SKELETONIZATION ALGORITHM OF HIGH RESOLUTION VASCULAR DATA

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Analysis of vascular structures can greatly improve accuracy of morphometric studies that may be used for early medical diagnosis. Laws and processes in vascular tree can be described by skeletal structure. Currently, there are numerous skeletonization methods that focus on computational efficiency. However, when data are too large to be loaded into the memory of a personal computer, such approaches are difficult to use. This paper presents an algorithm for constructing of skeleton, topologically equivalent to the original object, which processes data locally and at the same time preserves global attribute of the object - the centeredness. Built skeleton is based on distance maps and then can be used to calculate the morphological and topological characteristics.

Introduction

Non-invasive tests allow to obtain diagnostic information excluding the possibility of entering viruses and bacteria into a body and relieving a patient from complex and unpleasant pain. At the same time, the tools required not only for carrying out such studies, but for analysis too.

Skeleton is a convenient form for the analysis of objects, particularly for objects with complex topological structure. Comparison of features of vascular structures in norm and pathology allows us to understand many morphological processes.

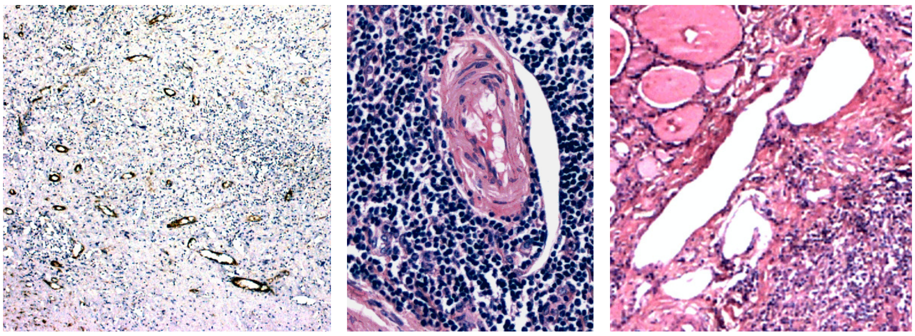
Currently there are many algorithms for skeleton constructing [1], but an input image has to be processed entirely in the vast majority of them. However, modern medical imaging algorithms allow to get the images of high accuracy, therefore it leads to an increase in processed data. E.g., the analyzed images of vascular structures may occupy several gigabytes. Such image may not always be loaded into memory and special methods should be offered for images of this size.

The main difficulty in the skeleton construction is to preserve the global characteristics of the skeleton (e.g. centeredness) during local transformations. In this article, we propose generalized skeletonization algorithm. We also give the analysis of obtained results, the advantages and drawbacks of our approach.

1. Properties of vessels image

All vessels are divided into three category by section: longitudinal, transverse, mixed. Elongated vessels are characterized by elongated shape and can be divided to two classes: thin, thick. These classes have different algorithms of extraction and description. Transverse vessels have ellipse-like shape and can to have a few extraction algorithms. These algorithms depend on different condition of vessels representation. Pattern of vessels can be defined by: border, contour of cell, free space.

This condition depends on type of histology sample. Therefore definition of vessels extraction method is choosing interactively by specialists (fig. 1).



a) b) c)

Fig. 1. Sample of vessels: a) transverse and mixed vessels that define by border; b) transverse that defined by contour of cell; c) longitudinal vessels that define by free space

2. Proposed algorithm

2.1. General Scheme

The general scheme of the proposed algorithm can be viewed in fig. 2.

On the first stage we acquire high resolution images with vessels. It is a mosaic with about a hundred of images, each of them contains about 2000x1000 voxels (15 Mb).

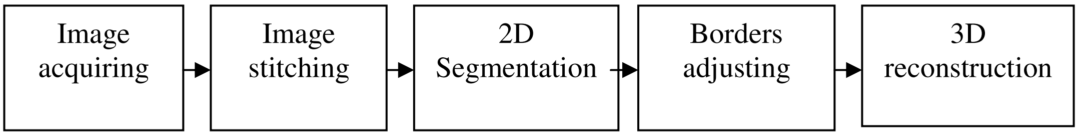
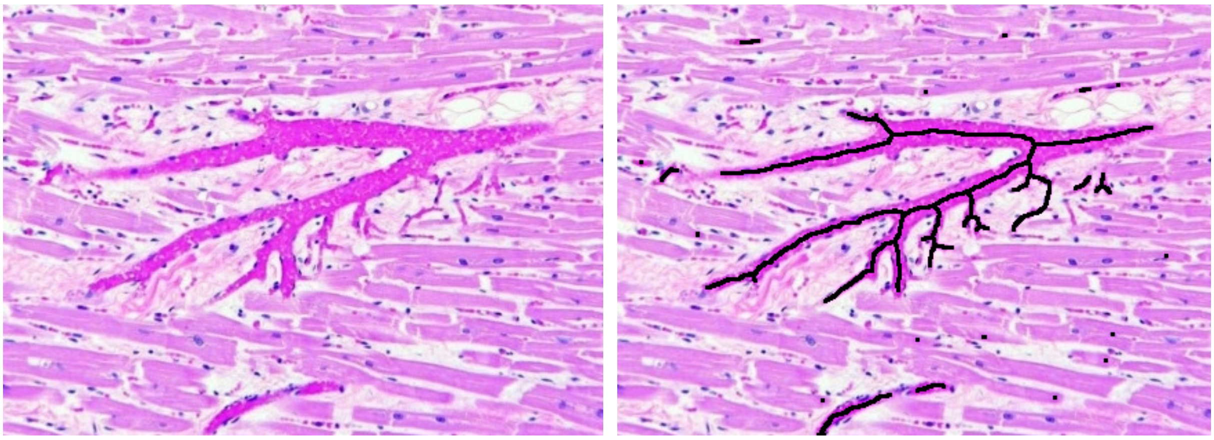


Fig. 2. General scheme of the algorithm

Obtained images have an overlap of about 50 voxel on each border between the mosaic images. For re-estimation of images positions stitch image stitching algorithm based on normalized statistical moment [2] can be applied. It is chosen because it optimized for high resolution images and robust to small rotations between subimages.

On the third stage for every subimage we apply the algorithm of color image processing of a histological image sample for membrane analysis described in [3]. Result of this operation is shown in fig. 3.



a) b)

Fig. 3. Original histological image (a); extracted skeletons (b)

We will take a look more closely at two final steps.

2.2. Preserving centeredness

Let's consider two neighboring subimages (fig. 4, a). If the initial algorithm is not changed, some artifacts will appear around the borders (fig. 4, b) and obtained skeleton will not be centered for the object.

To resolve this problem, we remove only those points for which the distance to the boundary of the object is less than the distance to the border of subimage:

$$P_{deletable} = P_{deletable} \wedge dist_P < \min(d_x, d_y, d_z),$$

where $dist_p$ – distance map value for P voxel, d_x, d_y, d_z – the distance to the nearest point of the boundary subimages respectively for axes Ox, Oy, Oz.

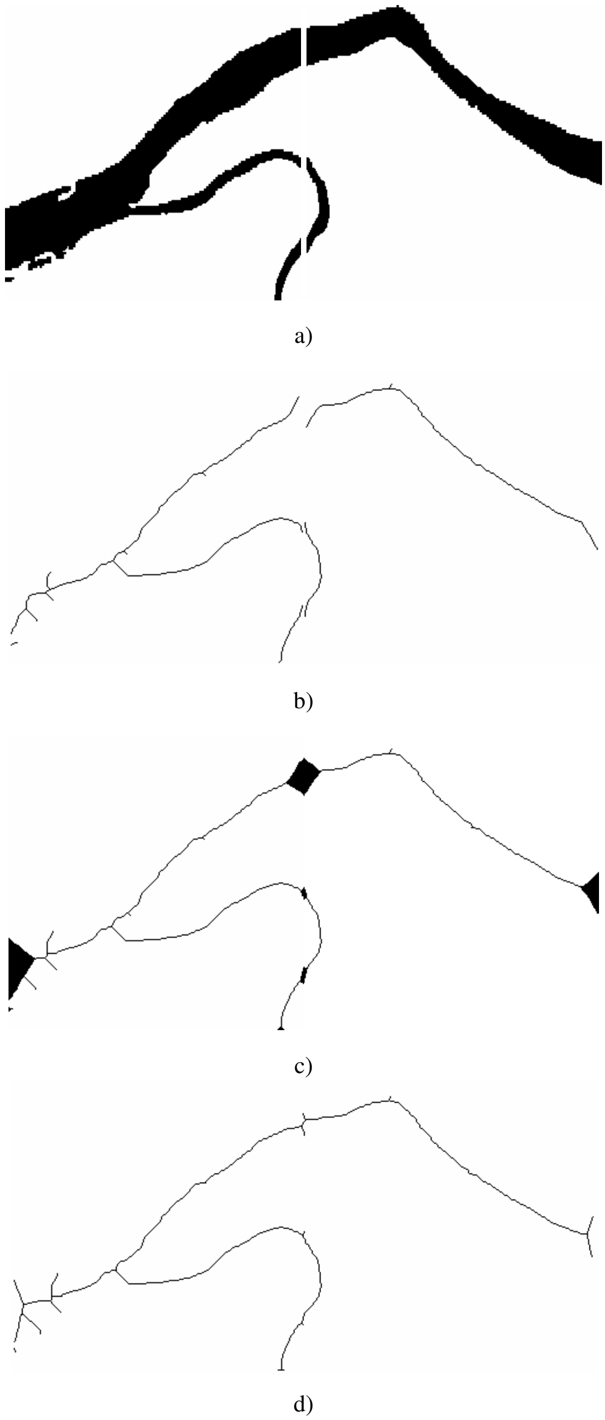


Fig. 4. Two neighboring subimages (a); result of stage 3 without correction (b); result of the first pass of the stage 4 (c); corrected skeleton (d)

This condition ensures that central points of the object will not be removed during this pass on the fourth stage (fig. 4, c).

This step is independent for each image and can be performed in parallel.

Unprocessed voxels are removed in the next steps of the stage. Their idea is that processing only occurs near the boundaries of the subimage. The subimage is cut into “strips” with width equal to doubled maximum distance on the distance map. This allows covering all voxels. Then, for each such “strip” used a slightly modified first step: in the removal condition is ignored for considered axis. For example, for the “strip” along the axis Ox condition removal is as follows:

$$P_{deletable} = P_{deletable} \wedge dist_P < \min(d_y, d_z).$$

Thus, the skeleton is thinned along each of the axes. After this stage we should to reconstruct skeleton for 3D-case.

3. Extension to 3D

The construction of intermediate layers can be realized by analysis of distance map properties [4]. Rides of distance map correspond to contours of optimal intermediate layer. Also they correspond to watershed lines. Taking in consideration aforesaid, we used technique [5] in order to reconstruct 3D-object surface from several closed, in general, non-planar curves.

Before that we applied dilatation to constructed skeleton. Detailed description of algorithm can found at [4], short scheme is shown on fig. 5, results on fig. 6.

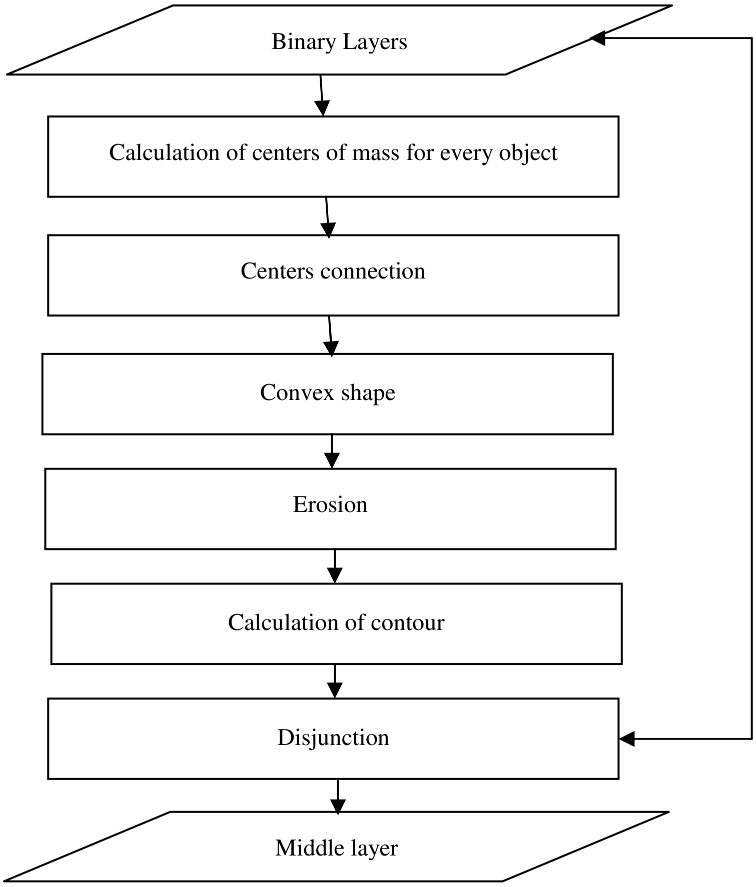


Fig. 5. Algorithm of construction of regions for definition

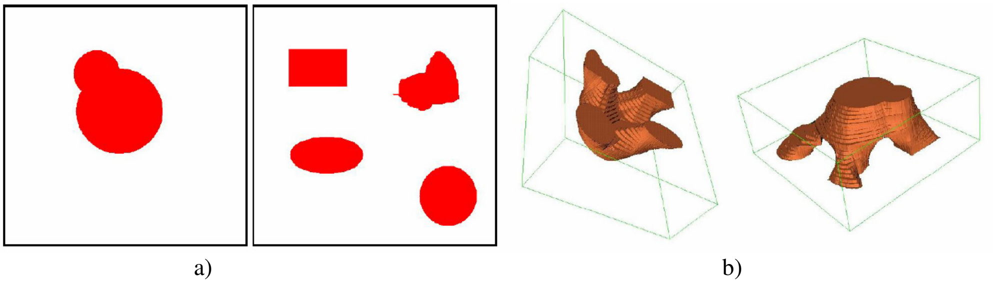


Fig. 6. Neighboring layers (a); reconstructed image (b)

Conclusion

The proposed algorithm has several advantages. Firstly, it allows processing a large amount of images, which is especially important for histology images as well as magnetic resonance images. Secondly, the considered algorithm can be easily parallelized, which will increase the speed of image processing and, consequently, the medical diagnosis. Thirdly, constructed skeleton contains information about the distance to the boundary of the object, and it can be used for further analysis.

The algorithm was tested on synthetic images and images of complex medical objects. It demonstrated good results for all cases. Compared to analogs, the proposed algorithm is self-contained – it works with raster layered images without additional transformations. In addition, the proposed algorithm is flexible; it has clearly marked stages, which can optionally be substituted with other alternatives.

References

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