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Fractal dimension-based similarity evaluation between retinal vessel segmentation images

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Abstract: A method that includes the fractal dimension to assess the similarity between retinal vessel segmentation images is presented. We propose that the method can contribute in the iterative refinement of vessel segmentation images. Manual vessel segmentation images are compared against an unsupervised automatic segmentation method. A small relative error is found when using standard metrics for comparison. The differences between segmentation methods are better understood by subdividing the images under study.

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1. Introduction

The assessment of anomalies in retinal vessels used to be a time-consuming task since high skilled technicians were required to assess the images and the diagnostic was based on their experience. The scarce availability of skilled technicians represent a drawback, and the diagnostic was prone to appreciation errors, see figure 1. For these reasons, there has been an increasing interest in the development of automatic of assessment techniques. However, one of the biggest challenges is the determination of the accuracy in the vessels detection in the presence of discontinuities in the vascular structures [1, 2].

Figure 1: a) Bit-wise difference (pixel-based subtraction) between the two manually labeled masks b) and c).

In this work, a method for the comparison of segmented retinal blood vessel images is presented. The method is used to compare the vessel segmentation obtained by a simple automatic segmentation against manual segmentation images [4, 5]. Our approach is based on linking the standard performance metrics, which are calculated blindly from the outcomes of the segmentation algorithm, with the actual structural properties of the images by using the fractal dimension. Other similarity assesment approaches are based on functions of the connectivy, area, and the length of the segmented vessels [3]. Both the segmentation algorithm and the evaluation algorithm were programmed in Python using OpenCV libraries, and the retina images and manual segmentation are taken from the DRIVE database.

2. Methods

We propose the use of the fractal dimension (FD) as an auxiliary metric that can help to connect the standard metrics of the algorithm, which are calculated blindly from the outcomes of the segmentation algorithm, to the actual structural properties of the image [6]. The FD can be approximated by the number of boxes needed to cover the object (N), and it typically increases slowly as we decrease the box size (r), then the FD is given by $FD = \log(N)/\log(1/r)$. Using this approach, the FD was calculated for the manually segmented masks 1 and 2, as well as for the automatically segmented mask. Additionally, besides applying it on the whole images, we extended this box-counting calculation to sub-regions of the original image and averaged the FD obtained from all the sub-images. This was done for 4 (2×2), 9 (3×3), 16 (4×4), and 25 (5×5) sub-images, respectively. Based on the differences between the FD of the reference image and the automatic segmentation image, the later can be iteratively refined.

3. Results

For our numerical experiments, we made use of the retinal images from the DRIVE database [4]. From the set of 20 images for which two manually labeled segmentation mask are available, 16 images were selected in which a simple segmentation algorithm worked the best.

Quantitative evaluation of the algorithm's performance and the accuracy of the extraction of the vascular tree was done based on the difference between images resulting from the bit-wise (pixel-based) subtraction with the manual mask 2 as a reference. The relation between the FD and the standard metrics is obtained by a linear regression analysis, and the Pearson's correlation coefficient was calculated for the different data sets, e.g., the correlation between the TNR and the FD using a different number of sub-images. Table 1 summarizes the correlation between all these datasets.

Table 1: Summary of the Pearson's correlation coefficient.

Standard Metric	1	4	9	16	25
TPR	0.5521	0.6811	0.6876	0.6107	0.5756
TNR	-0.8932	-0.8933	-0.9009	-0.9515	-0.9258
FPR	0.8932	0.8933	0.9009	0.9515	0.9258
FNR	-0.5521	-0.6811	-0.6876	-0.6107	-0.5756
ACC	-0.1915	-0.0693	-0.0776	-0.2163	-0.2378

4. Discussion

Linear regression analysis, on the standard metrics and image subdivision, showed that standard metrics strongly depend on the image complexity regardless of the sub-regions in which the original image is divided, as a consequence small relative errors are found when using only standard metrics as a comparison. The use of the fractal dimension as an auxiliary metric together with subdividing the images under study, help us to identify the nature of the differences between segmentations methods further. In future clinical applications, this approach will help to improve the outcome i.e. image quality and accuracy, of the segmentation stage instead of attempting to provide a quantitative diagnosis based only on the fractal dimension estimated.

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