Algorithm Description

Juan-Carlos PRIETO[1], Carolina PEREZ-ROMANELLO[2], Vanessa PEREZ-ROMANELLO[2], Chantal REVOL-MULLER[1], Christophe ODET[1], Maciej ORKISZ[1], Marcela HERNANDEZ-HOYOS[2]

[1]Université de Lyon, CREATIS; CNRS UMR5220; INSERM U1044; INSA-Lyon; Université Lyon 1, France

[2]Grupo Imagine, Grupo de Ingeniería Biomédica, Universidad de los Andes, Bogotá, Colombia

Description of the framework

1. **Preprocessing:** At this phase, the main goal is to exclude from the original lung mask the airways, the bronchial wall and the interlobular septum. This is done in 3 stages.

    a) **Airways segmentation:** A basic segmentation of the bronchi using an adaptive region growing method.

    b) **Bronchial wall identification:** In order to identify the bronchial wall, the airways are dilated. Due to the fact that the width of the bronchial wall decreases as the tree bifurcates, the dilation cannot be done with the same structuring element throughout the entire tree. Therefore, an adaptive dilation is applied to the tree.

    c) **Mask modification**: It is desired for the interlobular septum and the bronchial walls not to be incorrectly identified as vessels. For that reason, the mask is modified so that these are not labeled as belonging to the ROI. First, the mask is eroded to exclude the interlobular septum that is located in the pulmonary wall. Then, the airways and the bronchial wall segmented in the previous stages are subtracted from the eroded mask so that it is not included in the final segmentation.

2. **Computation of Vesselness image:** The algorithm is based on Frangi's [1] criteria for vessel enhancement. The idea is to calculate second order derivatives for each voxel in order to build the image's hessian matrix and determine for each voxel the probability of belonging to a vessel. Given that this derivatives present high sensibility to noise, a Gaussian filter is applied at several scales σ, to smoothen the image.

3. **Seed points selection:** The algorithm requires a number of seed points for a region growing initialization. Their selection is done according to the following criteria, defined by Pechin Lo [2] for vessels labeling:

$$\lambda_1,\ \lambda_2 < 0 \qquad (1)$$

$$w \geq c \qquad (2)$$

$$\left(\frac{|\lambda_1|-|\lambda_2|}{|\lambda_1|+|\lambda_2|}\right) < T1 \qquad (3)$$

$$\left(\frac{|\lambda_1|-|\lambda_3|}{|\lambda_1|+|\lambda_3|}\right) > T2 \qquad (4)$$

$w = \sqrt{{\lambda_1}^2 + {\lambda_2}^2 + {\lambda_3}^2}$ and $c = \overline{w} + 2\sigma(w)$, while $\overline{w}$ and $\sigma(w)$ are respectively the mean value and the standard deviation of w across the image.

The criterion defined by equation 4 considers brightness for a given voxel, while the criterion defined by equation 5 considers the contrast in the voxel. $T1$ and $T2$ are the tubeness criteria which sets thresholds for seed selection when the previous criteria are not met. Ideally, in bright tubular structures we should have $\lambda_1 \cong \lambda_2$ and $\lambda_3 \cong 0$. We have therefore set that $T1 = 0.1$ and $T2 = 0.9$. The seeds are generated in those voxels that fulfill these criteria, resulting in seeds that not only belong to vessels but are also centered inside them.

4. Variational Region Growing (VRG):

The algorithm is based on a variational region growing approach (VRG) defined by Pacureanu et al.[3]. The idea is to segment the object by means of a discrete function $\phi_n(x)$ with voxels labeled as 1 belonging to a vessel region Ω_{in}, and voxels labeled as 0 belonging to the outside region Ω_{out}.

$$\phi_n(x) = \begin{cases} 1, & para\ x\ \in \Omega_{in} \\ 0, & para\ x\ \in \Omega_{out} \end{cases} \qquad (5)$$

The regions defined in $\phi_n(x)$ change according to a region-based energy ΔJ designed so that its minimum corresponds to the expected solution. At each iteration *n*, the voxels connected to Ω_{in} are analyzed. If the addition of those voxels decreases the energy, then they are accepted and the discrete function is updated as:

$$\phi^{n+1}(x) = \frac{1}{2}\left(1 - sign\left(\Delta J(\phi^{n+1})\right)\right) \qquad (6)$$

The energy function used to define the behavior of the region growing for each iteration $\Delta J(\phi^{n+1})$ is based on the vesselness criterion v and the gray level values of the original image f:

$$\Delta J(\phi^{n+1}) = (1 - 2\phi^n)\left(\Delta J_1(f, v)\right) \qquad (13)$$

$$\Delta J_1(f, v) = \frac{v}{MaxV}\left(\left|v - \mu_{v_{in}}\right|^2 - \left|v - \mu_{v_{out}}\right|^2\right) \qquad (14)$$

$$+ \left|\frac{f}{MaxF}\right|\left(\left|f - \mu_{f_{in}}\right|^2 - \left|f - \mu_{f_{out}}\right|^2\right)$$

where $\mu_{v_{in}} y\ \mu_{v_{out}}$ are the medium values for the in and out regions of the vesselness image, and $\mu_{f_{in}}$ y $\mu_{f_{out}}$are the mean values for the in and out regions of the original image. $MaxF$ is the higher gray level value for the original image, and $MaxV$ is the higher value found for the vesselness image.

Methods

1. **Vesselness (probabilistic):** The final images were obtained simply by computing the vesselness image after applying the preprocessing method (steps 1 and 2).

2. **VRG (binary):** Using the vesselness images from the method above, final image results were obtained after applying the VRG algorithm from the seed point selection (steps 1 through 4).

3. **Probabilistic VRG:** This method uses results from the two methods above in order to calculate a third and more accurate probabilistic result. The idea is to obtain the vesselness image delimitated by the VRG binary image by first scaling the latter to [0,1] and then calculating the product of the vesselness image and the scaled binary image.

References

[1] A. F. Frangi, W. J. Niessen, K. . L. Vincken y M. A. Viergever, «Multiscale vessel enhancement filtering,» Medical Image Computing and Computer-Assisted Intervention - MICCAI'98, vol. 1496, pp. 130-137, 1998.

[2] L. Pechin, J. Sporring, H. Ashraf, J. J. Pedersen y M. de Bruijne, «Vessel-guided airway tree segmentation: A voxel classification approach,» Medical Image Analysis, vol. 14, nº 4, pp. 527-538, Agosto 2010.

[3] A. Pacureanu, C. Revol-Muller, J. Rose, M. Ruiz y F. Peyrin, «Vesselness-guided variational segmentation of cellular networks from 3D micro-CT,» Biomedical Imaging: From Nano to Macro, 2010 IEEE International Symposium, pp. 195-206, 2001.