

The segmentation process of lung vessels (applied in the 20 public datasets of <http://vessel12.grand-challenge.org/>) is shown in figure 1:

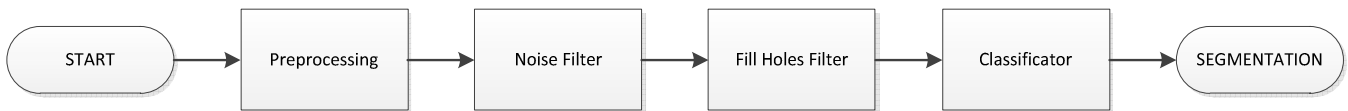


Figure 1. Segmentation process scheme.

Preprocessing

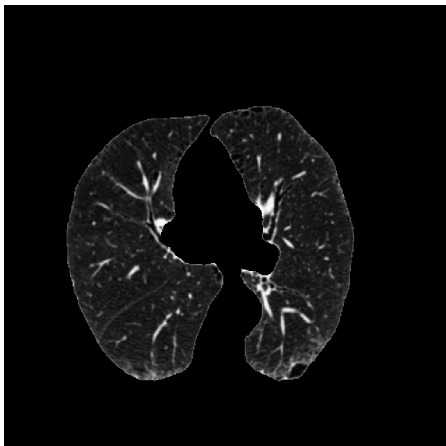


Figure 2. Image after preprocessing.

The process begins with the conversion of .raw files to 16 bits DICOM series. Then, a logical AND operator bitwise is performed between the lung mask and the DICOM series, in order to extract only the areas of interest (Figure 2). In the next step, the image is normalized to 8 bits (0-255).

Noise Filter

The first step of the method proposed in figure 1 requires a noise reduction filter. The filter proposed is an area opening [1]. This filter reduces local bright objects in the image. The local bright structures (in our case vessels spurious) that have an area fewer than “ λ ” pixels are integrated in the background (in our case lung tissue).

Fill holes filter

The next stage, the negative of the smooth image is carried out and the background is set to zero. After a morphological “fill holes” is applied to this image. The “fill holes” is based on an opening by reconstruction. The marker of this reconstruction is selected as a square of the same size of original images (512x512), [1]. In “fill holes” output, black input regions are filled and converted into bright regions. After, the residue is performed with the input image of the “fill holes” filter to have vessels structures more enhanced than in the original image (Figure 3, left).

Classifier

In the next stage, a K-means clustering is implemented. K-means classifier is a method of cluster analysis which aims to partition n observations into k clusters in which each observation belongs to the cluster with the nearest mean [2]. In our k-means classifier, the highest intensity cluster is considered as vessel (figure 3, right).

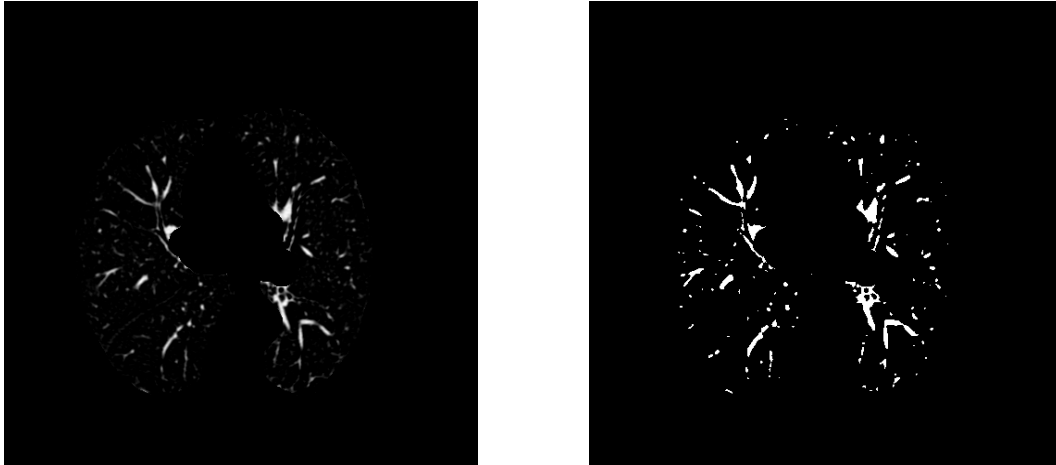


Figure 3. On the left the input of the k-means, on the right the output.

A 3D model that allows a better appreciation of the segmentation is shown in figure 4. A 3D filtering of the objects that have a size lower than a threshold is performed to remove spurious elements that generate discontinuities in vessel tree. Also thanks to this 3D model the emergence of "foreign elements" can be analyzed, such as the masses that are created around certain points which may be a tumor or something similar.

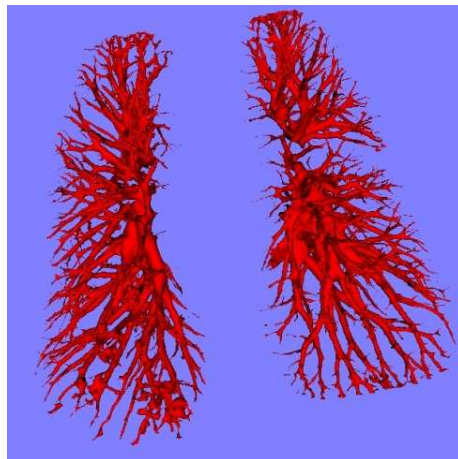


Figure 4. 3D model of lung vessels.

The algorithm has bugs that have already been discussed above, usually in areas where appears tumor ramifications. It doesn't need training and is being tested in the segmentation of hepatic vessel tree. The process typically takes less than 1 minute, since the average processing are 7.3 slices per second, although it depends on the length of the series. The algorithm is fully automatic, no user intervention is needed. The " λ " parameter used in the 20 datasets has been 8 and the number of clusters of the K-means classifier is ($k=3$). The final 3D threshold for selecting the objects with the highest area is 4000 pixels.

- [1]. P. Soille, Morphological Image Analysis. Springer, 2002. Second edition. ISBN: 3-540-42988-3. Chapter 4 and 6.
- [2]. Hartigan J. and Wong M. A K-Means Clustering Algorithm. Journal Of The Royal Statistical Society. March 1979;28(1):100.