Automatic Detection of Vessel Wall Contours from Cine-MRI for Aortic Compliance Determination

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Abstract

The aortic compliance is defined as the relative change of aortic cross-sectional area divided by the change in arterial pressure. Magnetic Resonance Imaging (MRI) can be used to evaluate aortic compliance.

A knowledge of the aortic contour is essential to determine the aortic area. To prevent important intra- and inter-observer variability, the aortic contours are detected automatically. This work consists in extracting automatically the aortic contour at different phases of the cardiac cycle.

An automatic edge detection making use of a Haralick filter and graph searching allows the estimation of aortic cross-sectional area on MR images, from which the aortic compliance is derived.

1. Introduction

The arterial system tends to smooth out the pulsatile arterial flow and delivers the blood in a more continuous fashion into the capillary beds [1]. This effect is in part accomplished by the arterial compliance. An abnormality of compliance can greatly affect cardiovascular function.

In such an event, aortic compliance quantification is essential when studying the aorta [2]. Two useful parameters are the compliance and the distensibility. These parameters are calculated by :

$$Compliance = \frac{\Delta S}{\Delta P} = \frac{\Delta S}{P_{Systolique} - P_{Diastolique}}$$

$$Distensibilty = \frac{\Delta S}{\Delta P - Surface_{\min}}$$

The determination of the compliance requires a knowledge of the systolic blood pressure ($P_{Systolique}$), the diastolic blood pressure ($P_{Diastolique}$) and the calculation of aortic cross-sectional areas (ΔS). ΔS is the difference between the maximum and minimum ($Surface_{min}$) cross-sectional area. The area is calculated on aortic images in the transverse plane acquired using a SSFP-type sequence. All images are from the same slice but at different phases of the cardiac cycle.

The main objective of this work was to develop an automatic method to detect the aortic contour on each image. Thereby, the evaluation of the aortic cross-sectional area and the compliance is possible.

2. Image sequence

Magnetic Resonance images were acquired on a 1.5T whole body imager, with an ECG-gated SSFP-type sequence (True-FISP). Images are acquired at different phases of the cardiac cycle. The aorta was imaged in the transverse plane at the level of the bifurcation of the pulmonary trunk. Thus, the ascending and descending aortas are on the same image and can be studied simultaneously. Before and after image acquisition, the arterial diastolic and systolic blood pressures were measured in the brachial artery by using a sphygmomanometer.

3. Methods

The ascending and descending aorta contours are detected by the same method. The centre of aorta is the starting point for the image processing. Each image was processed individually.

Our automatic detection method is composed of four different steps (Figure 1). The first operation is based on the edges present in the image. This image is transposed into the polar coordinate system. The result is associated with a region of interest for graph searching. Finally, the contour detected is transposed into the Cartesian coordinate system on the initial image.

3.1. Detection of the edges

The first step consists in detecting the contours present in the image. For that, a pre-processing step is necessary to increase the image quality. This pre-processing is performed with a Gaussian filter and non-linear signal enhancement.

Following the use of a gaussian filter to limit noise, non-linear signal enhancement is applied on images to increase the grey level contrast between pixels.

The edge detection is the result of the convolution of a Sobel operator and a Haralick operator on the image (Figure 2).

a) b)

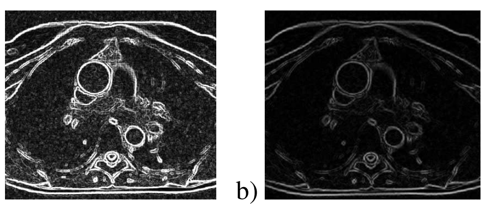

Figure 2. Edge detection with (a) Sobel filter and (b) Haralick filter.

To determine the best filter, we performed a rigorous study of filter parameters. The signal to noise ratio and Pratt index [3] are calculated for current edge detection filters such as Sobel filter, Roberts filter,….

The test is performed on a phantom image and an impulse noise probability equal to 0.2.

The signal to noise ratio is a measure of signal strength relative to background noise. The Pratt index depends on the difference between the expected contour and the detected contour. A better edge detection is characterised by a better Pratt index.

The results are presented in the figure 3. The Sobel and Haralick operators have been chosen according to a preliminary study.

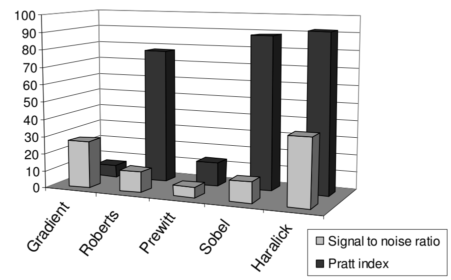

Figure 3. Contour detection filters study

The Sobel operator is a derivative method. It favours the horizontal and vertical directions to detect edges.

The Haralick mask is a surface and derivative method [4]. This processing method gives an optimum mask and is calculated from two parameters: the dimension of the vicinity (N) and the polynomial degree (K). N is always greater than K+1. This parameter allows a polynomial approximation.

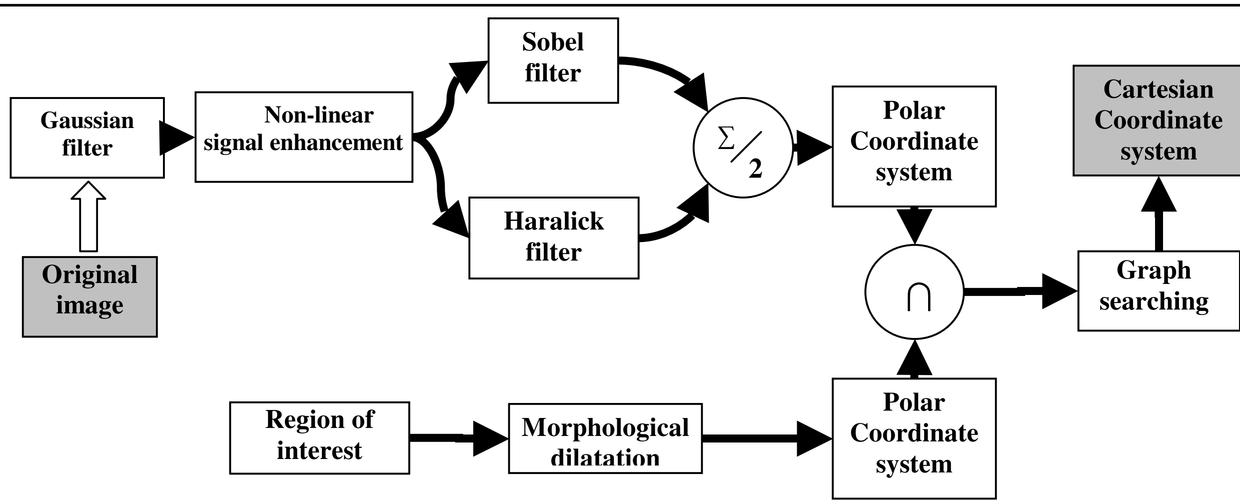

Figure 1. Flow diagram summarizing the automatic detection of the contour of the aorta for one image.

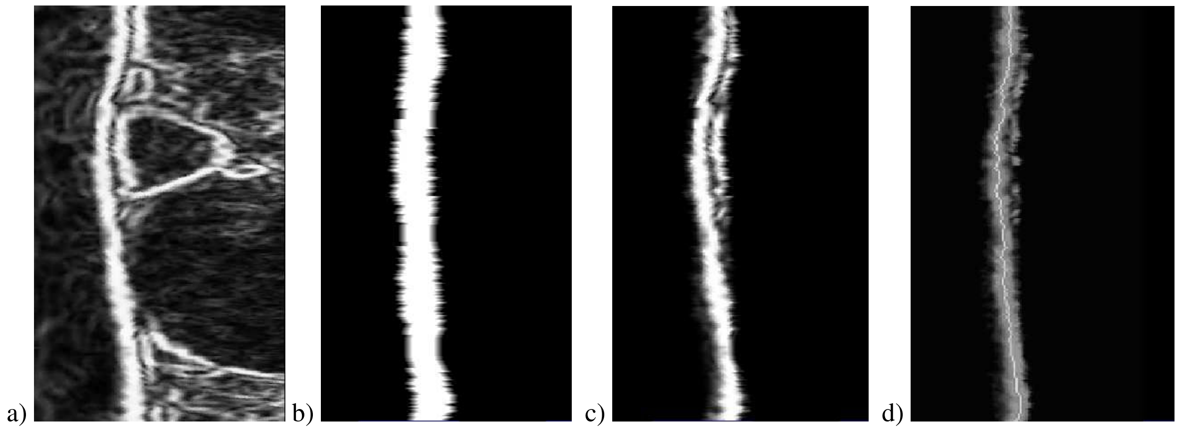

Figure 4. Automatic processing of aorta contour transposed into polar coordinate system. (a) Matrix of aorta contour (b) Region of interest (c) Intersection between (a) and (b) (d) Ascending aorta contour detected via graph searching.

With vicinity = 5 and polynomial degree = 2, the Haralick column mask is :

$$g_c = \frac{1}{350}\begin{Bmatrix} 6 & 3 & 0 & -3 & -6 \\ -24 & -12 & 0 & 12 & 24 \\ -34 & -17 & 0 & 17 & 34 \\ -24 & -12 & 0 & 12 & 24 \\ 6 & 3 & 0 & -3 & -6 \end{Bmatrix}$$

The line mask is obtaining with a g_c transpose.

We define the contour image as the fusion of the results obtained with Sobel and Haralick filters on the initial image. The study shows that the Haralick detection is the better filter. It allows one to limit the great amount of information provided by the Sobel detection.

3.2. Region of interest

All images are on the same slice but at different phases of the cardiac cycle. The aorta is localised roughly at the same place from one image to another. So the contour determined on a slice can define a region of interest (ROI) for the detection on the next image. In practice, the contour detected on the current image is morphologically dilated to define the ROI for the following image.

3.3. Polar coordinate system

The contour image and the ROI image are transposed into polar coordinates (Figures 4.a then 4.b). The centre of the aorta is the origin of the polar transformation. On the first image, the centre of aorta is determined manually and indicated by an experienced observer. This point is then determined by the centre of gravity of the aorta with precedent contour.

The result of the contour image transformation is multiplied by the result of ROI image transformation (Figure 4.c). The roughly circular form in Cartesian coordinates produces approximately vertical lines after transformation in polar coordinates. The line is detected with graph searching.

3.4. The graph searching

In polar coordinates, the aortic contour is nearly a vertical line (Figure 4.c). The graph searching is adapted to the detection of vertical lines. This method uses the local information. For the ascending aorta, the starting point of the graph searching is detected between aorta and lung. The contrast is better than between the aorta and superior veina cava or pulmonary trunk. The graph searching begins at this point.

A graph is defined by a set of nodes joined together by links. The processing is performed line by line, and only one point can belong to the contour per line. For one detected point, the processing determines 27 possible paths on the following four lines. Each path is a possible solution to the problem.

To detect the best path, we must evoke another parameter, called cost, and associate it to each node. The total cost of a path is the sum of the cost of all nodes that comprised the path.

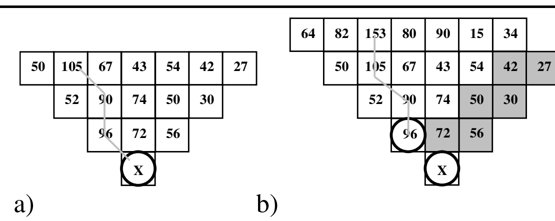

Figure 5. Principe of graph searching. (a) The maximum path (b) Validation of a contour point

The best path is the path with the highest total cost. We keep the node of the best path on the following line, and the processing is performed again with this point at the starting point (Figure 5). The aortic contour is defined as the set of the detected nodes (Figure 4.d).

At the end of the graph searching, the detected contour is transposed into Cartesian coordinates on the initial image (Figure 6).

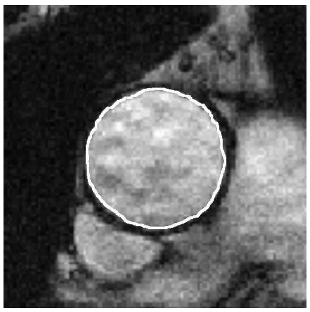

Figure 6. Final result with the ascending aorta contour in Cartesian system.

4. Results

The automatic detection method yields contours of the aorta on MRI images. From the ascending and descending aorta contours detected on each image, curves of variation of the aortic cross-sectional area versus time are obtained (Figure 7).

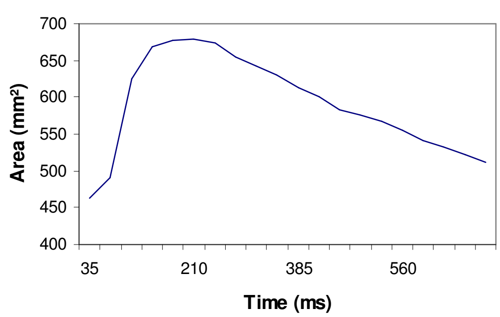

Figure 7. Evolution of ascending aortic area during a cardiac cycle

These curves allow one to determine the maximum amplitude of aorta cross-sectional area variation. With the arterial diastolic and systolic pressures, vessel compliance and distensibility were estimated. These parameters allow an estimation of the elasticity of the aorta.

5. Discussion and conclusions

This study uses MR Imaging and automatic post processing to determine aortic compliance of the ascending and descending aortas. The automatic aorta edge detection exploits Haralick methods and graph searching. The use of the Haralick method provides an optimal filter.

This method is robust even in the presence of flow turbulence within the image. A poor spatial resolution or image noise could however disturb a correct contour detection.

The described technique provides a measurement of aortic compliance with high spatial and temporal resolution.

Future work consists in a validation of our method on patient examinations in order to make aortic compliance measurement part of routine examination of the aorta.

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