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Using a multi-agent system approach for microaneurysm detection in fundus images

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ABSTRACT

Objective: Microaneurysms represent the first sign of diabetic retinopathy, and their detection is fundamental for the prevention of vision impairment. Despite several research attempts to develop an automated system to detect microaneurysms in fundus images, none has shown the level of performance required for clinical practice. We propose a new approach, based on a multi-agent system model, for microaneurysm segmentation.
Methods and materials: A multi-agent based approach, preceded by a preprocessing phase to allow construction of the environment in which agents are situated and interact, is presented. The proposed method is applied to two available online datasets and results are compared to other previously described approaches.
Results: Microaneurysm segmentation emerges from agent interaction. The final score of the proposed approach was 0.240 in the Retinopathy Online Challenge.
Conclusions: We achieved competitive results, primarily in detecting microaneurysms close to vessels, compared to more conventional algorithms. Despite these results not being optimum, they are encouraging and reveal that some improvements may be made.

1. Introduction

The presence of microaneurysms (MAs) in the retina is often the first sign of diabetic retinopathy (DR), so their early detection is crucial for the prevention of blindness. Therefore, it is of great importance to include automatic detection of MAs in a screening program. These types of lesions are commonly described as isolated, small, round objects, of 10–100 μm in diameter. In practice, they may appear as a conglomeration of more than one MA or in association with larger vessels. MAs are frequently indistinguishable from dot-hemorrhages in color fundus photographs, in which both appear red. However, these two types of lesions have the same clinical implications, so there is usually no need for an automated MA detector to distinguish between them. The number of MAs is positively correlated with the severity and progression of DR, at least in the early stages of the disease [1].

Since MAs can easily be observed in digital color fundus images and their number has clinical implications, several research attempts to develop an automated system to detect MAs have been made in recent years. However, none has shown the level of performance required for clinical practice. The primary difficulties with these algorithms lie in the low contrast between red lesions and background in fundus images, as well as the proximity of MAs to blood vessels. The algorithms often process the entire image in the same way and do not consider its local information, leading to rigid systems without the capacity to generalize. In the present study, a new approach, based on a multi-agent system (MAS), is proposed. The inclusion of MAS models in automatic medical image analysis systems is recent, and has been revealed as a research field in expansion. However, these models have already been used in the segmentation of magnetic resonance [2] and ultrasound [3] images. To the best of our knowledge, this kind of approach has been implemented by our group alone with regard to retinal blood vessel segmentation in fundus images [4].

A MAS is typically composed of a set of agents that are situated, and interact, in a virtual or real environment. In this new approach for detection of MAs in color fundus images, the environment includes an image resulting from a preprocessing step. The MA segmentation then emerges from agent interaction as a global behavior.

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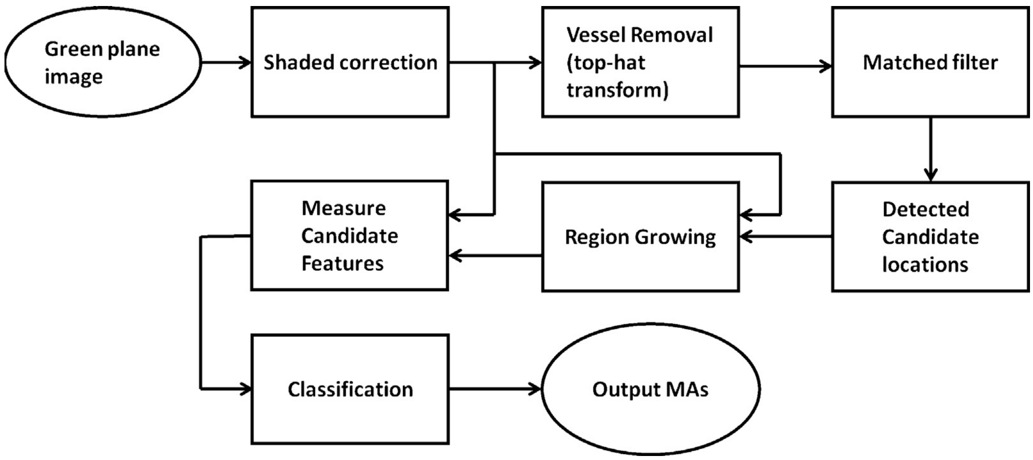

Fig. 1. Schematic of the “standard” approach to microaneurysm detection.

Adapted from [1]

This paper is organized as follows. Section 2 consists of a literature review of MA detection in color fundus images. Section 3 describes the proposed approach and its two main phases (preprocessing and the MAS model). The results are shown and discussed in Section 4. Finally, Section 5 presents the conclusion and some proposals for future research.

2. Related studies

Several approaches have previously been proposed with regard to MA segmentation through fundus image analysis. These approaches are frequently based on morphological [5,6], template-matched [7–9] and supervised learning methods [10,11]. The supervised methods are frequently preceded by one of the two other approaches [5,6,9].

Some previous approaches have examined the detection of MAs in fluorescein angiographies. In this type of image, MAs appear as bright patterns and with improved contrast, compared to the green plane image from the RGB color space. However, MAs have some characteristics in common in both images; they appear small, isolated and of a circular shape, which is fundamental when using morphological approaches. The first algorithm was developed by Laÿ [12] and then improved by other authors [6,10,13]. These approaches utilized the top-hat transformation to discriminate between circular, non-connected, red lesions and the elongated vasculature. The method consists of morphological opening of the green channel images, with a linear structuring element at different orientations to obtain the vasculature, and then removing it from the original image. The length of the structuring element is chosen to be sufficiently short to fit inside curved vessels, and long enough that it cannot fit inside MAs, such that it detects vessels (and other large extended features), but not MAs. However, if the length of the structuring element is increased to allow detection of larger objects, vessel segmentation deteriorates, leading to the detection of a greater number of spurious candidate objects on the vessel. This approach has been modified and subsequently used by other authors, such as Walter et al. [5], who detected MA candidates by applying diameter closing and an automatic threshold scheme.

Niemeijer et al. [10] developed an MA detection approach that has since inspired several research groups [6,13], and this is schematically illustrated in Fig. 1. First, the digital green plane image is shade-corrected to make uniform the background illumination of the retinal images. Shade-correction is normally achieved by estimating the background illumination image by means of a large median or mean filtering. The background image is either subtracted from, or divided by, the green plane image. The next step consists of detecting the vasculature by morphologically opening the shade-corrected image with a linear structuring element at several angles, to enhance all vessel segments (top-hat transformation). The segmented vessels are then subtracted from the shade-corrected image. The resulting image contains small, dark objects, such as MAs, and small fragments left over from the vessels, which are then highlighted by applying a matched-filter with a circularly symmetric 2D Gaussian as a kernel. Hereafter, the image is thresholded to detect the candidate MAs, which will be used as locations to initiate a region-growing process on the shade-corrected image to delineate the underlying morphology of the candidate. Finally, intensity and shape descriptors are determined in the region-grown object and a classifier used to ameliorate MA detection. The primary drawback of this approach is that it cannot typically detect MAs close to vessels.

Zhang et al. [8] presented an approach that differed from the “standard” in the way that the MA candidates and vessels were detected. Using this method to detect candidates, a non-linear filter with five Gaussian kernels with different standard deviations was applied to the input retinal images. By maintaining the maximal correlation coefficient for each pixel, a maximal correlation response image was obtained, which was then thresholded with a fixed threshold value to determine the candidates. The vessels were segmented by an adaptive thresholding technique and then used to reduce the number of candidates. Finally, the region-growing process was applied to determine the precise size of all candidates, and a set of features was extracted for each. The same research group [9] recently improved their method by including a supervised classifier at the final stage, which was the dictionary learning with sparse representation.

The approach used by Sánchez et al. [11] began with a normalization process identical to the standard approach. An unsupervised mixture-model-based clustering method was then used to extract candidates on the normalized image intensities. A fitted model was obtained by fitting a Gaussian mixture model to the image intensities. The MAs candidates were segmented by applying a threshold to the fitted model. After automatically masking out the vasculature, a set of color, shape and texture features were extracted from the remaining candidates for use in a logistic regression, to determine the likelihood of their being MAs.

Mizutani et al. [14] tailored their approach by applying brightness correction, gamma correction and contrast enhancement, in order to normalize the intensity and contrast between images. The extraction of MA candidates was performed using a modified