Multilocal Creaseness Measure

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Abstract

This document describes the implementation using the Insight Toolkit (ITK, `www.itk.org`) of an algorithm for detecting creases (ridges and valleys) in N-dimensional images, based on the Local Structure Tensor of the image. In addition to the filter used to calculate the creaseness image, a filter for the computation of the structure tensor is also included in this submission.

Contents

1 Introduction

Ridges and valleys are relevant image descriptors on image analysis used in several tasks of image processing and computer vision, such as centerline calculation, shape representation, and segmentation among others. The Insight Toolkit [2] has no filters available to detect ridges /valleys in N-Dimensional images. This paper presents an implementation –using ITK– of the Multilocal Creaseness Measure described in [4] for the detection of creases (ridges and valleys) in images of arbitrary dimensions.

2 Ridges and Valleys

If we think of a 2D image as a landscape, different definitions of ridges / valleys can be used [4]. One of the most useful states that ridges/valleys are extrema of curvature of the level curves of the landscape ("ridges" when the curvature is positive, "valleys" otherwise). The idea holds for N-dimensional images, since we can always define the concept of level hypersurfaces and, thus, their extrinsic curvature. However, the fact that such definition is too local, gives rise to different problems due to the discrete nature of images [4]. Accordingly, in [4] it is proposed a multi-local alternative called multi-local extrinsic curvature (MLSEC) based on the divergence of the image gradient. In fact, such base proposal is enhanced by involving the structure tensor (see Eq. 1) in the MLSEC computation, the so-called MLSEC-ST (see Eq. 2). This creaseness definition (ridgesness and valleyness) has been proved useful in different applications with both 2D [4] and 3D [3] images.

3 Structure Tensor

The Structure Tensor (ST) of an N-dimensional image (also called second order matrix) has the form of a NxN tensor matrix, and encodes information about the predominant directions of change around a specific point of the image. More formally the ST of the image I is defined as :

$$ST_{\sigma\rho}(I) = g_\rho * \begin{pmatrix} \partial_x I_\sigma^2 & \partial_x I_\sigma \partial_y I_\sigma & \partial_x I_\sigma \partial_z I_\sigma \\ \partial_x I_\sigma \partial_y I_\sigma & \partial_y I_\sigma^2 & \partial_y I_\sigma \partial_z I_\sigma \\ \partial_x I_\sigma \partial_z I_\sigma & \partial_y I_\sigma \partial_z I_\sigma & \partial_z I_\sigma^2 \end{pmatrix} \tag{1}$$

where g_ρ is a Gaussian kernel of standard deviation ρ and $\partial_x I_\sigma$ represents the convolution of image I with a first derivative of a Gaussian kernel of standard deviation σ.

ITK has no filters to compute the ST of an image. In [1],Enquobahrie presented an implementation for the structure tensor to the journal, however we use our own implementation as we need additional output from the ST, not available on the previous implementation.

4 Creaseness Detection

The information of the Structure Tensor allows the computation of the predominant direction of change around a point in the image.

Let $\vec{V}$ be the eigenvector of principal eigenvalue of $ST_{\rho,\sigma}(I)$ and consider its reorientation $\tilde{V}$, along the image gradient, ∇I, given as:

$$\tilde{V} = \text{sign}(< \vec{V} \cdot \nabla I >) \cdot \vec{V}$$

for $< \cdot >$ the scalar product. The creaseness measure [4] is given by the divergence:

$$C := -\text{div}(\tilde{V}) = \partial_x \tilde{V}_x + \partial_y \tilde{V}_y + \partial_z \tilde{V}_z \tag{2}$$

Values of C are normalized in the range $[-N, N]$ for N the dimension of the volume. Because of that the operator is highly discriminant. Creases have positive (for ridges) and negative (for valleys) responses. Those responses have similar value for creases of similar steepness, thus allowing the binarization of the creaseness map using a simple threshold.

5 Usage

The usage of this filters is similar to other ITK filters. The Structure Tensor image filter is a filter derived from `itk::ImageToImageFilter` with two outputs: the tensor image and the gradient image. The gradient image is calculated as part of the structure tensor and is presented as a second output in order to save it for further steps of the the Multilocal creaseness filter, saving computation time. Two parameters, Sigma and Rho modify the derivation and integration scales used in the structure tensor. The filter is templated over the input image, the tensor and the gradient image, but only the input image type is needed.

```
typedef itk::Image< float, 2 > ImageType;
typedef itk::StructureTensorImageFilter< ImageType > StructureTensorFilterType;
typedef StructureTensorFilterType::OutputImageType SymmetricSecondRankTensorImageType;
typedef StructureTensorFilterType::OutputImageType2 CovariantVectorImageType;
StructureTensorFilterType::Pointer strucTensFilter = StructureTensorFilterType::New();
strucTensFilter->SetInput( inputImage );
strucTensFilter->SetSigma( m_Sigma );
strucTensFilter->SetRho( m_Rho );
strucTensFilter->Update();
```

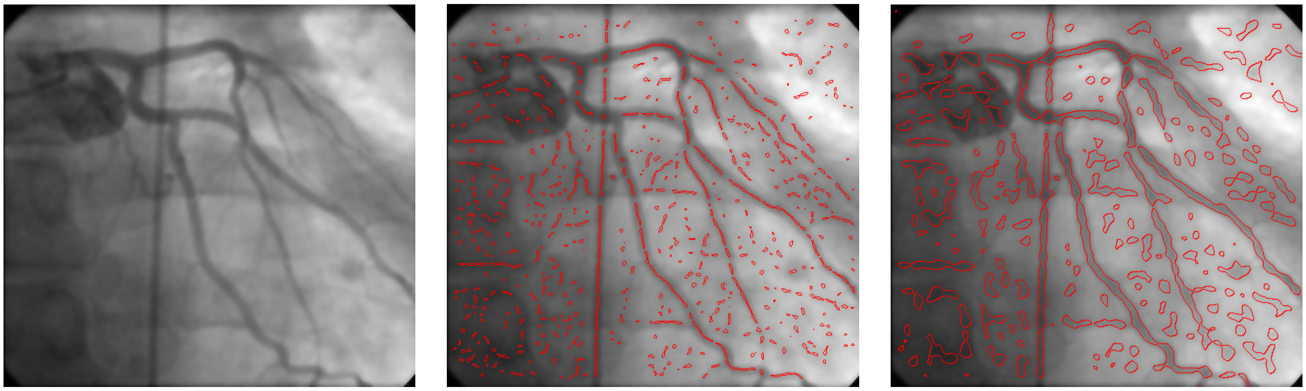
The filter exposes two functions to obtain the different outputs that the filter calculates: `GetTensor()` returns the Tensor Image, while `GetSmoothGradient()` returns the smoothed gradient:

```
SymmetricSecondRankTensorImageType::Pointer tensor = strucTensFilter->GetTensor();
CovariantVectorImageType::Pointer gradient = strucTensFilter->GetSmoothGradient();
```

The creaseness filter is also based on `itk::ImageToImageFilter`. It is templated over the input image and the output image, although the only required template is the input image. Sigma and Rho parameters allow the selection of scales in the inner Structure Tensor filter:

```
typedef itk::Image< float, 2 > ImageType;
typedef itk::MultiLocalCreasenessImageFilter< ImageType, ImageType > RidgeFilterType;

RidgeFilterType::Pointer creasesFilter = RidgeFilterType::New();
creasesFilter->SetSigma( 1.0 );
creasesFilter->SetRho( 1.0 );
creasesFilter->SetInput( inputImage );
creasesFilter->Update();
```



(a) (b) (c)

Figure 1: Ridges 2D example. Coronary angiography (a). Valleys found with $\sigma = 1.0, \rho = 0.5, \tau \leq -0.5$ (b). Valleys computed with $\sigma = 4.0, \rho = 4.0, \tau \leq -0.1$ (c).

(a) (b) (c)

Figure 2: Ridges of the distance map approximate to the skeleton of the image. Distance map of a shape (a). Ridges and valleys $\sigma = 1.0, \rho = 0.5$ (b). Threshold of (b) with $\tau \geq 0.3$ as a pseudo-skeleton of the shape (c).

6 Examples

Figure 1(a) shows a coronary angiography. Coronary arteries are dark and hence, form valleys on the image. Image in Fig. 1(b) shows an overlay of the image and the valleys detected with $\sigma = 1.0, \rho = 0.5$ and a threshold $\tau \leq -0.5$. Figure 1(c) depicts the valleys found with $\sigma = 4.0, \rho = 4.0, \tau \leq -0.1$.

Ridges of the distance map can be used to calculate the skeleton of arbitrary shapes and volumes. The example shown in Fig. 2 illustrates the usage of ridges of the distance map (a) and (b), while Fig. 2(c) shows an approximation (the resulting set is not thinned to one pixel-wide structures) of the skeleton by thresholding the ridge image with $\tau \geq 0.3$.

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B Final Words

In scientific publications that use this algorithm, please cite [4, 3] articles.

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