler information (in original colour coding), or together with backscatter only or Doppler only.

5. Results

The result of the annulus segmentation method applied to a complete three-dimensional data set with 90 slices is displayed in Figure 3. The figure shows the projection in the least-squares plane fitted to the annular curve. For comparison, the result of a manual segmentation in 10 % of the available slices is also shown and will be discussed in the next section.

Different three-dimensional visualisations are shown in Figures 4 to 7. The surface rendered annulus is displayed from two directions in Figure 4. The hybrid visualisation of the annulus together with the flow pattern obtained by colour Doppler imaging is shown in Figure 5. Figure 6 and 7 contain also hybrid visualisations, but this time of the annulus combined with the morphology and with both, morphology and colour Doppler information, respectively. A colour version of the paper can be requested from the author.

6. Discussion

Compared with manual segmentation (dashed line in Figure 3), our method for nearly automatic annulus segmentation approach is able to detect the shape of the annulus correctly. However, the method does not yield the centre of the annulus ring, but its innermost contour, resulting in the difference between manual and automatic

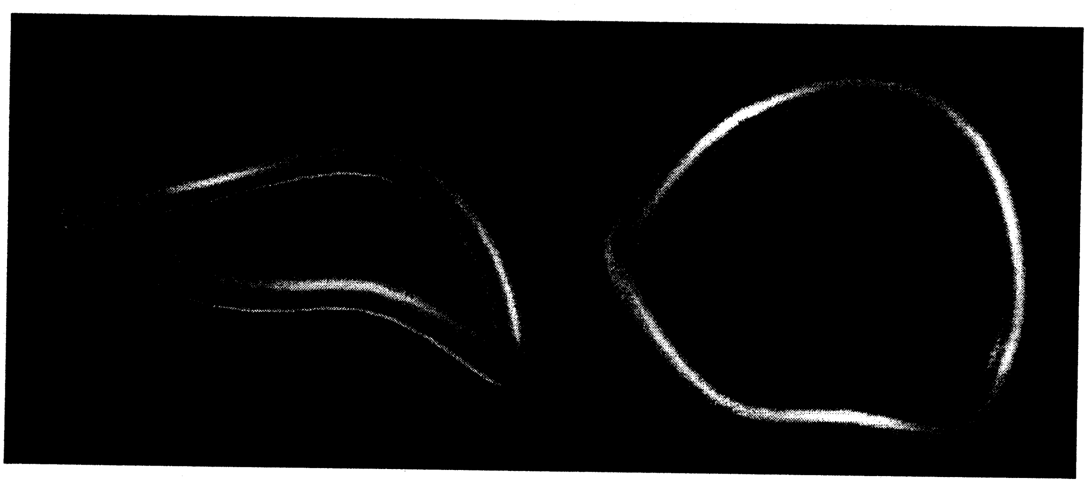

Figure 4: Surface reconstructed annulus from two different viewing positions.

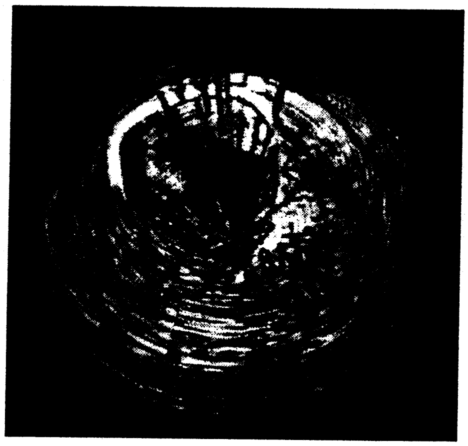

Figure 6. Hybrid visualisation of annulus combined with morphology.

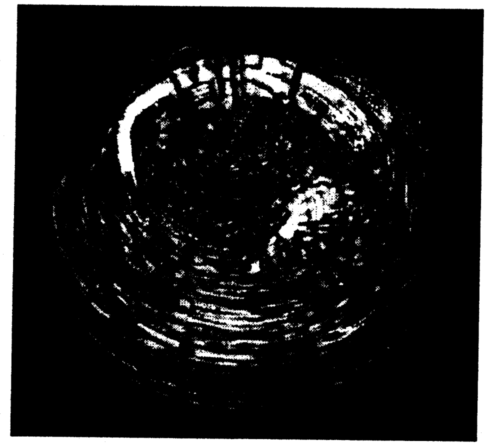

Figure 7. Hybrid visualisation of annulus combined with morphology.

result visible in Figure 3. This systematic underestimation can be avoided by letting the user specify a few points along the annulus at the correct position, which can be done in a reasonably short time.

If the valve is pathologically thickened, the algorithm as described above may have problems to detect the annulus, due to less distinct discontinuities in local wall thickness. A solution for this problem is to manually select the correct annulus position in the first slice, propagate the points to the following slice and restrict the search for discontinuities to the adjacent parts of the propagated points. An apparent prerequisite for the algorithm is that the annulus must lie inside the imaging sector.

7. Conclusion

The described nearly automatic detection method allows the segmentation of the annulus in a reasonably short time. Using the hybrid visualisation approach the dynamics of annulus motion can be studied simultaneously with the myocardial morphology and/or the blood flow, the latter being especially interesting in the case of heart valve insufficiencies.

Postoperative monitoring the functional outcome of valve repair operation is facilitated by these additional parameters.

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