A Framework for Tubular Organs Segmentation

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ABSTRACT

Tubular organs (blood vessels and bronchial tubes), because of their anti-compact nature, generally appear randomly cross-sectioned in CT slices. Because of this, it's difficult to analyze this kind of organ. We show how to use a previously presented work of ours to segment, and therefore be able to measure, tubular organs extracting local axis oriented slices. Finally, we show some examples of both types of organs and the parameters' values involved.

Keywords

Tubular organs, skeletonization, reslicing, medical imaging, 2D- and 3D-segmentation.

1. INTRODUCTION

Computed tomography (CT) scanner images are widely used for medical examination of vessels and bronchi. They are made of a series of parallel equidistant joined slices through the patient's body. Each pixel in each slice represents the opacity of a small volume (less than $1\,mm^3$) to the X-ray. This opacity is measured in Hounsfield units (HU) ranging from $-1{,}024$ (air) to more than 1,000 (hard bone), 0 being water.

Usually, radiologists are able to interpret and analyze such images in order to detect diseases and anomalies without using any kind of computer aid. It's when they come to *measure* (mean radius, perimeter, area) some part of the studied organ that the computer tool comes to help.

Making an automatic measure calls for image segmentation: recognizing one region allows us to measure it in number of pixels, thus in real world units. Furthermore, putting apart the segmentation problem, measuring a tubular organ, often means measuring its local axis cross-section. Yet, the slices of the CT series do not follow this axis, *i.e.* they are generally not perpendicular to the organ because of the organ's anti-compact nature. This makes difficult both steps of segmenting and measuring.

Not many works exist dealing with tubular organs as a whole. Indeed, almost all are oriented towards one kind of organ (either bronchial tubes or blood vessels). Some of them work in 2D and then reconstruct the organ, some others work in 3D directly.

Those dealing with blood vessels include [Ver96, KMA+98, SMD98] and mainly use the fact that the blood vessel is one of the lightest areas of the CT slice because of contrast agent use. On the other hand, bronchi are recognisable by their very low intensity (*i.e.* the air they contain) surrounded by a light wall [FP00, DRH96, BKK+00, SSH94].

Instead of focusing in a particular kind of organ, we consider that both kinds of organs differ "only" by their characterization. Thus, this could be part of a more general, modular framework.

On the other hand, tubular organs can be approached in such a way that segmentation becomes simple. Indeed, the main problem is that the cross section of a tubular organ and a CT image is not always optimal in terms of local direction. If we are able to extract a new slice giving the optimal local cross section of a tubular organ, then this cross section can be segmented rather "easily". In fact, the optimal local

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cross-section gives a near to circular shape.

The framework we use was previously presented in [dD01] and deeply explained in [dD03]. The main idea is to use the two above mentioned points, *i.e.* organ independence and slice relocation. The framework is divided in three steps. First a rough segmentation of the CT slices gives a binary volume. Then we are able to extract a 3D skeleton from this volume from which we finally extract new slices perpendicular to the organ's local axis.

In this paper we show how we can apply this framework to real cases and how do the parameters fit for each kind of organ.

2. SLICES EXTRACTION

Pre-Segmentation

As our goal is to extract a binary volume from the original CT slices, we choose a pre-segmentation operation based on bi-thresholding. And, in order attenuate the influence of both noise and resolution limits, we apply a sigma-filter[1] before, and a morphological erosion after, bi-thresholding.

In order to make easier the framework's usage we have fixed the values of the sigma-filter at $\sigma = 200\,\mathrm{HU}$ and a 5×5 neighbourhood. The erosion filter has been fixed with a 4-connected +-shaped structuring mask.

Upper and lower values of bi-threshold have to be selected by the user giving the proper HU values according to the selected organ. For the bronchi the range from $-1,024\,\mathrm{HU}$ to $-920\,\mathrm{HU}$ is generally satisfactory. For blood vessels the useful range depends on the kind of vessel studied and the proportion of contrast agent in blood. An HU intensity picker tool allows the user to tune the right range for the organ.

Binary Volume and Skeleton

The binary volume issued from the pre-segmentation step is built using a volume growing algorithm. A seed point is selected by the user, usually in the first CT image, inside the studied organ and marked as pre-segmented.

We use a 6-connected 3D-propagation mask in order to avoid undesirable connections to other organs having the same intensity range. If this ever happens, and it does, we let the user direct the volume growing by adding or subtracting chunks of voxels from the binary volume. The voxels are added or subtracted in the same order the volume growing would.

For a technical insight of the skeletonisation algorithm, see [dD01, dD03]. We just recall that this skeleton is build from a geodesic distance transform (GDT) propagating from the above selected seed on the binary volume surface. A sampling parameter Δ allows to extract a local center at each Δ-multiple valued connected component of the GDT. These local centers are connected in order to extract the binary volume topology and to build a skeletal tree. (In the examples below Δ is fixed to 10 voxels).

Finally, using the skeletal tree we place and orient the slices along its segments. Then the slices' pixels are extracted from the original CT data volume using a third order reconstruction filter.

[1]The sigma filter allows noise filtering without gradient degradation introduicing an homogeneity parameter σ.

3. EXAMPLES

Bronchial Tubes

Figure 1b shows the slice in Figure 1a after pre-segmentation. The threshold range is $-1024\,\mathrm{HU}$ to $-920\,\mathrm{HU}$. The resulting binary volume is shown in Figure 2a after picking a seed point in the first CT image (top of figure).

Figure 3 shows a series of extracted slices along the circled bronchus of Figure 2a (bottom right). We have one slice per skeleton segment locate at its upstream node and zoomed 400 % in each direction. The bronchus of interest is located at the center of each slice. Here we can note two things. First, our pre-segmentation is not perfect: slices 3c and 3d show a forking bronchus not visible in the binary volume. On the other hand, the bronchus wall in the two last slices are hardly visible, even for a radiologist. This points out that our pre-segmentation is able to go quite far in the bronchial tubes structure. In fact, the inner diameter of these bronchi is around 2–3 mm.

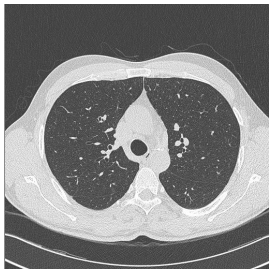
Abdominal Aorta

Figure 1d shows the slice in Figure 1c after pre-segmentation. The threshold range is $250\,\mathrm{HU}$ to $370\,\mathrm{HU}$. The resulting binary volume is shown in Figure 2b after picking a seed point in the first CT image (top of figure).

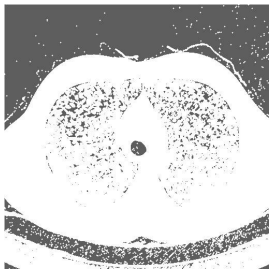
Figure 4 shows a series of extracted slices along the circled vessel of Figure 2b (middle left). Here we have two slices per skeleton segment. Again, the same problems arises: the roughness of the pre-segmentation stage and the need to apply a morphological erosion in order to avoid connecting spine bone voxels, are responsible for missing some small vessels. In spite of this, the main vessels are perfectly analyzable and measurable in most cases.

4. CONCLUSION

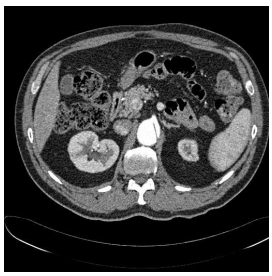
We have shown how to easily change some parameters in order to be able to do the same job with two very different kinds of tubular organs. Indeed, this is reflected in the examples above, where the only differences for building the skeleton and extracting the new slices lie in the threshold levels. Furthermore, these parameters are well known to the concerned users, radiologists.



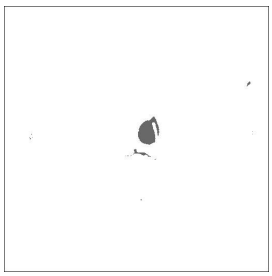
a. bronchial tubes



b. pre-segmented



c. abdominal aorta



d. pre-segmented

Figure 1. CT and Pre-Segmented Images of Tubular Organs

As this is a quite recent work, we still are not able to show post-segmentation results. However, recent works form the CHU (University Hospital Center) of Bordeaux [PBD+02], use the LoG (Laplacian of Gaussian) operator to measure inner and wall bronchi surfaces in CT slices. This work has been tested successfully in our framework and is currently being used for clinical studies.

In the case of blood vessels, work is in progress for using the framework in order to build vessel prosthesis in cases of aortic aneurisms. Immediate experiences include stenosis measuring in coronary vessels.

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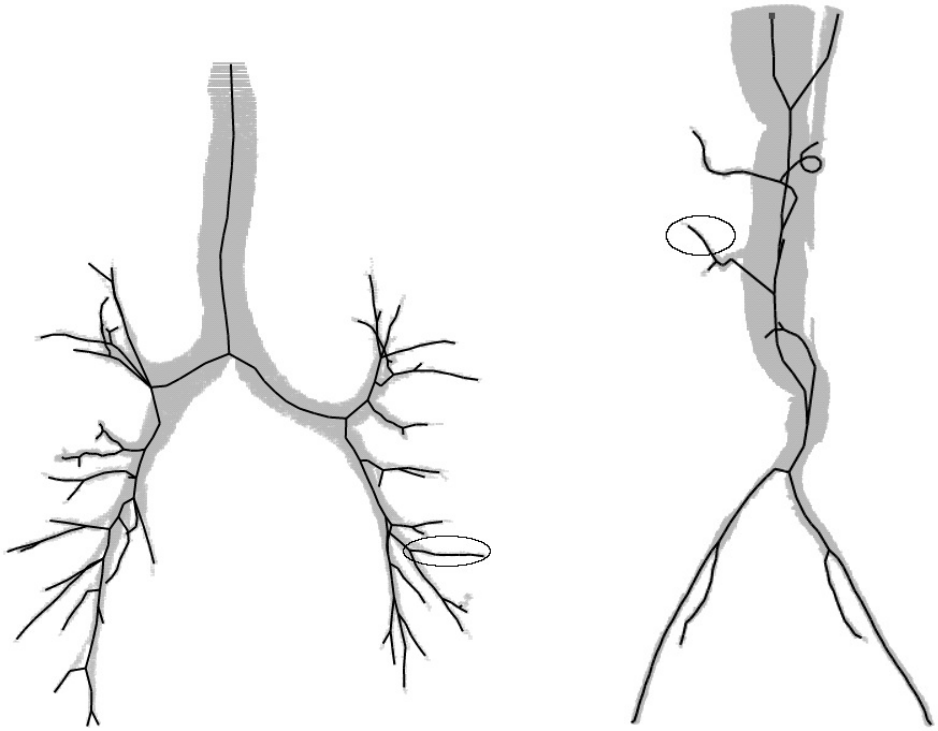
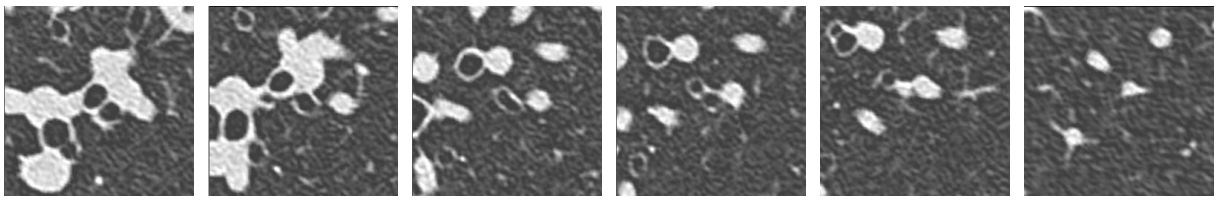


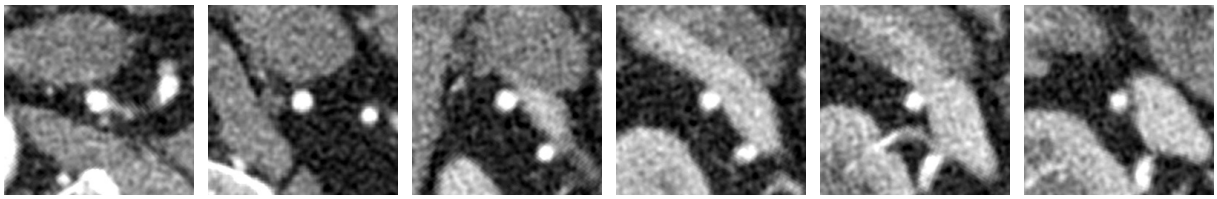
a. bronchial tree b. abdominal aorta

Figure 2. Binary Volume and Skeleton



a. b. c. d. e. f.

Figure 3. Slice Positioning along the Circled Bronchus in Figure 2a



a. b. c. d. e. f.

Figure 4. Slice Positioning along the Circled Vessel in Figure 2b