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Retinal blood vessel extraction using tunable bandpass filter and fuzzy conditional entropy

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ABSTRACT

Background and objectives: Extraction of blood vessels on retinal images plays a significant role for screening of different opthalmologic diseases. However, accurate extraction of the entire and individual type of vessel silhouette from the noisy images with poorly illuminated background is a complicated task. To this aim, an integrated system design platform is suggested in this work for vessel extraction using a sequential bandpass filter followed by fuzzy conditional entropy maximization on matched filter response.

Methods: At first noise is eliminated from the image under consideration through curvelet based denoising. To include the fine details and the relatively less thick vessel structures, the image is passed through a bank of sequential bandpass filter structure optimized for contrast enhancement. Fuzzy conditional entropy on matched filter response is then maximized to find the set of multiple optimal thresholds to extract the different types of vessel silhouettes from the background. Differential Evolution algorithm is used to determine the optimal gain in bandpass filter and the combination of the fuzzy parameters. Using the multiple thresholds, retinal image is classified as the thick, the medium and the thin vessels including neovascularization.

Results: Performance evaluated on different publicly available retinal image databases shows that the proposed method is very efficient in identifying the diverse types of vessels. Proposed method is also efficient in extracting the abnormal and the thin blood vessels in pathological retinal images. The average values of true positive rate, false positive rate and accuracy offered by the method is 76.32%, 1.99% and 96.28%, respectively for the DRIVE database and 72.82%, 2.6% and 96.16%, respectively for the STARE database. Simulation results demonstrate that the proposed method outperforms the existing methods in detecting the various types of vessels and the neovascularization structures.

Conclusions: The combination of curvelet transform and tunable bandpass filter is found to be very much effective in edge enhancement whereas fuzzy conditional entropy efficiently distinguishes vessels of different widths.

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1. Introduction

Blood vessels on retinal images are connected in curvilinear structures and emanate from the optic disc (OD) [1]. Knowledge about the changes in different intrinsic features of the blood vessels such as the length, the width, the diameter, the tortuosity, etc. are useful for detecting different stages of various opthalmologic diseases [2]. For example, proliferative diabetic retinopathy (PDR) which is the advanced stage of diabetic retinopathy (DR) is characterized by the abnormal growth of new, small, thin, fragile vascular nets (neovascularization) which cause frequent bleeding and may lead to permanent vision loss also [3]. Although the ophthalmologists precisely mark the area of neovascularization for PDR images, manual extraction of miscellaneous types of blood vessels (both normal and abnormal) on retinal images in presence of neovascularization, in general, is highly time consuming. Besides, the results are also subject to variability and error due to the relative technical skill of the individual. Furthermore the skilled ophthalmologists are also often limited in number. The challenges in the problem domain on one hand and dearth in efficient as well as skilled personnels on the other hand to extract the entire vessel map create a pressing demand to design an automated computer aided diagnosis (CAD) system capable of extracting the diverse types of blood vessels efficiently and accurately.

In general, most of the retinal images are noisy and nonuniformly illuminated due to improper focusing of light during image acquisition [4]. This makes the accurate extraction of the thin vessels difficult since the thin vessels are most often almost inseparable from the background. The task becomes more challenging when the retinal images contain symptoms of different opthalmologic diseases like background DR, hypertensive retinopathy, etc. as found in the publicly available DRIVE [3], STARE [5], DIARETDB1 [6] databases and many others available online. The characteristics, the contents and the diseases on the retinal images of different databases are also different from one another. Existing literature report that the state-of-the-art vessel extraction algorithms mostly show improved performance on a particular database, i.e. on similar types of images. Hence, development of an efficient algorithm with reliable detection performance across the image databases becomes essential.

Application of proper pre-processing and post-processing operations play important roles on accurate vessel extraction. Existing pre-processing techniques mostly employ kernel based lowpass filtering or histogram equalization for noise removal or highpass filtering for thin vessel enhancement [7]. Lowpass filtering reduces noise through background smoothing. However, majority of the thin vessel structures are smoothed out due to the averaging operation over their neighborhood [8]. Highpass filtering, on the other hand, not only enhances the small and the thin vessel edges but also enhances the high frequency noise components and other spurious components like imaging artifacts. Individual artifact spans a small frequency band and various abnormalities thus cover a wide range of frequency spectrum. This demands not only the noise removal and enhancement of high frequency image components, but also a bandpass-like processing that would highlight different frequency segments.

Accurate extraction and differentiation of blood vessels based on their widths help in gradation of DR and other clinical investigations. Blood vessels vary largely in shape, size, length, diameter, position, orientation, etc. Hence, finding an optimal global threshold to partition the whole vessel net into the thick and the thin vessels with equal accuracy is difficult to derive. This suggests different types of blood vessels' extraction problem as a multi-threshold analysis where the set of values are image dependent. Since the vessel properties are mostly subjective, their accurate classification involving several parameters become difficult through analytical solution. This suggests the use of linguistic descriptor, for example, fuzzy entropy based method as used in image segmentation using multiple thresholds [9]. To the best of our knowledge, the use of multiple thresholds on retinal blood vessel extraction problem is reported first by this research group [10]. Multiple thresholds are relevant to determine the different types of blood vessels' extraction that would then work in cooperative form. The extracted blood vessel information may be used later for diagnosis of different opthalmologic diseases to indicate the stages of DR, etc. Since there always lies some uncertainty among the different classes as observed in image segmentation problems, vessel extraction on retinal images is also addressed by absolute entropy using fuzzy set theoretic approach [11]. Although simulation results of both absolute and conditional fuzzy entropy [12] are found to be competitive, the latter one is computationally efficient. The relevance of conditional entropy lies in the uncertainties on the different types of vessel categorization, for example, the non-vessel and the thin vessel, the thin and the medium vessel and the medium and the thick vessels, etc. This motivates the exploration of fuzzy conditional entropy based thresholding instead of absolute entropy. This would improve the overall vessel extraction accuracy as well as identification of the individual ones.

The remainder of this paper is organized as follows: A comprehensive literature review on the state-of-the-art methods, their limitations and scope of the present work are presented in Section 2. Section 3 describes the tools, techniques used in the present work and objective measures used for performance analysis. Proposed method of vessel detection is illustrated in Section 4. Experimental results and performance evaluation are presented in Section 5. Conclusions and scope of future works are stated in Section 6.

2. Literature review, limitations and scope of present work

Literature on the retinal vessel extraction problem is quite rich. It is difficult to discuss all the different types used in the literature. Instead a brief overview on the state-of-the-art vessel extraction methods that are well suited to the problem considered here are reviewed. Interested readers can go through Ref. [13] to have an exhaustive survey on blood vessel segmentation in retinal images.

2.1. *Literature review and limitations*

The existing methods for vessel extraction can be broadly classified into the following categories based on the different tools