

A Minimum Cost Path Approach for the Segmentation of Bone Canalicular Network

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Abstract— This paper presents an approach for the segmentation of bone lacunar-canalicular networks in Synchrotron Radiation micro CT images. Segmentation of such structures is challenging due to several factors such as limited contrast and signal to noise ratio, partial volume effects and the large amount of data that needs to be processed which restrains user interaction. For this matter, we propose the use of a minimum cost path approach in combination with an automatic initialization scheme that avoids user interaction. Our method is based on a geodesic voting scheme that has been previously applied to 2D images. To the best of our knowledge, this is the first time that geodesic voting is extended to 3D images. Furthermore, while the original geodesic voting scheme is semi-automatic and requires at least one user-provided initialization point; we have introduced *a priori* knowledge on the lacuna location to make our approach fully automatic. The method was tested on real datasets and the results were visually assessed.

OSTEOPOROSIS is a skeletal disease characterized by low density and general deterioration of bone tissue that lead to an increased risk of fracture. According to the International Osteoporosis Foundation, it is estimated that one out of three women and one out of five men over the age of 50 will suffer an osteoporotic fracture, while the number of hip fractures worldwide caused by the disease will rise three-fold by the middle of the century [1]. Recent evidence, has called the attention on the role of osteocytes and their lacuna-canalicular networks in bone remodeling [2]. The osteocyte network is considered to play a major role in bone mechanotransduction but to date there is no satisfying quantification technique to assess it in 3D [3].

In the aim of performing a quantitative assessment of the lacuna-canalicular network, we have developed a level set based segmentation method that permits to extract these networks from novel 3D Synchrotron Radiation nanotomography (SR-nCT) images (voxel size 280nm) [4]. Segmentation of such structures is a challenging task since contrast and signal to noise ratio are limited and canaliculi are affected by partial volume effects as they are only one or two voxels thick. The latter becomes problematic in a level set based approach because the surface evolution tends to

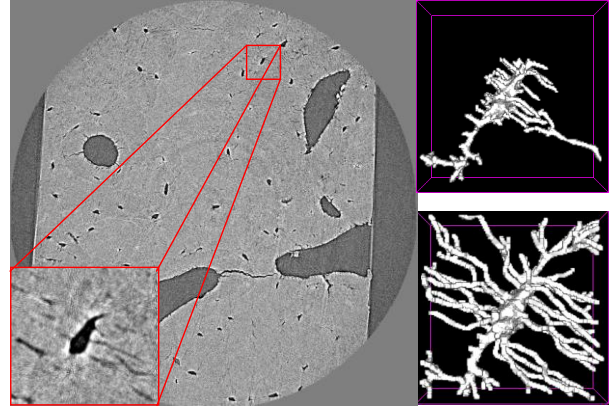


Fig. 1. *Left*, slice of a reconstructed SR- μ CT volume with a zoomed view of a region showing a lacuna and the low contrasted surrounding canaliculi. *Right*, 3D rendering of the segmented lacunar canalicular network. Continuity is evaluated by using the lacuna as a seed for region growing. *Top*, result using level sets. *Bottom*, result obtained with the developed methodology

stop at local minima caused by the partial volume effects. As a consequence, segmented canaliculi present discontinuities that affect the evaluation of the network extent and its connectivity (Fig 1). In this work, we seek to overcome the discontinuity problem by means of a minimum cost path approach. Minimal paths search to find a connected path between two user-provided *start* and *end* points in a cost image, such that the total cost of the path is minimum. They are well known to guarantee that the global minimum is found [5], thus avoiding early stopping.

In our case, we seek to connect the lacunae (*start* points) with the canaliculi extremities (*end* points) so that the extracted path allows us to obtain continuous segmented canaliculi. While user interaction in order to provide initialization points is a common practice in the segmentation of tubular structures such as blood vessels [6], it is an unfeasible task for our particular application. A typical dataset might contain thousands of lacunae to which numerous canaliculi are connected. For this matter, we propose an automatic initialization scheme that avoids user interaction.

Let us denote A as the set containing candidate *start* points. The A set is obtained by extracting the surface points from pre-segmented lacunae. For this matter, a rough segmentation of the lacuna, I_{TH} , is performed by image thresholding. Since the resulting image preserves background noise and small parts from the bone structure, a connected component analysis is done to remove such noise.

Manuscript received May 10, 2011.

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Elements being smaller than a fixed percentage of the largest object are removed. The noise-free image, I_C is eroded with a circular structuring element of radius one. Finally, the resulting eroded image is subtracted from I_C to obtain the lacuna surface points. The set of extracted surface points builds up the set A of candidate *start* points. Fig. 2 presents the different steps involved in this process.

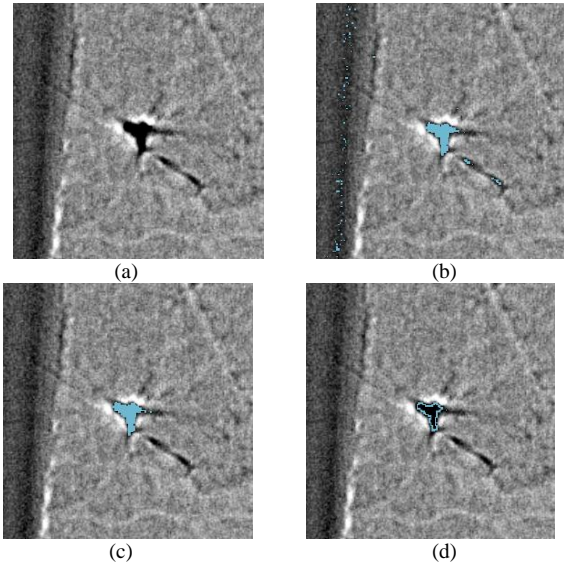


Fig. 2. Set A extraction. (a) Axial slice of the original image (Slice area $\sim 258 \times 258 \mu\text{m}^2$). (b) Overlaid rough lacuna segmentation. (c) Segmented lacuna after noise cleaning. (d) Extracted border points (A set) at the particular slice.

The selection of *end* points is more complex since it is difficult to establish the location of the canaliculi extremities. Given B a set of *end* random points dispersed in the image, Rouchdy and Cohen [7], proposed a geodesic voting scheme that allows the extraction of minimal paths without having any information about the location of the B set. The method propagates a front in an image using the Fast Marching algorithm [8] starting from a set of user provided *start* points. Then back-propagation [9] is used to extract minimal paths, y , that connect *end* points in B to the *start* points in A . The geodesic voting at voxel \mathbf{p} of the image is defined by:

$$G(\mathbf{p}) = \sum_{k=1}^N \delta_{\mathbf{p}}(y_k) \quad (1)$$

where $\delta_{\mathbf{p}}(y) = 1$ if the path y crosses the voxel \mathbf{p} and $\delta_{\mathbf{p}}(y) = 0$, otherwise. Voxels with a high geodesic voting score G , are kept while the others are rejected.

In this work, we have extended the original 2D geodesic voting scheme proposed in [7] so that it can be applied to 3D images and we have included the automatic selection of set A , since the original formulation assumes these such points are manually provided. Fig. 3 shows an example of the geodesic voting scheme procedure when using the surface of a volume of interest (VOI) to build up the set B . The VOI is defined such that it contains only one lacuna and it is centered on the lacunae centroid.

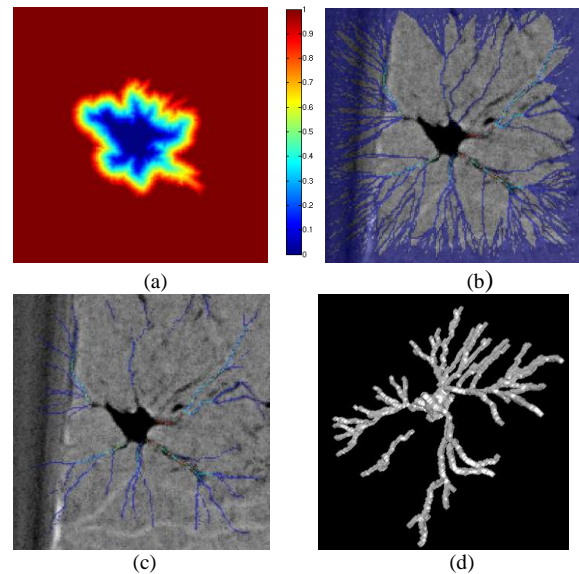


Fig. 3. Canaliculi segmentation (a) MIP view of the action map obtained after Fast Marching propagation using set A . (b) MIP view of the extracted geodesic paths superposed to a minimal intensity projection of the image. Surface of a VOI surrounding the lacuna is used as the B set. (c) Segmented canaliculi (voting threshold = 100). (d) 3D rendering of the segmented lacunar-canalicular network (voting threshold = 150).

Evaluation of the results was done by assessing the continuity of the extracted canaliculi. For this matter, a region growing, using the lacuna as a seed, was applied to the obtained segmentation and the extent of the resulting canaliculi was visually assessed. Results showed to be satisfactory since connectivity is improved w.r.t. the level-set based approach (Fig. 1). Immediate future work will focus on applying the method to larger datasets and in the development of a strategy to automate the selection of the voting threshold.

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