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Automatic Abdominal Aortic Aneurysm segmentation in MR images

Sergio Martinez-Muñoz [a], Daniel Ruiz-Fernandez [a,b,*], Juan Jose Galiana-Merino [c,d]

[a] IBIS Research Group, University of Alicante, P.O. Box 99, E-03080 Alicante, Spain
[b] Department of Computing Technology and Data Processing, University of Alicante, P.O. Box 99, E-03080 Alicante, Spain
[c] University Institute of Physics Applied to Sciences and Technologies, University of Alicante, Spain
[d] Department Physics, Systems Engineering and Signal Theory, University of Alicante, P.O. Box 99, E-03080 Alicante, Spain

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ABSTRACT

Abdominal Aortic Aneurism is a disease related to a weakening in the aortic wall that can cause a break in the aorta and the death. The detection of an unusual dilatation of a section of the aorta is an indicative of this disease. However, it is difficult to diagnose because it is necessary image diagnosis using computed tomography or magnetic resonance. An automatic diagnosis system would allow to analyze abdominal magnetic resonance images and to warn doctors if any anomaly is detected. We focus our research in magnetic resonance images because of the absence of ionizing radiation. Although there are proposals to identify this disease in magnetic resonance images, they need an intervention from clinicians to be precise and some of them are computationally hard. In this paper we develop a novel approach to analyze magnetic resonance abdominal images and detect the lumen and the aortic wall. The method combines different algorithms in two stages to improve the detection and the segmentation so it can be applied to similar problems with other type of images or structures. In a first stage, we use a spatial fuzzy C-means algorithm with morphological image analysis to detect and segment the lumen; and subsequently, in a second stage, we apply a graph cut algorithm to segment the aortic wall. The obtained results in the analyzed images are pretty successful obtaining an average of 79% of overlapping between the automatic segmentation provided by our method and the aortic wall identified by a medical specialist. The main impact of the proposed method is that it works in a completely automatic way with a low computational cost, which is of great significance for any expert and intelligent system.

1. Introduction

Abdominal Aortic Aneurysm (AAA) is a disease caused by a weakening in the aortic wall that leads to an abnormal dilation of the aorta. Probability of vessel rupture increases with the size of the aneurysm. Maximum diameter of the aorta is the key parameter in AAA diagnosis: a diameter of 30 mm is typically considered as the threshold to define an AAA, meanwhile a value of 55 mm means that the risk of rupture increases exponentially and surgical intervention is recommended (Hutchison, 2009).

Typical imaging techniques are ultrasonography, computed tomography (CT) and magnetic resonance (MR). The first one is used for general AAA screening but lacks the precision of the other imaging methods. Therefore, CT and MR imaging techniques are used for an accurate diagnosis (Isselbacher, 2005). MR imaging has some advantages over CT scans: absence of ionizing radiation; better soft tissue contrast (Haulon et al., 2001); and it is also not affected by calcifications. Besides, it is the only imaging technique in which the aortic wall surrounding the thrombus is visible.

Normally, aneurysms must be identified and segmented manually by a radiologist, which is a time-consuming and cumbersome task (Macia et al., 2009). A common approach in computer-assisted methods is to segment aortic wall and lumen from individual CT or MR images (Kronman & Joskowicz, 2015; Maiora, Ayerdi, & Graña, 2014; Zohios, Kossioris, & Papaharilaou, 2012). A 3D reconstruction of the artery could then be performed using the boundaries obtained (Kim et al., 2010; Shim, Gunay, & Shimada, 2009). Other methods perform a full 3D segmentation in one single step, profiting from the usage of more information simultaneously (Ayyalasomayajula et al., 2010; Lee et al., 2010). It should also be noted that 4D methods (3D throughout the cardiac cycle) have been also proposed (Hameeteman et al., 2013; Zhao et al., 2009).

In order to analyze this kind of information (2D, 3D CT or MR images) in a fast and effective way, automatic or semi-automatic computer-assisted segmentation methods become crucial for the diagnosis of AAA (Shang et al., 2015). Thus, many different

* Corresponding author at: Department of Computing Technology and Data Processing, University of Alicante, P.O. Box 99, E-03080 Alicante, Spain. Tel.: +34 965903400.
E-mail addresses: smartinez@ibisrg.com (S. Martinez-Muñoz), druiz@dtic.ua.es (D. Ruiz-Fernandez), juanjo@dfists.ua.es (J.J. Galiana-Merino).

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algorithms have been adopted to achieve semi-automatic aortic segmentation. Methods based on region growing (Borghi, Wood, Mohiaddin, & Xu, 2006), watershed (Lopez-Mir et al., 2011) or, especially, active contour (also called snakes) algorithms (Kass, Witkin, & Terzopoulos, 1988; Loncaric, Kovacevic, & Sorantin, 2000) have been proposed. However, these methods rely solely on intensity information in abdominal MR images, which is an error-prone characteristic as other structures with similar intensity levels may appear adjacent to the aorta. This may cause leaks in the segmented contour. These methods also require an accurate initialization process, which has to be done manually to achieve good results. Although several variations of snakes have been developed in order to minimize instability (Xu & Prince, 1998) or ease initialization restraints (Tauber, Batatia, & Ayache, 2010), snakes-based methods are computationally costly due to the use of differential equations and still require a clear differentiation of aortic structures to obtain good results.

A solution is to combine intensity information with shape models. This approach has been adopted by level-set methods (Nakhjavanlo, Ellis, Soan, & Dehmeshki, 2011; Subasic, Loncaric, & Sorantin, 2005; Zohios et al., 2012) with good results. However, level-sets are computationally demanding and hard to implement, besides of needing a previous knowledge of the aortic shape to segment. This is difficult to predict in the case of a diseased aorta and often translates into a time-consuming manual initialization.

In the research for fully automatic AAA segmentation, several methods based on fuzzy clustering have been proposed (Majd, Sheikh, & Abu-Bakar, 2010; Pham & Golledge, 2008). In Majd et al. (2010) a Fuzzy C-Means (FCM) clustering technique that incorporates spatial properties named Spatial-FCM (SFCM) (Ahmed, Yamany, Mohamed, & Farag, 1999; Chuang, Tzeng, Chen, Wu, & Chen, 2006) is applied to AAA segmentation. With the appropriate use of morphological operations this method can achieve automatic segmentation of the aortic thrombus. Unfortunately, it is only suitable for CT images, since it does not provide good results with abdominal MR imaging.

Another alternative is graph cut algorithms (Boykov and Jolly, 2001; Boykov, Veksler, & Zabih, 2001). Several methods for abdominal aortic segmentation using graph cuts have been proposed (Duquette, Jodoin, Bouchot, & Lalande, 2012; Freiman, Esses, Joskowicz, & Sosna, 2010). The method proposed in Duquette et al. (2012) is able to perform segmentation in MR images in addition to CT ones. However, despite being a method able to segment the lumen and aortic wall in a faster and more computationally efficient way in MR images, it needs an accurate manual initialization in order to work properly.

Thus, the main drawbacks detected in the previously commented algorithms can be summarized in the following points: non-completely automatic algorithms (most of them need the expert assistance to select the area of analysis); high-computational demand; or poor results when they are applied on MR images. Therefore it is clear that there is not a single method that can perform automatic AAA segmentation from MR images efficiently.

In this work we have developed a new approach that intends to surpass all these inconveniences, providing a complete automatic and low computational cost program that works properly with MR images. For that, the proposed scheme uses a combination of different techniques, profiting from their respective advantages and minimizing the corresponding drawbacks.

Thus, in this paper we propose specifically a mixed method for automatic AAA segmentation in MR images. Our method uses the SFCM algorithm to detect and segment the aortic lumen in a first stage, following with the thrombus and aortic wall segmentation via graph cuts. We use the results of the first stage (lumen segmentation) to improve the segmentation of the aortic wall in the second stage. In this way, we avoid manual or expert help in the second stage to maximize the results of graphs cut algorithm. The proposed approach is fully automatic, computationally efficient and works in MR images. The use of a mixed method is a novel approach and could open new possibilities in this field.

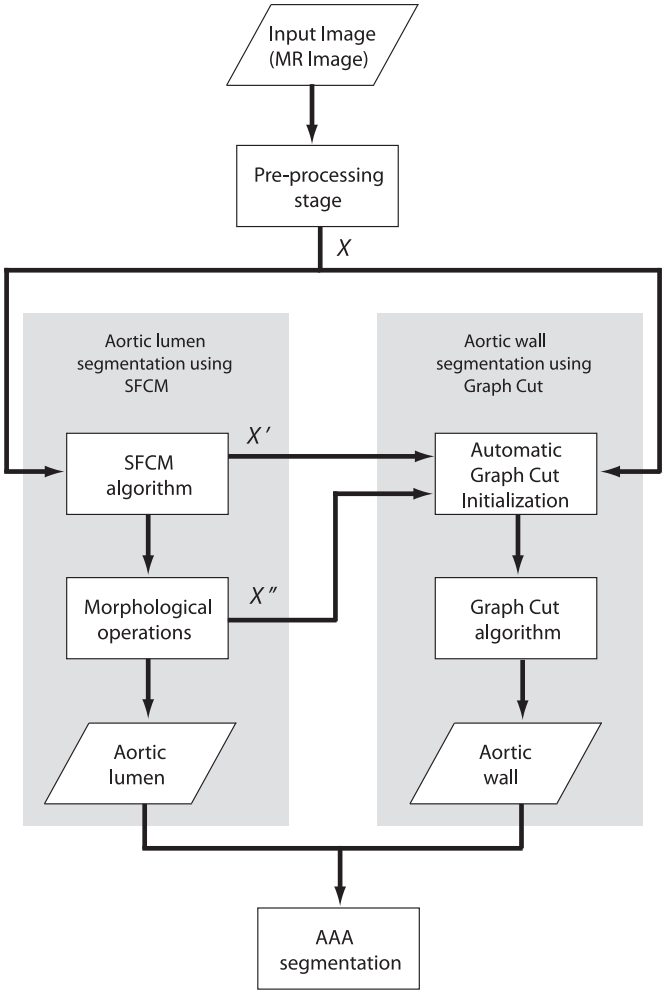

Fig. 1. Flow chart of the proposed method.

2. Methodology

The proposed method is divided basically in two different stages to achieve the automatic AAA segmentation, as it is shown in Fig. 1.

Previously to these stages, the acquired MR image is pre-processed using a low-pass Wiener filter to eliminate possible noise contamination and windowed to select the central region of interest in which the aorta appears in axial abdominal imaging.

Once the MR image has been pre-processed, the first processing stage provides the aortic lumen segmentation using the SFCM algorithm and morphological operations.

The second stage of the proposed method achieves the thrombus and aortic wall segmentation using graph cuts. To solve the problem of the manual initialization required by the graph cut to work correctly, an automatic initialization approach has been developed using the results previously obtained from the SFCM algorithm.

In the following sections, we describe in detail the different stages of the developed method.