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Techniques for the Detection of Blood Vessels in Diabetic Retinopathy

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Abstract: : *Identification of blood vessels in medical images plays a vital role in explaining many practical applications pertaining to the diagnosis of the blood vessels. Vessel segmentation algorithms are the important elements of automated radiological diagnostic systems. Based on the quality of image, domain of application and method applied (automatic or semi-automatic), segmentation methods may change. Some images may have artifacts such as noise and these require image pre-processing depending on the quality of image. Depending on the image quality and the general image artifacts such as noise, some methods may require image pre-processing. Blood vessel extraction is important for the diagnosis of various ophthalmic disorders like glaucoma, diabetic retinopathy and also brain tumour. Diabetic Retinopathy has no earlier symptoms and it can ultimately lead to the loss of vision. Hence, the detection of blood vessels and the classification of disease severity at an earlier stage are much important. There are several approaches for blood vessel detection.*
Keywords: *Diabetic Retinopathy, Vessel Segmentation, Vessel tree.*

I. Introduction

Diabetes is one of the main threats to human health in present century. Prolonged diabetes can lead to various ophthalmic disorders like glaucoma and diabetic retinopathy. Diabetic Retinopathy (DR) is caused by chronic uncontrolled hyperglycemia and is affecting eyes. If left untreated at an incipient stage, diabetic retinopathy can affect whole eye and can lead to vision loss. Diabetic Retinopathy has no prior symptoms. Hence the identification of the diseased condition at its earlier stage is utmost important. Diabetic Retinopathy is a degenerative eye disease characterized by abnormal blood vessel growth stimulated by increased blood glucose level which eventually leads to detached retina. Diabetic Retinopathy has no earlier symptoms and it can ultimately lead to vision loss. The disease is classified into 3 stages based on the disease severity as:-

- Background Diabetic Retinopathy(BDR)
- Proliferate Diabetic Retinopathy(PDR)
- Severe Diabetic Retinopathy(SDR)

Background Diabetic Retinopathy stage is also called as Non Proliferate Diabetic Retinopathy. In BDR stage, the retinal arteries weaken & extravasate forming minute dot like haemorrhages. These leaks in blood vessels can often lead to retinal swelling and hence cause decrease in vision. BDR has no prior symptoms and this condition cannot be identified by naked eyes. The way to detect BDR is by Fundus Photography, which detects micro aneurysms.

In Proliferate Diabetic Retinopathy stage, blood circulation hinders acquiring of sufficient oxygen, which leads to the growth of new small vessels. This new blood vessel formation is termed as 'Neovascularisation'. Since the newly formed blood vessels are weak, they may burst and cause blurred vision. At earlier stages, this condition is not severe. The leakage of blood into the retina and vitreous causes spots or floaters along with blurred vision.

In Severe Diabetic Retinopathy stage, there is a continuous growth of abnormal vessels & scar tissues. This leads to severe damages such as retinal detachment & glaucoma and hence gradual loss of vision. This stage is more dangerous. This can lead to complete loss of vision.

Early detection helps to cure the disease. As the severity increases treatment gets complicated and 100% cure becomes impossible. With the method of blood vessel extraction early detection of ophthalmic disorder is possible. Several methods for the detection of blood vessels are available. Automated detection of blood vessels and classification of disease severity is of great concern since the disease has no earlier symptoms. Various methods for the detection of blood vessels are discussed in this article.

II. Approaches to Detect Blood Vessels

There are several approaches for blood vessel detection in diabetic retinopathy. For the identification of vessels and registration of patient images obtained at different times, the delineation of blood vessels is necessary. Based on the imaging modality and application domain the method used for the blood vessel may vary. Each of the segmentation methods has its own pros and cons depending upon the application. Pure intensity-based pattern identification techniques like thresholding are employed in certain methods which are followed by connected component analysis. Some other methods employ explicit vessel models to obtain vessel contours. Based on the quality of image and noise presence, some methods employ image pre-processing before the execution of segmentation algorithm. Some methods use processes after the segmentation to remove the problems due to over segmentation. Different segmentation approaches are:

- ❖ Pattern recognition techniques
- ➢ Multi-scale approaches
- ➢ Skeleton-based approaches
- ➢ Region growing approaches
- ➢ Ridge-based approaches
- ➢ Differential geometry-based approaches
- ➢ Matching filters approaches
- ➢ Mathematical morphology schemes
- ❖ Model-based approaches
- ➢ Deformable models
- ▪ Parametric deformable models - Active contours (Snakes)
- ▪ Geometric deformable models and front propagation methods
- ➢ Parametric models
- ➢ Template matching approaches
- ❖ Tracking-based approaches
- ❖ Artificial Intelligence-based approaches
- ❖ Neural Network-based approaches
- ❖ Miscellaneous tube-like object detection approaches

2.1 Pattern Recognition Techniques

Automatic detection or classifications of objects or features are possible through Pattern Recognition (PR) techniques. PR tasks are well carried out by human beings. Computer systems imitate this human aspect for carrying out pattern recognition tasks. In case of blood vessel extraction, PR techniques are initially concerned with vessel anatomy and the features of vessel naturally. PR techniques can be divided into seven categories such as: (1) multi-scale approaches, (2) skeleton-based (centerline detection) approaches, (3) region growing approaches, (4)ridge-based approaches, (5)differential Geometry-based approaches, (6)matching filters approaches, and (7) mathematical morphology schemes.

2.1.1 Multi-scale Approaches

In multi-scale approaches [1,2], segmentation is done at different image resolutions. Major structures such as large vessels are obtained from low resolution images while fine structures are refined at high resolution. The main advantage of this technique is increase in processing speed and robustness. After segmenting, post processing operations are done.

2.1.2 Skeleton-Based (Centerline Detection) Approaches

Extraction of the blood vessel centerlines [3] are done in the Skeleton-based methods. Connecting of the centerlines is done to create the vessel tree. For the extraction of the centerline structure, different approaches can be used. The centerline structure obtained can be empoyed for 3D reconstruction of blood vessels.

2.1.3 Ridge-Based Approaches

In Ridge-based approach [4], the gray scale images are treated as 3D elevation maps. The elevation maps correspond to intensity ridges which give the structure of the object to be detected. In the intensity map, ridge points are local peaks in the direction of maximal surface gradient. Ridge-based approach can be used in different image modalities since it is invariant to different affine transforms. Ridge-based approaches mostly find application in medical image registration.

2.1.4 Region Growing Approaches

Region growing approach deals with the segmentation of an image based on a seed point. The segmentation is done by incrementally growing the pixels into a region based on some predefined criteria. Segmentation is done based on the criteria of value similarity and spatial proximity. It is believed that pixels which are close to each other have similar intensity values and hence they belong to same object. Region growing is a subjective process since the seed points are decided by the user. Variations in image intensities and noise can cause holes and over segmentation during region growing. Hence image post processing is done after region based segmentation method.

2.1.5 Differential Geometry-Based Approaches

In Differential geometry (DG) based methods [4,5], images are treated as hyper surfaces. The features are extracted using the curvature and the crest lines of the hyper surface. These crest points gives centerlines of the blood vessels. The 2D and 3D images are transformed as 3D and 4D hyper surfaces respectively. In DG based approach a 3D surface is described by two principal curvatures and their corresponding orthogonal directions. The orthogonal directions are called as principal directions. The features extracted using this technique can be used for medical image registration. Crest points posses the properties of the hyper surfaces. Centerlines are obtained by linking these crest-points.

2.1.6 Matching Filters Approaches

Matching filters (MF) approach [6] convolves several matched filters with the image from which the objects are to be extracted. The order of the filter and its orientation has a great significance in the extraction of the vessel structure. Computational load is determined by the convolution kernel. Usage of matched filters is followed by image processing operations such as thinning.

2.1.7 Mathematical Morphology Schemes

Morphology refers to the study of object forms or shapes. In morphological schemes based approach [7-9] structuring elements are applied to the images. Dilation and erosion are the important morphological operators. Dilation operation performs filling of holes by using the desired structuring element. Erosion reduces objects by a SE. Other operations performed in morphological operators include closing and opening operations. For segmentation of blood vessels in diabetic retinopathy, usually the algorithms such as hat transformations and watershed algorithms are used.

2.2 Model-Based Approaches

Model-based approaches [10] use predefined models to extract vessel structure. Model-based approaches can be classified into four categories: (1) Deformable models, (2) Parametric models, (3) Template matching, and (4) Generalized cylinders.

2.2.1 Deformable Models

Deformable models are divided into two categories: parametric deformable models and geometric deformable models.

Parametric Deformable models [11] are used to find the contours of the blood vessels by using active contour models or snaxels. The matching of the blood vessels with the models is done by minimization of the energy. Control points in deformable models are called as snaxels. Snaxels connect each of the points in the image. The variation in the energy of the snaxels corresponds to the detection of the blood vessels edges and links. The parameters are needed to be initially set by the user.

Geometric Deformable Models [12] posses several advantages such as ability to handle complex structures, extension to higher dimensions etc.

2.2.2 Parametric Models (PM)

Parametric models approach defines the structure of blood vessels parametrically. When the object to be detected is of tubular structure, the objects are described as ellipsoids. The parameters of the model used are calculated from the image. The disadvantage of this method is that it cannot detect the abnormal blood vessels. Based on the application, circular vessel models are being used.

2.2.3 Template Matching

The Template matching approach [13] recognizes blood vessel as template. The template acts as a priori model for the detection of other blood vessels. Since the detection of blood vessels are based on the prior model, it can be called as a contextual based method. In applications such as extraction of arteries, the arterial tree template is usually shown in the form of a series of nodes connected in segments. The template thus obtained is then programmed using a stochastic deformation process such as Hidden Markov Model (HMM).

2.3 Tracking-Based Approaches

Tracking-based approaches apply local operators on the structure thought to be as a vessel and track it. But, Pattern based recognition approaches apply local operators to the entire image. Tracking based approaches detect the blood vessels by analyzing each pixel starting from an initial point. For determining the edges and boundaries of blood vessels, several approaches can be used. After the detection of blood vessels, connectivity is done by sequential tracing. Clustering [14, 15] is another approach for the identification of blood vessels. These techniques classify the pixels into blood vessels and non-blood vessels. After the clustering, tracking process can be implemented. The major demerit of this method is that it is not automatic. The person who uses needs to select the starting and end points for vessel tracking. .

2.4 Artificial Intelligence-Based Approaches

Artificial Intelligence-based approaches (AIBA) [15-17] utilize knowledge for the segmentation of blood vessels. Different types of knowledge can be utilized for blood vessel detection in diabetic retinopathy. Based on the applications the knowledge source can vary. Encode the knowledge on blood vessel appearance in the form of rules, for example the vessel have high intensity center lines, with high intensity areas surrounded by parallel edges etc. Knowledge-based systems exploit an earlier knowledge of the anatomy. Some low-level image processing algorithms are used in the systems. These algorithms include thresholding [18] thinning and linking with high-level knowledge. AIBA works well inspite of the straneous computational complexity.

2.5 Neural Network-Based Approaches

Neural networks (NN) [19-22] are employed to imitate biological learning and commonly help in pattern recognition. Neural nets are generally a classification approach. The network is a group of elementary processor (nodes). Each node uses a numerous inputs, carry out elementary computations, and produce solitary output. Each node is allocated with a weight and output is a function of weighted addition of inputs. These weights are learned through training and then used in identification. Back-propagation algorithm [23] is a commonly employed learning algorithm. One problem associated with learning is that learning depends on the training data set. Magnitude of training data set influence the process of learning. Training procedure should be again used each time new training data is added. Since the above explained neural networks require a training data set, the learning process is a supervised learning. The fact which makes NN appreciable is that it uses nonlinear classification boundaries. The demerit of NN approach is that it need training every time a new feature is introduced.

2.6 Miscellaneous Tube-Like Object Detection Approach

This approach uses extrication of tubular structures from images [24-27]. It is a ”miscellaneous” approach which is applicable to vascular extraction in tubular entities. These approaches were not intended for vessel extraction.

II. Conclusion

Proper interpretation of retinal images is vital in the diagnosis of many eye pathologies for the ophthalmologists. Diabetic retinopathy is a severe and end complication of diabetes in retina. Non proliferative diabetic retinopathy is usually linked with macula edema. Diabetic retinopathy is initially identified by the presence of exudates. Hence identification of the presence of exudates is highly significant in the diagnosis of diabetic retinopathy. In order to recognize exudates, segmentation of blood vessels in retinal images is mandatory. For this, different methods are generally used. Since diabetic retinopathy has no alarming symptoms, processing of data available and its classification is vital. Hence a method for the automatic detection and classification of disease severity is aimed at this work. Several methods for the detection of blood vessels have been discussed in this work.

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