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Tubular Structure Filtering by Ranking Orientation Responses of Path Operators

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Résumé
Thin objects in 3D volumes, for instance vascular networks in medical imaging or various kinds of fibres in materials science, have been of interest for some time to computer vision. Particularly, tubular objects are everywhere elongated in one principal direction – which varies spatially – and are thin in the other two perpendicular directions. Filters for detecting such structures use for instance an analysis of the three principal directions of the Hessian, which is a local feature. In this article, we present a low-level tubular structure detection filter. This filter relies on paths, which are semi-global features that avoid any blurring effect induced by scale-space convolution. More precisely, our filter is based on recently developed morphological path operators. These require sampling only in a few principal directions, are robust to noise and do not assume feature regularity. We show that by ranking the directional response of this operator, we are further able to efficiently distinguish between blob, thin planar and tubular structures. We validate this approach on several applications, both from a qualitative and a quantitative point of view, demonstrating an efficient response on tubular structures. This article is a summary of [MTNP14].

Mots clé : mathematical morphology, thin structures, path operators, 3D imaging.

1. Path Operators

Path operators were first introduced in 2001 by Buckley and Talbot [BT00]. Path operators include two dual operators: path opening and path closing. Without loss of generality, we consider in this paper bright objects on dark background and consequently focus our explanations on path opening.
A path opening is a classical morphological opening but instead of using only one structuring element, it uses a set of structuring elements called paths.
A path of size L is a set of L connected pixels on a graph G defining a global path orientation (see Fig. 1(a)). Consequently, a path opening with path length L preserves a structure if at least one path of length L can fit in this structure (see Fig. 1(b)).

Each path opening is associated to a graph G which defines the global orientation. In order to preserve thin elongated structures in all directions, a fusion of several path opening associated to different orientations is needed. A space discretization in 7 orientations is sufficient to cover all thin structures orientations (see Fig. 2).

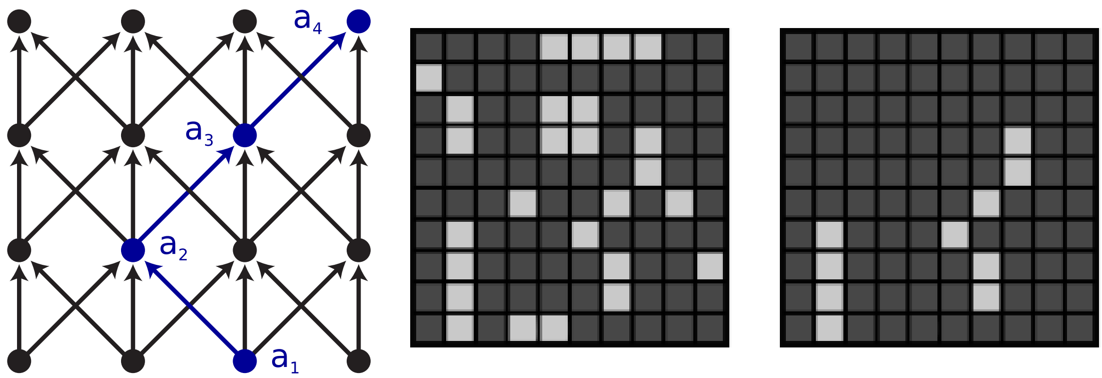
According to that definition, a path opening preserves all thin structures in 3D images which means both tube-like and plane-like structures. We proposed a new filter, called RORPO, based on path operators in order to preserve only tube-like structures in 3D images.
In the following, we will use the Robust Path Opening (RPO) of Cokelaer et al. [CTC12] which is a version of the classical path opening robust to noise.

2. RORPO

RORPO is based on a simple hypothesis : as a plane-like structure is elongated in one more direction than a tube-like structure, a plane-like structure should be detected in at least one more RPO orientation than a tube-like structure. Consequently, counting the number of RPO orientations detecting a voxel x gives information about the type of structure x belongs to.
We though proposed to pointwise rank the 7 RPO responses $R_{c_i}^L(I)(x)$ to obtain the 7 rank-filtered images $\Phi_i^L(I)$ (see Eq. **??**). In particular, $\Phi_1^L(I)$ is the pointwise maximum filtered image which is the classical RPO filter.

$$\Phi_i^L(I)(x) = RF\{R_{c_i}^L(I)(x), i \in [\![1,7]\!]\} \quad (1)$$

We show experimentally that tubular structures are generally detected by at most 3 RPO orientations whereas plane-like structures are detected in at least 5 RPO orientations.
Based on these remarks, $\Phi_1^L(I)$ has a high response for both tubular and plane-like structures whereas $\Phi_4^L(I)$ only has a high response for plane-like structures.



(a) (b)

Figure 1: *(a) A graph G (in black) defining a global vertical path orientation and a path (in blue) of length 4 pixels. (b) An example of a path opening of length 4 pixels. From left to right, the initial image and the result of the path opening. Only pixels belonging to a path of at least 4 pixels are kept. Paths are defined using the graph of figure (a).*

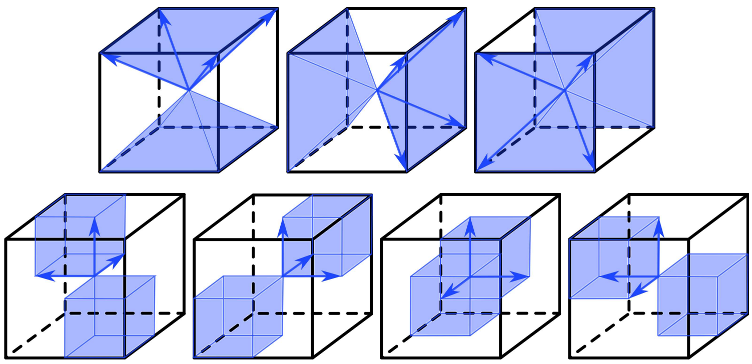


Figure 2: *The 7 path opening orientations. From left to right, from top to bottom : vertical, horizontal, depth, diagonal 1 to 4 orientations. The center of the cube, each corner and the center of each face of the cube represent a voxel. The blue arrows are the neighborhood relations.*

RORPO is then defined as the top hat between $\Phi_1^L(I)$ and $\Phi_4^L(I)$ see Eq. 2:

$$\Phi_i^L(I)(x) = \Phi_1^L(I) - \Phi_4^L(I) \qquad (2)$$

3. Results

Synthetic Images

RORPO was applied on a synthetic image. This image contains an helix as a tubular structure with various diameters and orientations, a plane and blob-like structures (see Fig. 3(a)). Moreover, we compared RORPO with Frangi's Vesselness [FNVV98], which is the gold standard in tubular structure filtering, and a combination of RPO and a classical top hat. Results of the comparison are shown in Fig. 3.

Real Images

The same quantitative analysis was also performed on 15 CT of the heart from the Rotterdam repository [SMvW*09] with RORPO and Frangi's Vesselness only. Results are shown in Fig. 3. We observe that RORPO detects significantly less false positive than Frangi's Vesselness.

4. Conclusion

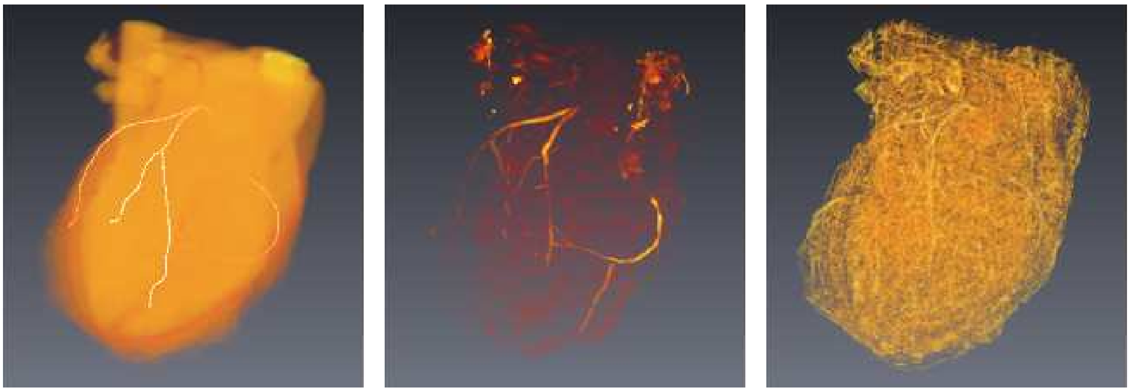
We proposed a new filter for 3D tubular structure enhancement based on path operators. Both qualitative and quantitative experiments show that RORPO outperformed the gold standard in tubular structure filtering, namely the Frangi's Vesselness.

RORPO is a low-level tubular structure filtering, consequently, it does not detect junction of tubular structures which are not tubular. Then, RORPO should be used as a feature among others in a vessel detection pipeline.

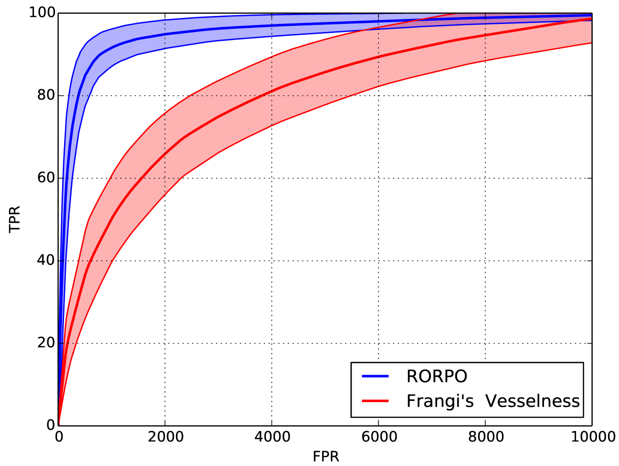
A complete 3D implementation is available at `http://path-openings.github.io/RORPO/`.

(a) (b) (c)

Figure 3: *The initial image (a) and the result of the RORPO multiscale with length* 40, 57, 74 *and* 90 *(b). The ROC curves of the comparison (c).*



(a) (b) (c)



(d)

Figure 4: *The initial image and the ground truth (a), the result of the RORPO multiscale (b) and the result of the Frangi's Vesselness (c). The mean and standard deviation of the ROC curves (d).*

Références

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