Comparative Assessment of Retinal Vasculature using Topological and Geometric Measures

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Presentation Reference

Poster Presentation

Principal Author's Biography

Denis Fan completed his BEng in Computer Engineering from Queen Mary, University of London in 2001. He is currently studying for his PhD in Medical Image Processing at Warwick University and is working on the application of Markov Chain Monte Carlo methods to the problems in image analysis and, in particular, for retinal imagery. His research interest include biomedical image processing and statistical image analysis.

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Abstract

We present a quantitative method for the comparison of vascular topology and geometry measured from retinal fundus photographs. The measure compares the difference between distributions taken from a graph representation of the vasculature, which is derived by image segmentation. The measure uses the Kullback-Leibler distance between statistical measures on the reference and test segmentations which can be geometrical, like the distribution of vessel widths, or topological, like local connectivity or a combination of the two. The user is free to build any meaningful description and here we illustrate two local topology measures graphically. Using this assessment method, we also show that our model based segmentation method has better geometrical accuracy than a technique based on matched filtering. We have tested out the measures on a set of 20 images from the STARE project data [3].

Expanded Summary

The geometrical and topological changes in retinal vasculature are one of the critical indicators of retinal disease but such changes are also symptomatic of the onset of diabetes [5]. The growth of high-quality retinal imaging for assessment has required the development of methods for the accurate measurement of vascular geometry to quantify changes in arteries, their diameters, tortuosity etc. Many such techniques have been proposed.g. [4, 2, 6].

We present a quantitative method for the comparison of vascular topology and geometry of retinal vasculature measured from retinal fundus photographs. The measure compares the difference between distributions taken from a graph representation of the vasculature, which is derived by image segmentation. We have compared our own vessel segmentation method [1] based on a statistical random tree model (RTM) of the vessel topology and a popular technique that uses matched filtering(MSF) [2] on a set of 10 manual segmented images available from the STARE project [3]. The RTM method

works by fitting a forest of binary random trees which grow according to pre-defined statistical length, width and amplitude distributions and are altered randomly to fit the image data described as a set of vessels segments, modelled as Gaussian blobs ([6]). The trees grow, shrink, branch, join and split according to a randomised proposal regime and at each step or move, the fit of a given configuration is tested against the data. The output of the RTM method is a graph describing the topology of the data and attached weights that parametrically quantify the width and amplitude of each vessel segment. For comparison purposes, we take the binarized output labelling from the manual-labelling and the MSF method, skeletonize the data and convert it to a graph. A distance map is used together with the skeleton to estimate the vessel widths and the amplitudes are looked-up from the corresponding input data. A number of geometrical and topological measurements are taken from these output graphs and compared.

The comparison method works as follows. Given geometrical or topological distribution, such as vessel width distribution (i.e. number of image pixels being part of retinal vessels with a given width), between a manually delineated 'ground-truth' by an expert observer and a segmentation result, the comparison calculates the Kullback-Leibler (KLD) distance or relative entropy. KLD is a measure of the *similarity* of two probability densities, f and g defined as

$$\mathcal{D}(f(\theta)||g(\theta)) = \int_{\Theta} f(\theta) \log\Big[\frac{f}{g}\Big] d\theta. \tag{1}$$

The greater the magnitude of this distance, the further apart are f and g. We are free to estimate any univariate or multivariate form for f. Note that such a statistic is fairly independent of the original segmentation on which the probability distribution was estimated. Thus, per-pixel segmentation errors which would show up in a simple labelling error or boundary-distance type metric, are overcome.

New or breakthrough work to be presented

Our results show that the RTM is better at capturing the true geometry of the data in terms of vessel width and amplitude distributions, table 1. In fact, matched filtering methods are shown to skew the measured geometry of the vessels which make the method unreliable for assessment of vascular diseases, figure 1. Furthermore, we propose that these KLD geometrical

measures are in themselves useful for repeated quantitative assessment of retinal vasculature. For example, one useful measure of local topology is to estimate the distribution of vessels widths at different orientations in a given radius across the vasculature, figure 2. The expectations is that aneurysms and small-scale revascularization would flatten this distribution rather making it peak roughly at angles of 0° and 180°, and $\pm 40^o$. We have formulated a variant of this measure which does not require connectivity between the vessel segments in the given search radius, which can allow the vessel segmentation results to be an over-segmentation. Our graphical illustrations show how such a topological measure can differentiate finer arterial vascularisation characteristic of one image from another which may be critical in the diagnosis and monitoring of such changes.

Conclusions

We have presented a method to assess the geometrical and topological changes in retinal vasculature using the Kullback-Leibler distance (KLD). The measure can be used to compare the results of a given segmentation method described as a parameterised graph structure, or to compare the differences between successive images of the same subject scan by a chosen method, like RTM or MSF. We have presented two illustrative measures of local topology that describe the vessel width/intensity changes around a circle or a given radius across the images. These provide a graphical map of the characteristic of a given retinal image and, by use of the KLD measure, could be converted to a number between normal and diseased subjects or to assess the changes after therapy. Our approach is relatively independent of the underlying segmentation, and we anticipate that other more elaborate measures could be devised.

References

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	MSF		RTM	
Image	Width	Amplitude	Width	Amplitude
im0077	-18.524	-0.364	-20.231	-1.052
im0081	-25.803	-0.691	-22.769	-0.118
im0082	-18.912	-0.667	-16.679	-0.054
im0139	-18.661	-5.858	-16.863	-0.105
im0162	-35.462	-0.116	-21.769	-0.079
im0163	-28.148	-0.194	-23.858	-0.005
im0235	-13.895	-0.519	-12.802	-0.068
im0236	-10.271	-0.653	-7.656	-0.048
im0240	-5.787	-1.233	-5.711	-0.061
im0255	-16.731	-2.023	-8.345	-0.304

Table 1: Comparison of geometry (width and amplitude distributions) on vascular segmentations using MSF and RTM methods and ground-truth images from STARE database using KLD. The more negative the number the worse the comparison. RTM is superior in all but one instance.

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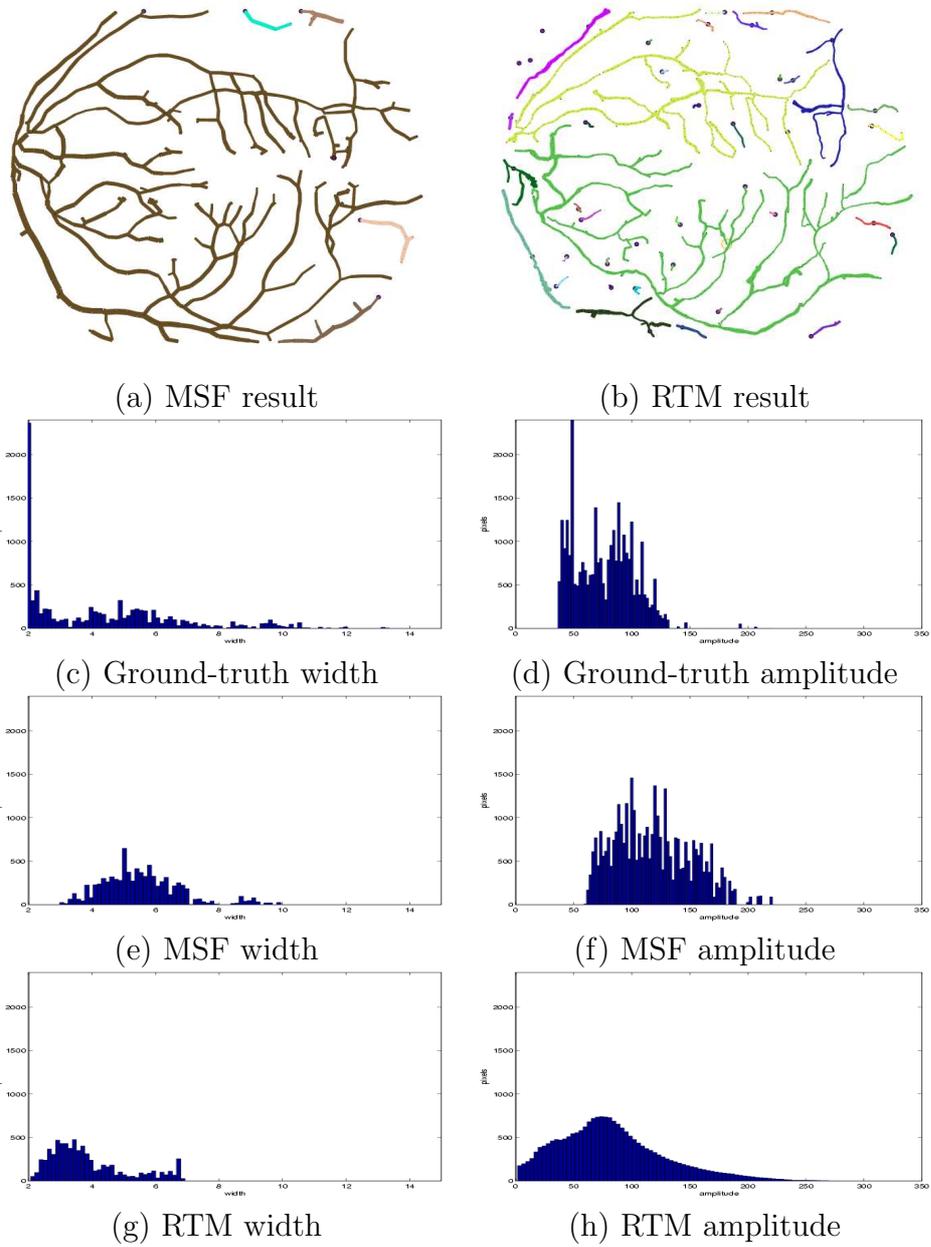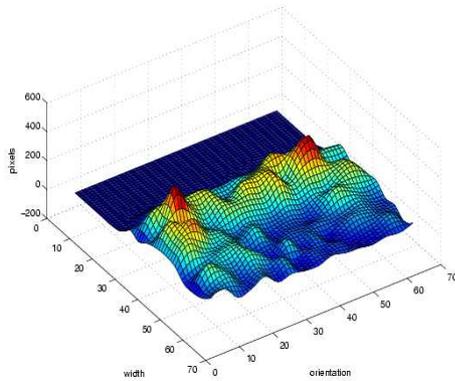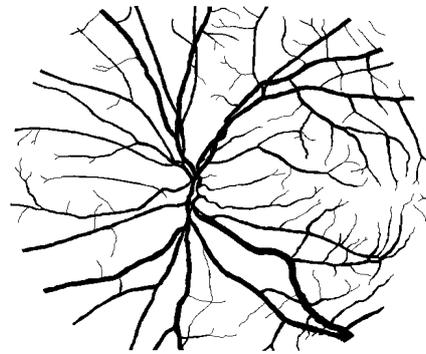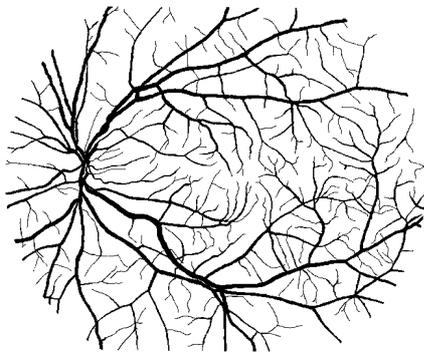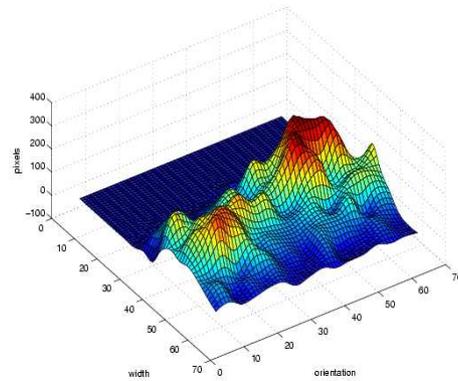
Figure 1: Comparison of width/amplitude distribution on image im0077 between the MSF and RTM models. The RTM output is closer to the distribution taken from ground truth (shown at same y-scale for each method).

(a)   (b)

Figure 2: Graphical plots of local width at a given orientation in a fixed radius measured across the segmented output. The measurements are for two different input images. KLD could be used to compare such multidimensional histograms also if an absolute number is required.