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# A multiscale decomposition approach to detect abnormal vasculature in the optic disc

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ABSTRACT

This paper presents a multiscale method to detect neovascularization in the optic disc (NVD) using fundus images. Our method is applied to a manually selected region of interest (ROI) containing the optic disc. All the vessels in the ROI are segmented by adaptively combining contrast enhancement methods with a vessel segmentation technique. Textural features extracted using multiscale amplitude-modulation frequency-modulation, morphological granulometry, and fractal dimension are used. A linear SVM is used to perform the classification, which is tested by means of 10-fold cross-validation. The performance is evaluated using 300 images achieving an AUC of 0.93 with maximum accuracy of 88%.



## 1. Introduction

Diabetic retinopathy (DR) is one of the leading causes of blindness in the world [6]. The disease is asymptomatic in its early stages and can be best managed by the patient by maintaining tight blood sugar and blood pressure control. However, as the disease progresses, it can become sight threatening. Studies [4,17] have demonstrated that 50% of type I diabetics and 20% of patients with type II diabetes will progress to advanced stages of DR some time in their lives. One of these advanced stages is proliferative diabetic retinopathy (PDR). PDR is characterized by the appearance of new, abnormal vessels in the retina. Depending on the location of these new vessels, they can be classified as neovascularization on the optic disc (NVD), where new vessels grow on or within 1 disc diameter (DD) of the optic disc, or neovascularization elsewhere (NVE), where the new vessels are present anywhere outside this NVD region. This paper focuses on the detection of NVD. In early stages, NVD appears as loops or networks of fine vessels [16]. As the disease progresses, the vessels extend outside the optic disc margin and their caliber increases. These new vessels are fragile and can grow into the vitreous gel. Vitreous traction with normal eye movement may lead to the rupture of the new vessels, causing hemorrhages and significant vision loss. Timely treatment with laser photocoagulation can slow progression of the disease. Therefore, detection of these new vessels is of critical clinical importance.

Most of the methodologies used to detect DR have been focused on finding other pathologies such as microaneurysms, hemorrhages, and hard exudates, as summarized in Winder et al. [34], while a few have looked for vascular abnormalities [12,9]. An approach to detect NVD has been presented by Goatman et al. [10]. In their paper, vessel segments were separated into abnormal and normal classes. Vessel-like candidate segments on the optic papilla are detected by using watershed lines and ridge strength measurements. Fifteen features, including shape, position, brightness, contrast, and density, were extracted from each candidate. Gaussian-kernel support vector machines (SVM) was used to classify data represented by those features. The results were validated using leave-one-out cross-validation. Based on 38 NVD and 71 normal cases, the method achieved an area under the receiver operator characteristic curve (AUC) of 0.79 for the detection of segments with NVD and an AUC of 0.91 for the detection of optic discs with neovascularization.

Others papers in the literature are focused in the detection of neovascularization in the images such as [13], in which they combine morphology-based operations, Gaussian filtering, and

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thresholding techniques. In their approach, 11 images that presented neovascularization were analyzed, obtaining an average sensitivity/specificity of 89%/64%. Lee et al. [18] proposed a vessel detection method which includes statistical texture analysis, high order spectrum analysis, and fractal analysis for the detection of neovascularization. They obtained an accuracy of 98.5% but good quality images were hand-picked from DR datasets and 27 out of 137 images present neovascularization.

The fundamental advantages from the use of amplitude-modulation frequency-modulation (AM-FM) features have been previously documented in Pattichis [26] and Murray et al. [22]. In summary, AM-FM models: (i) provide a large number of non-stationary texture features that are meaningful (e.g., instantaneous frequency, instantaneous amplitude), (ii) allow image reconstructions using multi-scale AM-FM decompositions, and (iii) enable the implementation of robust methods (e.g., [23]). A summary of recent medical imaging applications is given in Murray et al. [22]. Beyond DR applications, we note the recent application to MRI images in Loizou et al. [19], and tree image analysis in Ramachandran et al. [29].

In what follows, we present a summary of our prior research and list the new contributions of the current paper. In Agurto et al. [1], we presented an early study of the use of AM-FM methods for DR. The focus of this paper was on the use of AM-FM features for image classification. The results included a summary of classification of retinal images from different risk levels. The statistics for different AM-FM features were compared over regions with different types of lesions. In Agurto et al. [35], we presented a robust method for the detection of the optic disc in DR images. The approach did not use AM-FM features. In Yu et al. [2], we presented a multi-scale approach for detecting exudates regions in DR images. In an earlier conference publication in Agurto et al. [3], we presented preliminary results over a limited dataset, a reduced set of AM-FM features, and a different classification approach.

The current paper makes the following contribution over our prior research:

- ***Adaptive vessel segmentation method:*** A new approach for adaptive vessel segmentation is developed that uses feedback to determine jointly optimal parameters for image enhancement and segmentation. This new approach allows the use of different levels of enhancement. The new approach is described in Section 3.1.
- ***Extended texture feature set extraction and comparison:*** we focus on the development of a multiscale image processing approach to better capture NVD vessel properties such as narrow vessel caliber and tortuosity levels. The paper provides a comparative study that investigates the use of AM-FM features, granulometries, fractal dimension, as well as the combination of all of them together. The paper establishes the performance of each set of texture features independently and shows that the combined use of all of the features yields the best results.
- ***Analysis of the vasculature:*** We focus in the characterization of the entire vasculature in the optic disc to determine the presence of neovascularization without the need to analyze each vessel segment independently. By doing so, we obtain high accuracy in the detection of NVD, which is the ultimate goal of this research.
- ***Large dataset validation:*** The approach is tested on a larger database than those used in other papers and it is shown to perform better than current techniques for NVD segmentation and detection.

The organization of this paper is as follows. Section 2 describes the database used to test the proposed approach. The methodology is described in Section 3. Results and discussion based on 300 images are presented in Section 4. Conclusions are presented in Section 5.

## 2. Data description

The images used to test this approach were acquired at the Retina Institute of South Texas (RIST, San Antonio, TX) and the University of Texas Health Science Center in San Antonio (UTHSC SA). The images were acquired at RIST with a TRC 50EX camera with 50 and 35 degrees of field of view (FOV) and at UTHSC SA with a Canon CF-60uv with 60 and 40 degrees of FOV. The size of the RIST images is 2224 × 1888 pixels and the size of the UTHSC SA images is 2392 × 2048 pixels. Although images centered on the optic disc (field 1) were preferred for this study, images centered on the macula (field 2) that included the optic disc were allowed. Since we wanted to evaluate the performance of this algorithm as an independent block which can be added to a DR screening system, we manually selected the optic disc from the retinal images. However, our group previously developed an algorithm for the detection of the optic disc with high accuracy [35]. The dataset consists of 19 NVD and 45 normal cases from RIST and 81 NVD and 155 normal cases from UTHSC SA. Because of the differences in FOV and the variation of disc size diameter between individuals, which is in the range of 0.96–2.91 mm for the vertical axis and 0.91–2.61 mm for the horizontal axis [32], the images were resized so each had an optic disc with a DD = 400 pixels. Fig. 1 shows four examples of normal and NVD cases from the images used in this paper.

## 3. Methodology

Since the green channel provides excellent contrast for vessel segmentation [33,31,24], we restrict our approach to working with the green image. To avoid possible boundary artifacts, a margin of 60 pixels was added to our region of interest (ROI) of 800 × 800 pixels. However, features were extracted from the ROI only.

The method is summarized in Fig. 2. First, the vessels are segmented using an adaptive vessel segmentation approach. AM-FM features are then extracted from the segmented vessels areas. Next, we compute the fractal dimension and morphological granulometry from the segmented vessels. The extracted features are classified using an SVM with a linear kernel. We provide further details on the approach in the remaining subsections.

### 3.1. Adaptive vessel segmentation

In Fig. 3, we present a block diagram that shows the components of the adaptive vessel segmentation. Our vessel segmentation technique is based on the methodology presented in Yu et al. [36]. In Yu et al. [36], the retinal vasculature was segmented after applying a multiscale enhancement with Frangi filters [8] and second order local entropy for thresholding [25]. The same procedure presented in Yu et al. [36] cannot be used to detect the very fine vessels characteristic of NVD. Over-segmenting the retinal vasculature can help to detect small vessels, but it also introduces a high amount of segmented pixels in the avasculature zone (false positives per image). In addition, images taken at different alignment positions, such as those in our dataset, vary in contrast. The optic disc is directly illuminated by the light of the camera in disc-centered images; in macula-centered images, the nasal area receives less light intensity. For these images, different parts of the retina require different levels of enhancement.

In this paper, we introduce an adaptive approach that uses multiple levels to enhance vessel boundaries.

The first step is to analyze overlapping windows of 200 × 200 pixels that constitute the entire optic disc image (920 × 920 pixels).