Applied Mathematics and Computation 339 (2018) 568–587

Contents lists available at ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

Blood vessel segmentation in retinal fundus images using Gabor filters, fractional derivatives, and Expectation Maximization

Hugo Aguirre-Ramos[a], Juan Gabriel Avina-Cervantes[a,*], Ivan Cruz-Aceves[b], José Ruiz-Pinales[a], Sergio Ledesma[a]

[a] Telematics Group (CA), Engineering Division (DICIS), University of Guanajuato, Campus Irapuato-Salamanca, Carr. Salamanca-Valle km 3.5 + 1.8 km, Com. Palo Blanco, Salamanca Gto. 36885, Mexico
[b] CONACyT Research-Fellow, Center for Research in Mathematics (CIMAT), A.C., Jalisco S/N, Col. Valenciana, Guanajuato Gto. 36000, Mexico

ARTICLE INFO

Keywords:
Segmentation
Gabor Filter
Fractional derivatives
Radius filter
Retinal fundus images

ABSTRACT

In recent decades, the eye diseases have become the leading causes of blindness in young adults. Most of the cases can be prevented if detected in the early stages. For instance, the analysis of retinal blood vessels can help the physician to detect and prescribe appropriate treatment to the diabetic patient as a special case. This work describes a novel framework for blood vessels detection in retinal images. In the proposed methodology, the noise present in the green channel of the RGB image is reduced by a Low-Pass Radius Filter, subsequently, a 30-element Gabor filter and a Gaussian fractional derivative are used to remarkably enhance both the blood vessels structure and its contours. Thereafter, a threshold and a series of morphology-based decision rules are applied to isolate the blood vessels and reduce the incidence of false positive pixels. Additionally, our method can be used to detect the Optic Disc in the original image and remove it from the threshold result. The proposed method was assessed using the public DRIVE database, for the *Test* image set and the 1st *manual* delineations. In this database, our method is able to obtain an average accuracy of 0.9503, an average specificity of 0.7854, and an average balanced accuracy of 0.8758. Moreover, the proposed method shows a better performance than comparative methods, such as the threshold for a Frangi filter, Adaptive Threshold, and multiple classes Otsu method. After the analysis of the computer simulations, it was concluded that the proposed method is a competitive and reliable methodology for blood vessels segmentation.

1. Introduction

In medicine, the segmentation of blood vessels in color retinal fundus images (RI) is a usual procedure in the evaluation of several cardiovascular and eye diseases (retinopathy). The analysis of blood vessel length, orientation, and thickness can

* Corresponding author.
E-mail addresses: h.aguirreramos@ugto.mx (H. Aguirre-Ramos), avina@ugto.mx (J.G. Avina-Cervantes), ivan.cruz@cimat.mx (I. Cruz-Aceves), pinales@ugto.mx (J. Ruiz-Pinales), selo@ugto.mx (S. Ledesma).

https://doi.org/10.1016/j.amc.2018.07.057
0096-3003/

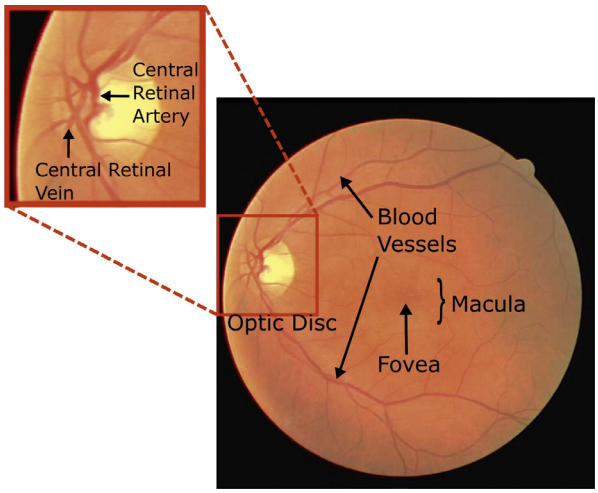

Fig. 1. The typical distribution of the blood vessels in a human retinal picture image.

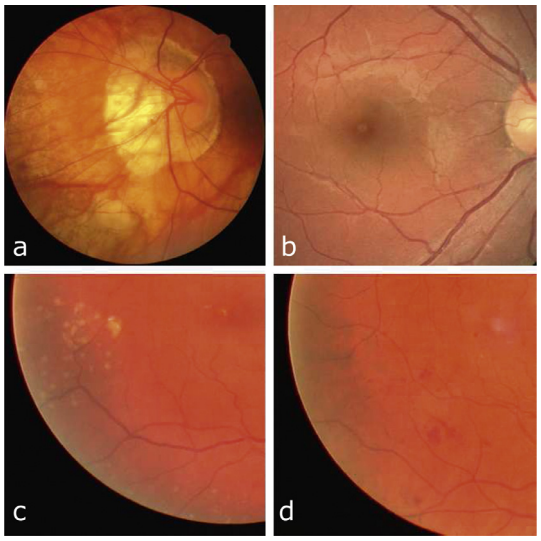

Fig. 2. The anomalies found in RIs: (a) High cupping of the optical disc, (b) cotton wool spots, (c) hard exudates, (d) hemorrhage.

help the physician in the diagnosis of hypertension, diabetes, etc [1–3]. In almost any healthy RI, the structures shown in Fig. 1 can be appreciated.

A circular (to oval) white region, called the Optic Disc, can be easily recognized from any other structure as the brightest region in the RI. From the center of the Optic Disc, the major blood vessels, the central retinal vein and artery, are radiated. These structures exist over almost the entire image through a series of connections and bifurcations, which connect them to smaller elements at their ends, called retinal venules and arterioles. Although blood vessels can be presented along the entire image, there is a region where they never appear. This region, called the macula, encloses the fovea, a slightly oval-shaped reddish spot where the cone cells are located, these cells transform the light stimulus to electrical stimulus. On the other hand, it is possible that an unhealthy RI includes several other structures besides those shown in Fig. 1. These anomalies can appear as bright spots outside the Optic Disc, small (to big) irregular reddish elements, and even blackish elements that cover the Optic Disk. All these anomalies are usually produced by different diseases or injuries [4,5]. Glaucoma, the first cause of permanent blindness, tends to increment the cup-to-disc ratio [6], generating retinal images like the one shown in Fig. 2(a) where the Optic Disc appears larger than usual. Other diseases, like diabetes and hypertension, tend to develop soft, whitish to grey, cloud-like lesions. They are called cotton-wool spots or soft exudates and are shown in Fig. 2(c). These diseases can also produce yellow-white deposits called hard exudates; like those shown in Fig. 2(d) that can vary in size (forming small specks to larger regions). These lesions blur the images perceived by the human being or, in advanced and severe cases, appear as black spots blocking completely the image perceived by the person [7–9]. Hemorrhages are another type of lesions caused by these diseases or traumatic injuries in adults and infants [10,11]; they are formed when a blood vessel wall breaks, propitiating the apparition of reddish spots in the retinal image. These kinds of