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Retinal image blood vessel extraction and quantification with Euclidean distance transform approach

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Abstract: Image processing applications remarkably contributes to modern ophthalmology. This technology is designed to analyse the characteristics of the human eye microvasculature images. The retinal microvasculature is an excellent non-invasive screening window for the assessment of systemic diseases such as diabetes, hypertension, and stroke. Retinal microvasculature character such as widening vessel diameter is recognised as an analysable feature for stroke or transient ischemic attack for predicting the progression of this pathology. Thus, in this study, a computer-assisted method has been developed for this task applying the Euclidean distance transform (EDT) technique. This newly developed algorithm computes the Euclidean distance of the remaining white pixels on the area of interest. Central Light Reflex Image Set (CLRIS) and Vascular Disease Image Set (VDIS) of Retinal Vessel Image set for Estimation of Width database were used for the performance evaluation of the proposed algorithm that showed 98.1 and 97.7% accurate result for both CLRIS and VDIS, respectively. The significantly high accuracy in this newly developed vessel diameter quantification algorithm indicates excellent potential for further development, evaluation, validation, and integration into ophthalmic diagnostic instruments.

1 Introduction

Image processing is the process in which mathematical operations of the signal processing system are employed to retrieve the output as an image or related parameters of the image from the given input image or video [1]. Digital image processing is being used extensively in the researches of biomedical engineering and disease diagnosis, treatment planning and supervising, and state monitoring of the respective disease [2]. Due to the simple and non-invasive visualisation of the microvasculature of the human retina, fundus eye image can be analysed to extract the remarkable features of the retinal microvasculature that can be used to predict some dangerous cardiovascular diseases such as diabetes, hypertension, and stroke [3–6].

Several changes in the microvascular structure of the human retina are found to be associated as the pre-indicator of a subsequent vascular event such as ischemic stroke [7]. Many types of researches revealed that ocular funduscopic abnormalities and acute stroke are closely associated even though the blood pressure and other vascular risk factors are optimally controlled [8]. Furthermore, Kawasaki *et al.* [9] disclosed that the narrowing in the retinal artery and retinopathy of diabetic free people have an association with increased risk of stroke. After a long-term observation in the Rotterdam cohort study, the retinal venular diameter was found to be significantly associated with any stroke or ischemic stroke [10].

The destruction of retinal arterioles and venules is found to be consistent with hypertensive retinopathy which can lead to blindness. Several classification systems had been drawn up to simplify the early prediction of hypertensive retinopathy [11]. According to the population-based study, there is a close association between hypertensive retinopathy and the risk of stroke [12]. Witt *et al.* [3] proposed a population-based study with the collaboration of Beaver Dam Eye Study. Their research revealed that the increased diameter ratio had been found associative with increased stroke mortality ($P = 0.02$ unadjusted).

A baseline cohort study, data analysis study, by Cheung *et al.*, on 3189 Asian Malay patients who were free from stroke reported that 1.93% (51) participants had an incident stroke event within 4.41 years follow-up period [13]. The similar study [13] also claimed that the analysis of the changes in retinal microvasculature could be used to predict this event. Besides a systematic review, Doubal *et al.* [14] revealed that there is an association between prevalence and incidence of stroke and venular widening. According to another research [15], the diameter widening of the retinal vessel is the predictor of hypertensive retinopathy and is associated with stroke.

Retinal Vessel Image set for Estimation of Width (REVIEW) is a publicly available database consisting of normal and pathological retinal images that are widely used to evaluate the performance of the retinal vessel diameter measurement algorithm [16]. There are four subsets of retinal images available in the REVIEW database namely Kick Point Image Set (KPIS), High-Resolution Image Set (HRIS), Central Light Reflex Image Set (CLRIS), and Vascular Disease Image Set (VDIS) [16]. There are several developed techniques for computing the retinal vessel diameter by employing the image processing principles [17] which were evaluated on the different image sets of the REVIEW database. The review and comparison of these techniques were presented in [18]. The authors of [19, 20] developed retinal vessel diameter computing methods based on the image gradient segmentation technique for vessel edge detection, using the active contour model, and linear discriminant analysis (LDA). There are a few other retinal vessel diameter quantification techniques that were developed based on different image processing principles such as adaptive Higuchi's dimension [21], graph-theoretic method [22, 23], multi-step regression method (higher-order Gaussian modelling) [24], and mask creation [19]. Lupaşcu *et al.* [25] proposed a supervised learning algorithm in which the bagged decision tree technique and extended multi-resolution Hermit model had been employed. The developed algorithm by Lupaşcu *et al.* [25] was evaluated on