Tubular Structure Filtering by Ranking Orientation Responses of Path Operators

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Introduction

Tubular objects, like vascular networks or fibres in materials science, have been of interest for some time in computer vision. Usually, tubular structure filtering uses an analysis of the three principal directions of the Hessian which is a local feature.
We propose a low-level tubular structure detection filter based on paths, which are semi global features that avoid any blurring effect induced by scale-space convolution.

Context

3D Path Operators can filter thin objects, which means both tubular and plane-like structures.
Our strategy for filtering only tubular structures derives from the simple observation of figure 1.
A blob, a plane and a tubular structure in 3D can be distinguished by "counting" the number of responses of any oriented filter as path operators.

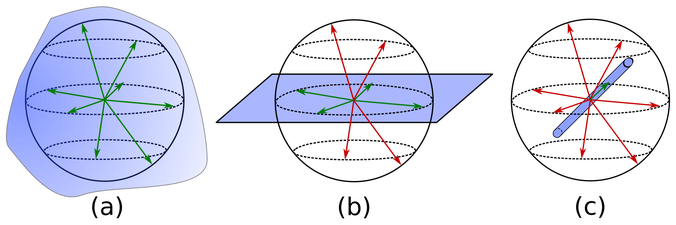
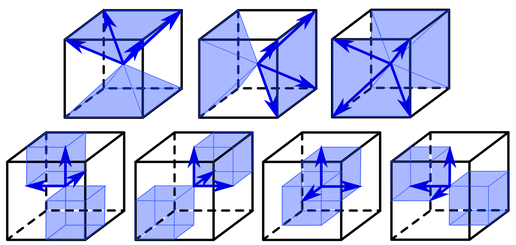


Figure 1 *: When sampling orientations from a point, in an isotropic structure a.k.a a blob (a), oriented operators all respond nearly identically (green arrow). In a plane (b), some proportion respond positively. In a tube (c), only a few orientations respond.*

Ranking Orientation Responses of Path Operators: RORPO

Hypothesis: Plane structures are detected in at least one more RPO orientation than tubular structures.

Figure 2 *: The seven 3D orientations*

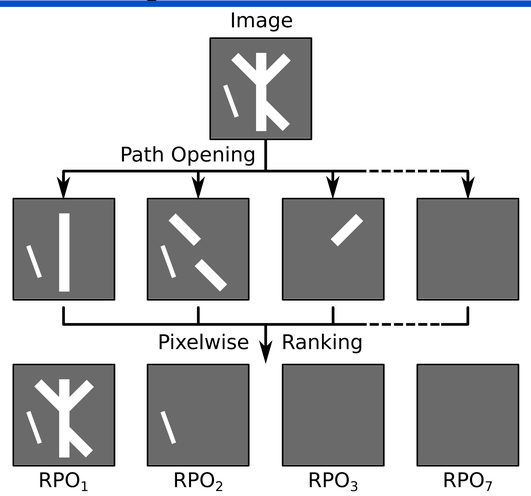


Based on the orientations of figure 2, we proposed the $RORPO$ operator:

$$\boxed{RORPO = RPO_1 - RPO_i}$$

with RPO_1 : 1[th] ranked orientation (=RPO result)
RPO_i : i[th] ranked orientation

We showed on synthetic images that RPO, with these orientations detects:
- Tubular structures in at most 3 orientations
- Plane structures in at least 5 orientations



A structure present in 2 RPO orientations will appear in RPO1 and RPO2.

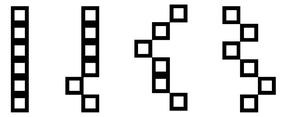
So according to this hypothesis we chose i=4 :

$$\boxed{RORPO = RPO_1 - RPO_4}$$

- RPO_1 contains all tubes and planes
- RPO_4 contains no tubes and all planes
- RORPO contains all tubes and no planes

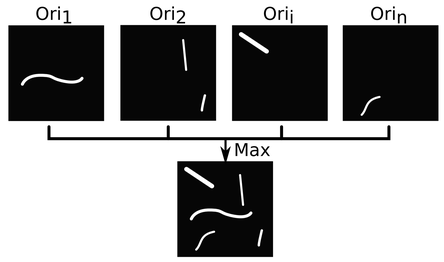
Previous Work: Path Operators

Definition: Morphological opening or closing which use as structuring element a set of oriented connected pixels of fixed length called paths.

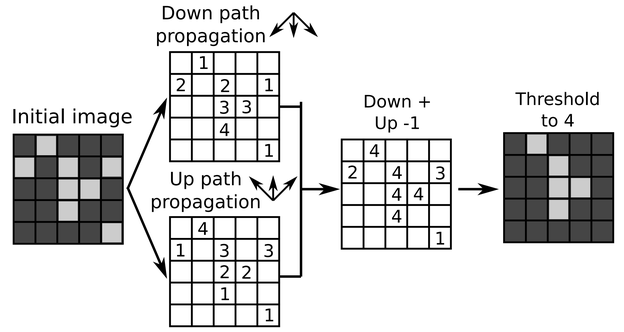


Example of paths of length 6 pixels

Filtering tubular structures in all directions requires the fusion of RPO in several orientations.



Robust Path Opening (RPO): A version of Path Opening that is robust to noise.

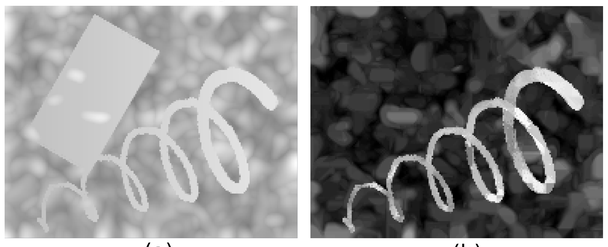


Example of path propagation with a vertical orientation

Result of a 2D RPO (b) on an initial image (a)

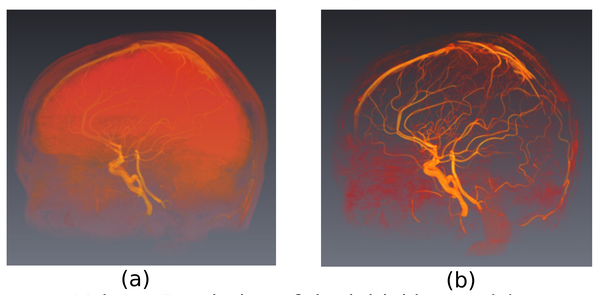
Results and Comparisons

Synthetic image



MIP of the initial image (a) and the RORPO result (b)

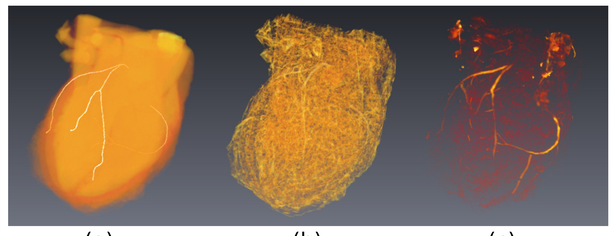
Brain MRI

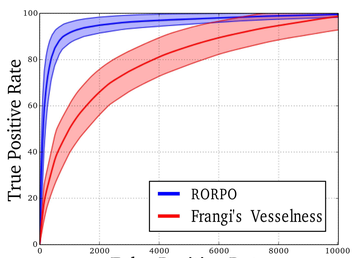


Volume Rendering of the initial image (a) and the RORPO result (b)

Comparison with Frangi's Vesselness on Heart CT

Quantitative comparison with Frangi's Vesselness (gold standard in tubular filtering) on 15 patients of the Rotterdam repository (Challenge MICCAI 2012)





Volume Rendering of
(a) Initial image and ground truth
(b) Frangi's result
(c) RORPO result

(d) ROC curves on 15 Patients