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Tomasz PIĘCIAK[1], Mateusz BARAN[1], Michał URBAŃCZYK[1]

LEVEL-SET BASED SEGMENTATION OF CAROTID ARTERIES IN COMPUTED TOMOGRAPHY ANGIOGRAPHY IMAGES

In this paper a segmentation algorithm of carotid arteries on computed tomography angiography (CTA) images is proposed. The algorithm is based on the threshold level set approach. In the basic version, the algorithm analyzes CTA slices beginning at the brachiocephalic trunk and going towards carotid arteries. Second variant of the algorithm performs segmentation in the opposite direction, which implies that the algorithm can follow branches e.g. subclavian arteries.

The localization process of the initial contour, for threshold level set method, on the first slice is based on curvature anisotropic diffusion filter, the Gaussian filter and fast marching method.

The article contains segmentation results for tested sets of method parameters. Experimental results show that optimal set of parameters ensuring that the threshold level set method performs segmentation of the entire subclavian arteries, does not exist.

1. INTRODUCTION

Carotid arteries are capillaries of circulatory system, which supply oxygenated blood to the neck and the head. Lesions of the carotid arteries are usually caused by atherosclerotic plaques, and can in turn lead to neurological complications, including movement, speech, proprioception and balance disorders [6]. According to World Health Organization (WHO), a stroke is second after the ischaemic heart disease cause of deaths, contributing to 6.15 million deaths worldwide [10].

Proper location and visibility of carotid arteries lesions is an essential part of invasive treatment e.g. endarterectomy or stenting [1,3]. The process of localization of lesions and surgical decision planning may be supported by virtual reconstruction and computer-aided detection (CAD) system. However, three-dimensional reconstruction process must be preceded by appropriate and correct, from the medical point of view, segmentation of arteries areas.

In this paper, we present an algorithm based on thresholding level set method, addressed to the carotid arteries segmentation on computed tomography angiography (CTA) images. We show two variants of the algorithm, which separate internal carotid and subclavian carotid arteries each. This paper is organized as follows. In the next section, we recall threshold level set method. In section III, we propose segmentation algorithms. In the last section, the segmentation results and method parameters are shown, along with concluding remarks.

2. THRESHOLD LEVEL SET METHOD

The most important part of the presented algorithm is a threshold level set method. Level set methods [2,8] are a family of algorithms based on evolution of curve, which is given implicitly as level set formulation of certain function [5]. This curve can dynamically change its topology — split and merge, what is especially useful in segmentation of tree-like structures on different transverse slices [2].

The algorithm approximates edges of desirable object (or group of objects) with a regular time-variant curve in $\Re^2$, which is modified in successive iterations until boundaries of objects are approximated sufficient precision.

[1] AGH University of Science and Technology, Faculty of Electrical Engineering, Automatics, Computer Science and Electronics, Department of Automatics, al. Mickiewicza 30, 30–059 Krakow, Poland,
email: pieciak@agh.edu.pl.

The curve $\gamma(t)$ is represented as a level set of function $\psi(x,y,t)$. It may be written as [2]:

$$\gamma(t) = \{(x,y) \in \Re^2 : \psi(x,y,t) = 0\} \tag{1}$$

We assume that the initial condition $\gamma(0)$ is given. The values of $\psi(x,y,0)$ are positive (or negative) for points respectively located outside (inside) of the curve $\gamma(0)$. The level set for value *0* of function defined this way matches to $\gamma(0)$ [2].

The second important issue is modification of function $\psi(x,y,t)$, which in turn means changing of $\gamma(t)$ [2,4]. For function which denotes movement speed of level set of ψ, partial differential equation describing evolution of the curve is written as:

$$\frac{\partial}{\partial t}\psi(x(t),y(t),t) + F(x(t),y(t),t)\|\nabla\psi\| = 0 \tag{2}$$

The Hamilton-Jacobi equation (2) can be solved, with respect to ψ by the Engquist-Osher scheme [2,4].

In threshold level set method, the speed function *F* is defined as [8]:

$$F = -\alpha A(x,y)\nabla\psi - \beta P(x,y)\|\nabla\psi\| + \gamma Z(x,y)\kappa\|\psi\| \tag{3}$$

where α, β, γ are arbitrary weights used to control the curve's evolution and κ is curvature of the curve. The $A(x,y)$ function represents an advection (it is equal to zero in threshold level set method), Z is a spatial modifier of curvature of level set, and allows marking of areas, where the curvature is an effect of noise. The propagation at a point (x,y) is defined as [8]:

$$P(x,y) = \begin{cases} I(x,y) - L & if \quad I(x,y) < \frac{U-L}{2} + L \\ U - I(x,y) & otherwise \end{cases} \tag{4}$$

Let Ω be an area of luminance inside (L,U) interval. The form of equation (4) implies that the level set should be at the boundary of Ω. If an intersection of (L,U) interval and luminance range of inside of level set is non empty, then the level set covers the border of Ω.

3. CAROTID ARTERIES SEGMENTATION ALGORITHM

The proposed algorithm analyzes slices beginning at the brachiocephalic trunk and going towards carotid arteries (Algorithm A). Starting from the first slice, threshold level set segmentation algorithm is performed and the result is stored. The input of single instance of segmentation is composed of two images: the current slice as a feature image and the result of previous instance as an initial contour $\gamma(0)$ (Fig.1). Output contains segmented image with contours of arteries inside of current slice.

Results found in each segmentation area serve as initial level set for the next segmentation, and match is improved by using threshold level set method to appropriately approximate arteries in the next slice.

The two conditions must be met in order to achieve correct segmentation:

1. It is possible to identify an interval of luminance (L,U), containing luminance values for pixels of arteries. Moreover, the luminance of direct neighbourhood areas is required to be outside the range (L,U). Then the entire area of arteries on single slice can be extracted accurately,
2. Each artery on every slice has at least one common point (with respect to coordinates on slice) with corresponding artery on the previous slice. Then the algorithm do not loses branching off paths.

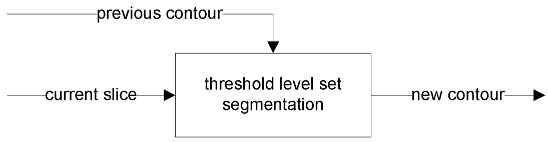

Fig. 1. A single instance of segmentation.

Since segmentation of each slice requires results of previous segmentation as a part of input, we need to calculate the initial contour on the first slice using different method. Described algorithm uses the method proposed in [8].

In the first step an image of edge potential is calculated and filtered by curvature anisotropic diffusion filter to reduce small noise without destroying edges (Fig.2) [9]. Then the norm of gradient of the image is calculated, convolved with Gaussian filter ($\sigma = 0.1$), and scaled by sigmoid filter ($\alpha = -28.3$, $\beta = 115$, $Min = 0$, $Max = 1$) (5).

$$f(x) = (Max - Min)\frac{1}{1 + e^{-\left(\frac{x-\beta}{\alpha}\right)}} + Min \tag{5}$$

In result, pixels have values *0* on edges and close to *1* elsewhere.

In the second step, a fast marching method is used to expand from a set of initial points (provided as input) to the entire area of both arteries. The edge potential image defines speed of expansion for fast marching method. The curve expands over tissue areas until edges are encountered. In result, the first contour for main segmentation algorithm is obtained.

The algorithm presented above can separate all arteries going upwards from the brachiocephalic trunk to the brain arteries, which in particular include both carotid arteries.

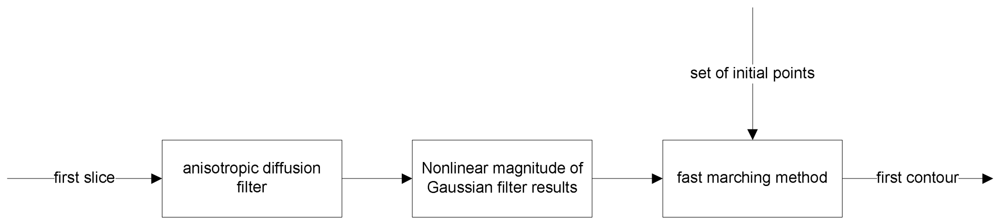

Fig. 2. Scheme of the initial contour segmentation for threshold level set method.

3.1. EXTENDED VERSION OF THE ALGORITHM (ALGORITHM B)

Extended version of the algorithm can separate arteries going downwards as well. After first pass (Algorithm A), the algorithm performs a second one in the opposite direction: from the brain to brachiocephalic trunk. In that way, the algorithm follows subclavian arteries.

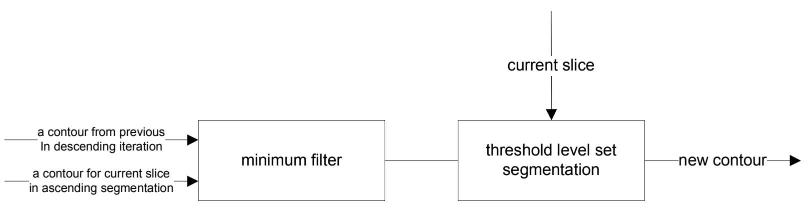

Fig. 3. Scheme of segmentation in opposite direction

The second pass of segmentation algorithm is performed for every slice beginning at one before the last (localized in brain), and ending at previously initial one (near heart). In this case, the input for threshold level set algorithm is the result of minimum filter of current slice segmentation results from the first stage and the output from the previous step of this stage (Fig.3).

The usage of minimum filter is a consequence of representation of arteries, where negative values represent their interior and the zero level set is their borders. Therefore, output of minimum filter contains both old and new (detected in the second pass) arteries.

The segmentation process adapts obtained contour to arteries from slice. New contours of the arteries are added to the previous ones, which were detected in first pass of the algorithm. The output of this instance of segmentation is written over the results of previous phase.

4. RESULTS AND CONCLUDING REMARKS

Presented algorithm has been implemented and used in segmentation of carotid arteries on CTA images. Both variants of the algorithm has been applied numerous times, with varying values of method parameters. The most satisfying results are shown in Fig.4. Parameters corresponding to these results are specified in Table 1.

Branches of carotid arteries were detected correctly, including subclavian arteries (Fig.4b-e), however in certain cases there was some distortions present in this area, as well as in the brain area (Fig. 4b, d).

The difference between basic and extended version of the algorithm (Algorithm A and Algorithm B) is clear. The second stage in Algorithm B allows to identify descending arteries, mainly significant part of subclavian arteries (Fig.4b-e).

Two parameters are essential for the algorithm to succeed: upper (U) and lower (L) threshold level. The threshold levels must be chosen in that way so that only the luminance of arteries contains in (L, U). Sometimes arteries are very close to other tissues e.g. bones — then the algorithm is not able to properly detect the artery' border. In the set of test images, increasing the lower threshold parameter (L) leads to false constrictions of arteries detection (only part of artery is detected, Fig. 4 c). In other case, lowering the lower threshold level leads to growth of number of false segmentations (bones near arteries are detected as arteries).

Another aspect of the proposed approach is the ratio of curvature term γ to the propagation term β (3). Increasing parameter γ, we get smoother arteries shapes but the algorithm is less capable to follow branches.

Unfortunately, there is no single set of parameters, which guarantee error-free segmentation from medical point of view. It is caused by violation of assumption 1 - certain interval of luminance of arteries sometimes represents arteries and sometimes represent adjacent other tissues. In general, this assumption is difficult to meet, and that ultimately limits applicability of the algorithm.

Table 1. Proposed method parameters used to extract areas of arteries in Fig.4.

Figure	Steps	L	U	β	γ
a	1	400	750	1	1
b	2	400	750	1	1
c	2	450	750	1	1
d	2	400	750	1	25
e	2	425	750	1	25
f	2	400	750	1	75

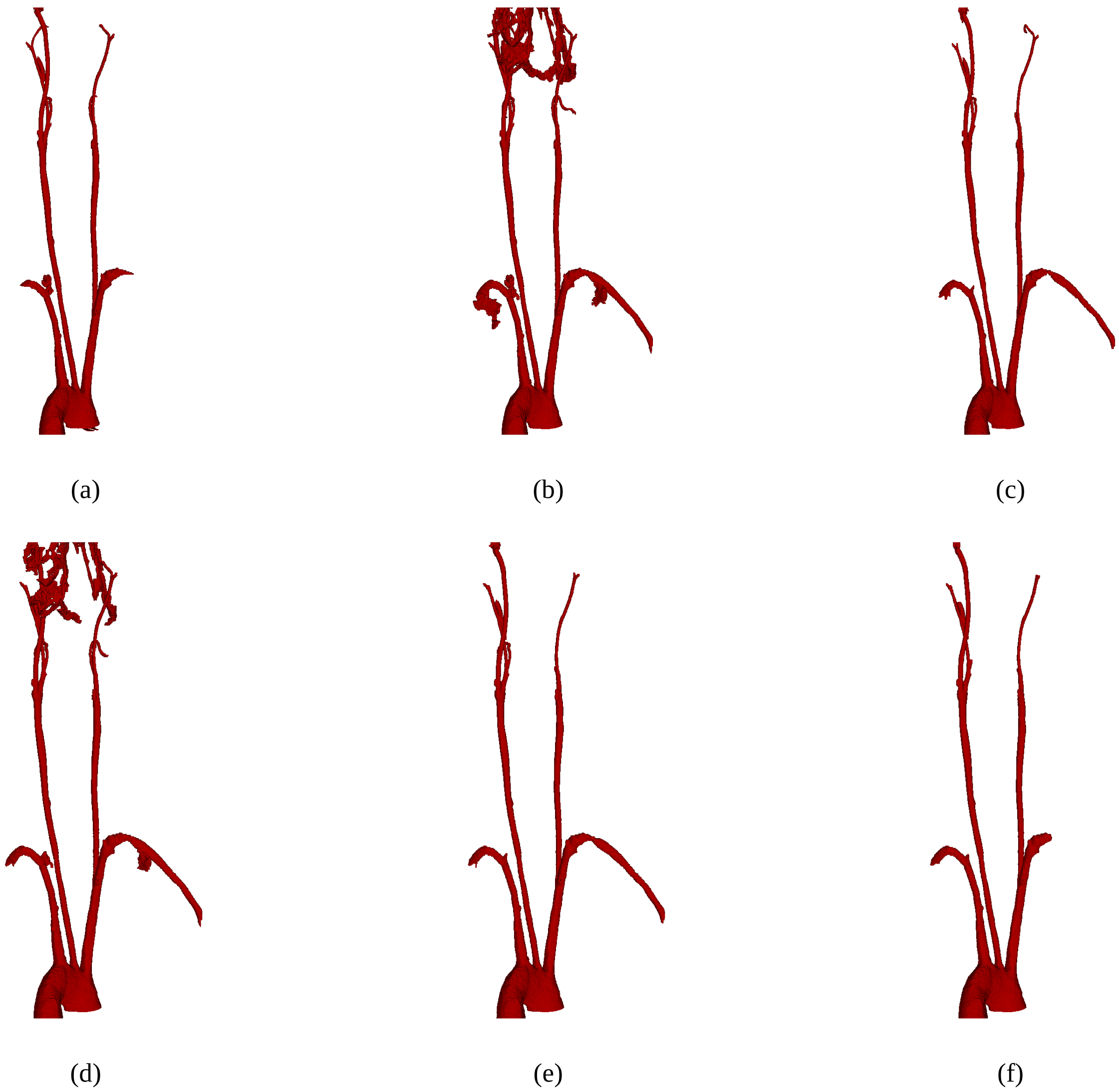

Fig. 4. Three-dimensional reconstruction of segmented arteries by volume rendering technique.

5. ACKNOWLEDGMENT

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