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Detection of neovascularization in retinal images using mutual information maximization☆

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ABSTRACT

Proliferative diabetic retinopathy (PDR) is characterized by the proliferation of new abnormal blood vessels (neovascularization) that cause their detachment from retina. An automated computer aided diagnosis (CAD) system is developed for neovascularization (new abnormal blood vessel) detection on retinal images. Curvelet transform is used to intensify the fine details of the vascular network followed by maximization of mutual information (MI) on the maximum matched filter response for optimal thresholding to partition the vessels into the thick and the thin categories. Vessel density and tortuosity, being two unique and distinct features for the abnormal vessels, are calculated from the thin vessel class followed by MI maximization and post-processing for neovascularization detection. Simulation results demonstrate that an average accuracy gain of 97.49% is achieved by the proposed method in abnormal vessel detection over the existing methods.

1. Introduction

Diabetic retinopathy (DR) is a chronic sight threatening disease of diabetes [1]. Its most advanced stage, called proliferative diabetic retinopathy (PDR) is characterized by new abnormal blood vessels (neovascularization) that originate from the pre-existing vascular bed due to the extensive lack of oxygen in the retinal capillaries [2]. These newly formed vessels are weak, delicate, fragile in nature. They are referred to as new vessels on the optic disc (NVD) and new vessels elsewhere (NVE)[3] based on their location. They are more tortuous and convoluted than the normal blood vessels, thereby, lack their bifurcating pattern [1]. Neovascularization detection performance highly depends on the efficiency of accurate vessel extraction followed by separation of thin vessels in presence of noise, poor illumination, nonuniform intensity distribution etc. Lack of number in skilled opthalmologist and variation in their assessment demand automated segmentation of vessels [4] and different approaches, such as Gabor filters [5], wavelet transform [6], clustering based segmentation [7], hit-or-miss transform [8] etc. are reported in the literature on different medical images. However, blood vessel extraction and neovascularization detection, in an integrated framework, is less explored and is the motivation of this work.

Neovascularization detection may be considered as a two stage classification problem. In the first stage, the thick and the thin (both normal and abnormal i.e. neovascularization) vessels need extraction from the entire vessel map. Blood vessel profile assumes to follow a Gaussian distribution and due to diverse types of vessel structures, a large variation in Gaussian kernel templates are used in matched filtering operation [9]. Moreover, orientation of vessels yield changes in matched

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filter responses (MFRs) that suggest the selection of the maximum one to identify a pixel as vessel. The maximum MFRs of the diverse types of vessels have an overlap, however, finding a distinctive sharp (single valued) boundary to partition the maximum MFRs as the thick and the thin vessels by automatic means is a bit difficult task. This needs solving efficiently a classification problem where the thickness of the vessel is subjective, governed by the variance of the Gaussian profile. The abnormal thin vessels can be differentiated from their normal counterpart in density and tortuosity values. Hence, these two distinct and unique features as two discrete random variables are used for neovascularization detection in the next stage and is studied across the diverse image databases rich with pathological disorders.

The rest of the paper is arranged as follows: a brief literature review is discussed in Section 2 followed by mathematical preliminaries in Section 3. The proposed method of neovascularization detection is presented in Section 4 while experimental results are reported in Section 5. Conclusions and future research issues are reported in Section 6.

2. Literature review: limitations and scope of present work

A brief literature review with scope of work is presented here. A large set of pattern recognition and rule based methods that include vessel tracking, matched filtering and morphology based techniques are used for vessel extraction in the literature. Chaudhuri et al. [9] proposed matched filter (MF) based method with a single Gaussian kernel rotated at multiple angles for retinal blood vessel detection. The combination of curvelet transform and tunable bandpass filter is implemented in [10] for vessel extraction from pathological retinal images. Morphological component analysis (MCA) algorithm that includes the Morlet wavelet transform for vessel enhancement and distinguishing the vessels from the lesions is presented in [4]. Vega et al. [11] used a Lattice Neural Network with Dendritic Processing (LNNDP) for blood vessel extraction from fundus images. Lazar and Hajdu [12] used directional response vector similarity and region growing for segmentation and extraction of the blood vessels.

Agurto et al. [13] first manually selected a region of interest (ROI) from the image that contains the optic disc (OD). The ROI is gradually reduced and textural features are extracted using some modulation of amplitude-frequency (AM-FM) technique followed by granulometry to differentiate NVD from a normal OD. A multi-level m-Mediods based classifier is used for abnormal blood vessel detection by Akram et al. [3] but requires a large number of features for classification and hence leads to an increased system complexity. Hassan et al. [2] used just two local features, the number of vessels and the area of vessels within a small scanning sub-window to indicate the new vessels. A dual classification approach, using the standard line operator and a novel modified line operator, is implemented by Welikala et al. [1] to generate two different segmented vessel maps. Limitations of the existing neovascularization detection methods are

- Most of the existing methods ([3,13,14] etc.) first extract the retinal vasculature followed by a large set of features from the entire vascular map for classification, hence, is highly time consuming.
- A number of methods ([13,14] etc.) only detect the abnormal vessels on the OD, i.e., NVD only and detection of NVE is not explored.
- Neovascularization detection methods reported in the literature mostly employ linear regression [13] or support vector machine (SVM) classifier [14] based on supervised learning. However, real world problems demand some sort of unsupervised classification approach.

The main contributions of the present work are as follows:

- Curvelet transform is used purposely to enhance the dense and the thin elongated curvilinear vessel structures.
- A two-dimensional (2D) MF using different Gaussian kernels are convolved at different directions and then MI on maximum MFR is maximized using Differential Evolution (DE) algorithm to detect the thick and the thin vessels using multilevel thresholding.
- Neovascularization being thin microvascular nets in appearance, only the thin vessel class from the extracted vessel nets is considered which in turn makes the classification task faster and simpler.
- MI of the vessel density (compactness) and the tortuosity of the thin vessel class in 2D is maximized using DE which reduces the computational cost and is completely unsupervised as no training set is required.
- Performance of the proposed method is evaluated over the publicly available DRIVE [15], STARE [16], DIARETDB1 [17], HRF [18] and MESSIDOR [19] database. Superiority in the performance is supported by high sensitivity (97.45%) and specificity (96.03%) values.

3. Mathematical preliminaries

Different tools and the performance measures used are briefly presented.

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