A review on automatic analysis techniques for color fundus photographs

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ABSTRACT

In this paper, we give a review on automatic image processing tools to recognize diseases causing specific distortions in the human retina. After a brief summary of the biology of the retina, we give an overview of the types of lesions that may appear as biomarkers of both eye and non-eye diseases. We present several state-of-the-art procedures to extract the anatomic components and lesions in color fundus photographs and decision support methods to help clinical diagnosis. We list publicly available databases and appropriate measurement techniques to compare quantitatively the performance of these approaches. Furthermore, we discuss on how the performance of image processing-based systems can be improved by fusing the output of individual detector algorithms. Retinal image analysis using mobile phones is also addressed as an expected future trend in this field.

1. Introduction

The retina (fundus) [1] has a very specific diagnostic role regarding human health. The eye is a window into the body responsible for sensing information in the visible light domain, thus, it is also suitable to make clinical diagnoses in a non-invasive manner. The retina is a spherical anatomic structure on the inner side of the back of the eye as shown in Fig. 1 (a). It can be subdivided into ten layers supporting the extraction of visual information by photoreceptor cells: the rods and the cones. As any other tissue, the retina also has blood support through the vascular system, which is clearly visible from outside with an ophthalmoscope during clinical examinations. At the center of the retina a darker, round spot, the macula resides, whose center is known as the fovea, which is responsible for sharp vision. The optic disc – including the optic cup – is a bright oval patch, where the optic nerve fibers leave the eye and where the major arteries and veins enter and exit. The special structure of the retina limits the possible appearances of distortions caused by different diseases. Namely, the most common lesions appear as patches of blood or fat in retinal images. Diseases affecting the blood vessel system cause similar vascular distortions here than in any other part of the body, but are easier and better seen if examined by an experienced professional.

From diagnostic point of view, retinal image analysis is a natural approach to deal with eye diseases. However, it is getting more and more important nowadays, since the types and quantities of different lesions can be associated with several non-eye diseases, as well. In automatic image analysis, the fovea, macula, optic disc, optic cup, and blood vessels are the most essential anatomic landmarks to extract (see Fig. 1 (b)). Besides them, the recognition of specific lesions is also critical to deduce to the presence of diseases they are specific to.

In this work, we focus on automatic color fundus photograph analysis techniques to support clinical diagnoses. Accordingly, the rest of the paper is organized as follows. We highlight the major eye and non-eye diseases having symptoms in the retina in Section 2. In Section 3, we provide an overview of image acquisition techniques and summarize the most important automatic image processing approaches. These tools include image enhancement and segmentation methods to extract anatomic components and lesions. We exhibit both supervised and non-supervised techniques here. Moreover, we discuss on how the aggregation of the findings of different algorithms by fusion-based methods may improve diagnostic performance. For the quantitative, objective comparability of different approaches, we also present several publicly available datasets and the commonly applied performance measures. We discuss on possible future trends including retinal image analysis on mobile platform

(a)   (b)

Fig. 1. Basic concepts of retinal image analysis Basic concepts of retinal image analysis; (a) the structure of the human eye and the location of the retina, (b) sample fundus image with the main anatomic parts and some lesions.

in Section 4. Finally, in Section 5, we draw some conclusions to provide a more comprehensive comparison of the available approaches and to give suggestions on possible improvements regarding both detection accuracy and efficient computing.

2. Clinical background of color fundus photograph analysis

The retina is the only site to observe vessel-related and other specific lesions *in vivo* and recent studies showed that these abnormalities are predictive to several major diseases listed next.

2.1. Diabetes

In 2015, 415 million adults suffered from diabetes mellitus [2]. This number is growing, and by 2040, it is expected to reach 642 million. Long-time diabetes affects the blood vessels also in the eyes, causing diabetic retinopathy (DR). In the case of DR, the blood vessels supplying the retina may become thick and weak, causing leaks called hemorrhages (see Fig. 2). These leaking vessels lead to swelling and edema, causing eyesight deterioration. The fluid exudates in the retina can be observed as small yellowish spots (see Fig. 1 (b)). The earliest signs of diabetes are microaneurysms (MAs, see Fig. 1 (b)), which are focal dilations of the capillaries and appear as small darkish spots. The identification of exudates, hemorrhages, and MAs are important for the early prevention of DR-caused blindness.
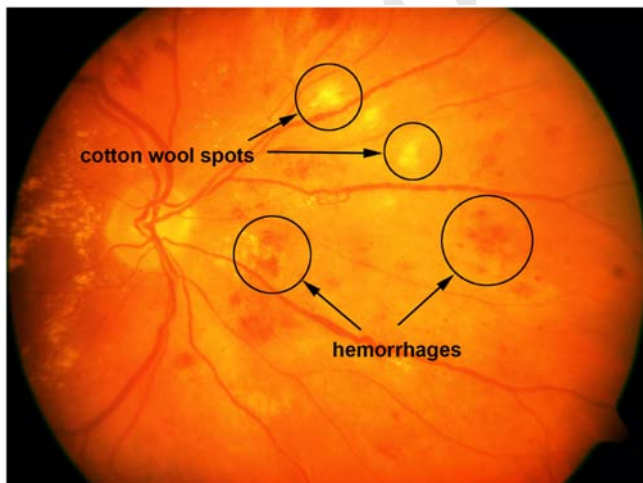
Fig. 2. A sample retinal image with cotton wool spots and hemorrhages.

2.2. Cardiovascular diseases

2.2.1. Hypertension

Wong et al. [3] summarized the major effects of systemic hypertension in the retina. Hypertensive retinopathy may cause blot- or flame-shaped hemorrhages, hard exudates, micro- or macroaneurysms, and cotton wool spots, which occur due to the occlusion of arteriole and appear as fluffy yellow-white lesions (see Fig. 2). Ikram et al. [4] pointed out that the risk of hypertension was increased with general arteriolar narrowing in the retina, mainly in the elderly population. There is a connection also between the arteriolar-to-venular diameter ratio and higher blood pressure, but with lower influence than the arteriolar narrowing. Cheung et al. [5] concluded that retinal arteriolar tortuosity was connected with higher systemic blood pressure and body mass index, while venular tortuosity was associated with lower high-density lipoprotein cholesterol level, as well.

2.2.2. Coronary heart disease

Coronary heart disease is the leading cause of death worldwide. Recent studies (e.g., [6]) showed that there is a correlation between coronary heart disease and coronary microvascular dysfunction. Liew et al. [7] collected the main symptoms of microvascular dysfunctions like focal arteriolar narrowing, arteriovenous nicking and venular dilation. McClintic et al. [8] reviewed the recent findings regarding the connection between coronary heart disease and retinal microvascular dysfunction. Liew et al. [9] examined retinal vessels with fractal analysis in order to detect whether it had any connection to coronary heart disease. Their observations suggest that non-optimal microvascular branching may cause the disease. Vessel abnormalities can be characterized by geometric measures that will be discussed in Section 3.3.3.

2.3. Stroke

Since the cerebral and retinal vasculature share similar physiologic and anatomic characteristics, reasonable research efforts have been made in the recent years to reveal the connection between cerebral stroke and retinal vasculature. Baker et al. [10] concluded that signs of hypertensive retinopathy were associated with different types of stroke. Cheung et al. [11] showed that increased retinal microvascular complexity was associated with lacunar stroke and alterations of retinal vasculature may cause microangiopathic events in the brain. Patton et al. [12] summarized the recent advancements in the possibilities of examining the retina to search for cerebrovascular diseases.