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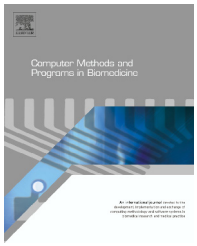

Automated detection of proliferative diabetic retinopathy using a modified line operator and dual classification

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ABSTRACT

Proliferative diabetic retinopathy (PDR) is a condition that carries a high risk of severe visual impairment. The hallmark of PDR is neovascularisation, the growth of abnormal new vessels. This paper describes an automated method for the detection of new vessels in retinal images. Two vessel segmentation approaches are applied, using the standard line operator and a novel modified line operator. The latter is designed to reduce false responses to non-vessel edges. Both generated binary vessel maps hold vital information which must be processed separately. This is achieved with a dual classification system. Local morphology features are measured from each binary vessel map to produce two separate feature sets. Independent classification is performed for each feature set using a support vector machine (SVM) classifier. The system then combines these individual classification outcomes to produce a final decision. Sensitivity and specificity results using a dataset of 60 images are 0.862 and 0.944 respectively on a per patch basis and 1.00 and 0.90 respectively on a per image basis.

1. Introduction

Diabetes is a disorder of sugar metabolism and is characterized by raised levels of glucose in the blood. These high levels can damage the vessels that supply blood to vital organs. Diabetic retinopathy (DR) is the resultant condition affecting the retinal vasculature, leading to progressive retinal damage that can end in loss to vision and blindness [1]. DR is recognized as the leading cause of blindness in the working-age population [2]. The problem is increasing in its scale, with diabetes having been identified as a significant growing global public health problem [3]. 171 million people were estimated to have diabetes worldwide in the year 2000 and this figure is expected to rise to 366 million by the year 2030 [4].

The purpose of DR screening is to detect potentially sight threatening disease at an early stage which is when treatment and management is the most effective [5,6]. In the United

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Kingdom diabetic patients aged 12 and above are invited, at least annually, for a screening appointment where retinal images are captured using digital photography [7]. With such a large diabetic population, assessment of these images can be a time consuming and costly task. Therefore the introduction of automated detection systems would be greatly beneficial to this field [8].

The damage to the retinal blood vessels will cause blood and fluid to leak on the retina and form features such as microaneurysms, haemorrhages, exudates, cotton wool spots and venous loops [9]. With progression, the blockages and damage to blood vessels will cause areas of retinal ischaemia to develop and in an attempt of revascularization the growth of new blood vessels is triggered. The growth of new vessels represent the advanced stages of DR known as proliferative diabetic retinopathy (PDR), which poses a high risk of severe vision loss due to the fragile nature of the new vessels making them prone to bleed and cause pre-retinal and vitreous haemorrhages. Also fibrous tissue gradually develops in association as new vessels increase in size and this can cause tractional retinal detachment [10]. Patients presenting PDR require an urgent referral to a specialist.

Whilst disease/no disease automated grading system do provide benefits [11], an additional aim is to develop a system capable of triaging images. This should include the ability to detect and prioritize PDR images to ensure immediate attention and treatment. The automatic detection of DR has received a lot of research attention, with studies investigating microaneurysm and haemorrhage detection [12–16], and exudate detection [17–21]. In contrast, little work has been done to detect PDR.

New vessels are termed according their location, new vessels at the optic disc (NVD) and new vessels elsewhere (NVE). They appear as unregulated vessel growth, initially appearing as loops or networks that appear on the optic disc or near a vein. As they grow they form dense lacy networks which usually pass across the underlying veins and arteries. They tend to be fine in calibre and are more tortuous and convoluted than normal vessels. New vessels tend to grow away from the retinal surface and hence can appear out of the focal plane of the photograph, which can result in a blurry and obscure appearance. A retinal image containing new vessels is shown in Fig. 1(a).

Vessel segmentation is often the first step of new vessel detection methods, with the purpose of analysing the morphology of the binary vessel map in search of abnormality. Vessel segmentation has received the largest share of attention in the field of retinal image analysis, studies include [22–29]. Segmentation techniques often proceed into methodologies that classify vessels as arteries or veins and measure vessel calibre [30,31] for application in cardiovascular disease studies. A comprehensive review of this mature field of vessel segmentation is provided by Fraz [32]. However these techniques struggle with segmenting new vessels due to their irregular appearance.

The following vessel segmentation techniques were designed with new vessels taken into consideration. Zhang [33] proposed a modified matched filter that used double sided thresholding. The main emphasis was not on the increased segmentation of new vessels, but instead the reduction of the false response to exudates which can cause large local densities on the segmented map and therefore can be mistaken for new vessels. B.Zhang [34] applied the matched filter with the first-order derivative of the Gaussian to reduce the false response to exudates. Fig. 1(b) shows a retinal image with exudates, also known as bright lesions. Ramlugun [35] described a small vessel extraction technique, the main contribution was the varying of the clip limit for contrast limited adaptive histogram equalization (CLAHE) to allow more contrast for small vessels.

The following new vessel detection methods applied vessel segmentation prior to the described analysis methods. Daxer [36] and Karperien [37] both described the retinal vasculature as a fractal and used the fractal dimension to quantify its complexity to indicate the presence of new vessel growth. Jelinek [38] extracted morphological features based on data obtained from the application of the derivatives of Gaussian wavelets to the vessel skeleton. Goatman [39] developed a comprehensive set of 15 features including the number of vessel segments, the mean vessel wall gradient and various tortuosity measures to detect new vessels on the optic disc. Akram [40] proposed a Gaussian mixture model based classifier with a 5 dimensional feature set based on intensity and gradient values. Hassan [41] used just two local features, the number of vessels and the area of vessels within a small scanning sub-window to indicate new vessels. In [42], the majority of normal vasculature was removed from the vessel map to simplify new vessel detection.

The next described methods do not perform vessel segmentation and therefore avoid the difficulties associated with segmenting new vessels. Statistical texture measures calculated using the grey level co-occurrence matrix (GLCM) were applied by Frame [43] to identify irregular distributions of pixel intensities associated with neovascularisation. Acharya [44] calculated texture features from the GLCM and the run length matrix to identify the stage of DR. Agurto [45] utilized multiscale amplitude modulation frequency modulation (AM-FM) methods for spectral texture analysis to characterize different retinal structures, including new vessels. However, later work by Agurto [46] involved AM-FM along with granulometry and vessel segmentation to detect new vessels on the optic disc.

There exist techniques developed from other research topics that are very relevant to PDR detection. Zutis [47] presented a system using edge contour analysis for detecting abnormal retinal capillary regions, with the focus on telangiectasia. Doukas [48] created an automated method for the quantification of micro-vessel density within the inner surface of egg shells in order to study the angiogenesis in developing chick embryos. Measures included vessel length, branching points and GLCM textural information.

The main contribution of the proposed method is the novel application of a dual classification approach to independently process the binary maps from two different vessel segmentation methods with the aim to detect new vessels and reduce false responses caused by other retinal features. This includes a novel modified line operator, based on double sided thresholding, designed to segment vessels whilst reducing false responses to non-vessel edges. The organization of this paper is as follows. Section 2 describes details of the methodology.