

**DETECTION OF LUMEN, THROMBUS AND OUTER WALL BOUNDARIES OF AN
 ABDOMINAL AORTIC ANEURYSM FROM 2D MEDICAL IMAGES USING LEVEL SET
 METHODS**

Georgios Kossioris (1, 2), Yannis Papaharilaou (2), Christos Zohios (1)

(1) Department of Mathematics
 University of Crete
 Heraklion, Crete
 Greece

(2) Institute of Applied and Computational Mathematics
 Foundation for Research and Technology-Hellas
 Heraklion, Crete
 Greece

INTRODUCTION

Abdominal aortic aneurysm (AAA) is a localized dilatation of the aortic wall. Accurate geometric characterization is critical for a reliable patient specific estimate of AAA rupture risk. However, current imaging modalities do not provide sufficient contrast between thrombus, arterial wall and surrounding tissue thus making the task of segmenting these structures very challenging.

The aim of this paper is to develop a robust automatic 2D segmentation method to extract the lumen, thrombus and outer wall boundaries from cross sections of a 3D AAA image data set (MRI or CT) using Level Set Methods (LSM). One of the drawbacks of LSM is that they are computationally expensive and thus slow. This is resolved by using a Fast Marching Method (FMM) as a first step to obtain an optimized initialization for the LSM. Another typical problem associated with the lack of image contrast between thrombus, arterial wall and surrounding tissue is the leakage of the advancing front into regions of similar intensity not stopping at the target boundary. Three new stopping criteria to resolve this problem and two methods to obtain the thrombus and outer wall boundaries are presented.

MATERIALS AND METHODS

The equation of the FMM used in the 1st phase of our model is [1]:

$$g_t |\nabla T| = 1 \tag{1}$$

where, $g_t(x, y) = \frac{1}{1 + \lambda |\nabla G_s * I(x, y)|^2}$

$T(x, y)$ is the arrival time of the front at point $(x, y) \in \mathbb{R}^2$. The moving front at time t is given by the t -level set of T . I is the image

intensity and G_s is the Gaussian with width s . Finally, λ is a positive parameter. The result of this method is a good initial condition for the LSM, which we obtain in a quite rapid way.

In the second phase, a modified model of the classical level set equation [1] is used:

$$\phi_t = g_t(x, y)(\kappa - c) |\nabla \phi| + \nabla \phi \cdot \nabla P. \tag{2}$$

At any time, the front is given by the zero level set of the time-dependent level set function ϕ . κ is twice the mean curvature, $c > 0$ is a parameter used for faster convergence and

$$P(x, y) = - |\nabla G_s * I(x, y)|. \tag{3}$$

For the way a similar to (2) equation is extracted, see [2].

We applied the FMM using the Fast Marching Toolbox in MatLab. We took $\lambda = 50$ at g_t and used a 5×5 Gaussian filter with $s = 1$. The results of the method for a cross section of the 3D data set ($256 \times 256 \times 64$) for the lumen and thrombus initialization are shown in Fig. 1(b) and (c), respectively. For the application of the LSM we used the Level Set toolbox in MatLab created by Baris Sumengen.

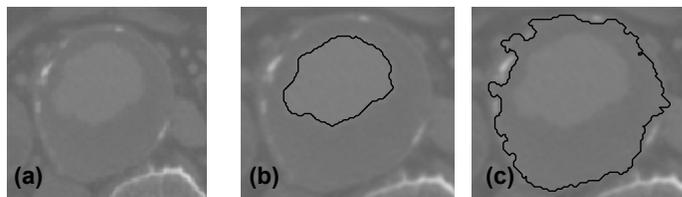


Figure 1. Lumen (b) and thrombus (c) boundary initializations using the Fast Marching Method on image (a)

STOPPING CRITERIA

Sector Criterion (SC) - Detection of Leakage Region (DLR)

Method

To detect the region of leakage we first split the interior of the initialization curve into sectors using as center point the center of mass and a user defined sector angle. As the curve evolves, the area and the “relative error” of the area of each sector is calculated every 10 iterations. The evolution of the curve is stopped as soon as this “relative error” presents a local minimum for all sectors. The leakage region consists of the sectors for which their “relative error” is of order 10^{-2} (or greater) for all sets of 10 iterations. This method is also a stopping criterion (called SC) for the evolution of the curve. Fig. 2(a) shows the outcome of the DLR method and SC after 80 iterations with a sector angle of $\pi/12$. The thick line segments depict the leakage region.

Length Difference Rate Criterion (LDRC)

This stopping criterion is connected to the total length of the moving curve. The absolute value of the difference rate of the length of the curve should be continuously reducing. A sudden increase of the rate is due to the leakage and denotes that the curve has to stop. This criterion (LDRC) stops the curve when the first maximum of the absolute value of the difference rate of the length of the curve appears. Fig. 2(b) shows the LDRC result after 40 iterations and the curve after 100 iterations.

Internal-External Contact Criterion (IECC)

The idea of this stopping criterion is to consider an inner and an outer (to the aortic wall) initialization, which move towards each other. A possible contact implies that in that region the image intensity is similar, so a leakage occurs. As an inner initialization we take the result of the FMM. As an outer initialization we consider the smallest circle which contains the inner initialization extended by 1.5 pixels. The final result is the inner curve at the time of contact of the two curves. Fig. 2(c) shows the IECC result. The inner curve stops after 60 iterations.

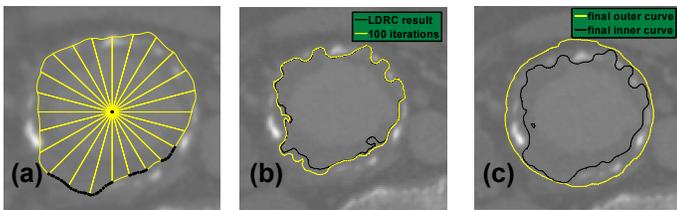


Figure 2. Results of the three stopping criteria

CREATION OF THROMBUS AND OUTER WALL BOUNDARY

Thrombus boundary

The presence of calcified deposits, which are typically located within the AAA arterial wall and the reduced contrast between thrombus and wall results in a “toothed” thrombus boundary, as the evolving curve enters the regions between the calcifications (Fig. 2b). To eliminate these regions, we take the inversion mapping of the final curve of our model with respect to its center of mass. Then, we find the points of the convex hull of the extracted curve and the preimages of these points under the inversion mapping. Finally, to improve our result, we apply the level set equation for a few iterations to the so constructed curve that is the boundary of the set of all these preimages, with an outward direction (see Fig. 3(a) for the final result).

Outer wall boundary

The first step of this method is to apply appropriate thresholding to the image so that calcifications can be more easily located. Then we apply a stopping criterion and we consider the smallest circle containing the extracted curve. At least one point of each calcification will be inside this circle. For each one of these points we consider its 8 neighbors and move along these 8 directions until a non-calcified point is found, thus detecting all the calcification points in the image. For each calcification point, we consider its 4 neighbors that are 0.5 pixels away from it. Then we take the union of these neighbors, the calcification points and the points of the curve which was the stopping criterion outcome. We find the convex hull of this union and, finally, we apply the level set equation for a few iterations to the boundary of the convex hull, in an inward motion, aiming at a more accurate result.

RESULTS

Fig. 3(a) shows the final outcome from the application of the above methods for a single cross section, using SC as stopping criterion (sector angle $\pi/8$, stop after 70 iterations). From the segmented 64 MR cross sectional images the 3D AAA true vessel lumen surface was reconstructed (Fig. 3(b,c)) using purpose-developed software [3]. The roughness in the reconstructed surface is primarily attributed to the widespread calcifications present in this data set.

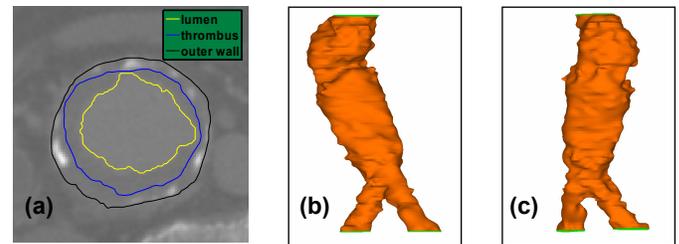


Figure 3. Extracted lumen, thrombus and exterior wall boundaries (a) and 3D reconstructed lumen surface (b,c)

CONCLUSION

A recent study [4] showed that in AAA, arterial wall regions with calcified atheroma can be 20 times thicker than plaque-free regions. The same ratio obtained, using the methodology in extracting the wall thickness proposed here, is close to 10, which could be considered satisfactory. Future work will include the transformation and application of our model for 3D data.

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