Color image analysis of the optic disc to assist diagnosis of glaucoma risk and evolution

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Abstract

This work aims to build an algorithm to segment the optic cup inside the optic disc, and the optic disc from the rest of the eye fundus image. The algorithm is intended to give assistance in the cup to disc ratio estimation of glaucomatous eyes. Often the contours of both the optic cup and disc are faint and intersected by entangled veins that make it difficult to draw their silhouettes. The algorithm, which includes the spatial filtering proposed in the S-CIELAB extension, is based on the information of color, the color differences between neighbor pixels and the geometry of the areas involved.

1 Introduction

The optic disc (optic nerve head) is the entrance region of blood vessels and optic nerves to retina (Figure 1). The examination of the optical disc appearance in retina fundus images is a general practice of ophthalmologists to evaluate the potential risk of glaucoma or to monitor the evolution of glaucomatous eyes. Reductions of the neuroretinal rim may reveal the pathological damage. A common parameter to assess the severity of the damage is the cup to disc ratio, which gives an idea of the area occupied by the cup in the optic disc.

In the last years there is an increasing interest to obtain an objective estimation of the cup to disc ratio from the analysis of the digital retina images provided by a variety of improved and sophisticated instruments of the ophthalmologic clinic.

Greaney et al. [1] used optic nerve head stereophotographs (ONHPs), confocal scanning laser ophthalmoscopy (CSLO), scanning laser polarimetry (SLP), and optical coherence tomography (OCT) to measure different characteristics of glaucomatous optic nerve damage with the goal of diagnosing early to moderate glaucoma in the same population sample. The authors concluded that the quantitative methods CSLO, SLP and OCT were no better than qualitative assessment of disc ONHPs by experienced observers. However, this capability could significantly be improved by a combination of the imaging methods.

Li and Chutatape [2, 3], used principal component analysis and proposed a modified active shape model to detect the disc boundaries in retinal images. They built a point distribution model from a training set and applied an iterative searching procedure to locate instance of such shapes (represented by the position of *n* landmark points) in a new image. Walter et al. [4] have detected the optic disc by means of morphological filtering techniques and the watershed transformation. Pinz et al. [5] presented a prototype software system for automatic map generation of retina. They apply a circular shape approach for the optic disc and used a two-stage gradient-based Hough transform.

Zana and Klein [6] present an interesting algorithm based on mathematical morphology and curvature evaluation for the detection of vessel-like patterns in a noisy environment and applied it to the analysis of a variety of retinal images. A method for automated blood vessel detection in the optic disc area that takes into account the axial specular reflection of vessels is described by Vermeer et al. [7].

Although the development of automatic retinal image analysis to assist diagnostic systems has attracted the interests of many researchers, there are difficulties mainly due to noise, uneven illumination and great variation between individuals. The combination of several images of the same eye fundus acquired by different instruments and techniques contributes to improved results. But, on the other hand, the extensive testing to create such combination is expensive, cumbersome and too time consuming to be clinically practical.

An automated or semiautomated computer-assisted mass screening for diagnosis and monitoring of glaucomatous eyes is the most important task to which image processing can contribute. As main advantages it could bring a diminution of the necessary resources in terms of specialists and a diminution of the examination time. To this end, we consider single images captured by a non-mydriatic retinal camera [8]. This sort of cameras can be handily used by technicians, not necessarily ophthalmologists, thus saving resources of such specialists.

We consider digital color images of the eye fundus obtained using a non-mydriatic retinal camera that incorporates an infrared focusing system and a white-light flash to register eye fundus with no need of paralyzing the iris diaphragm function. Images can be digitized by computer and displayed on a CRT monitor screen, or printed for visualization. In our case, we use the Topcon TRC-NW6S retinal camera that has a 3CCD Sony DXC-990P camera for imaging and a Xenon flash lamp. Retina fundus images of 30º field are digitized in arrays of 768 x 576 pixels size, where the region of interest corresponding to the optic disc area occupies 100 x 100 pixels approximately (Figure 1).

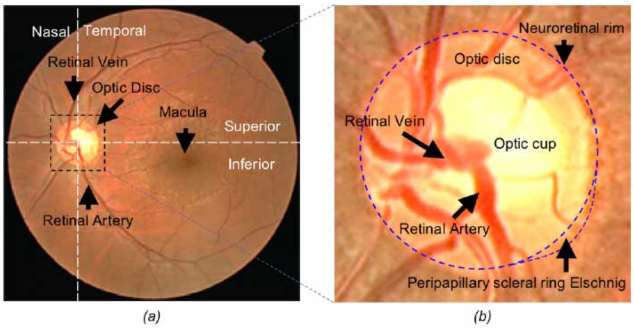

***Figure 1.** (a) Retinal image and (b) optic disc (region of interest).*

This work aims to build an algorithm to segment the optic cup inside the optic disc, and the optic disc from the rest of the eye fundus image. The algorithm is intended to give assistance in the cup to disc ratio estimation. Note that the contours of both the optic cup and disc are faint and intersected by entangled veins that make it difficult to draw their silhouettes. The algorithm is based on the information of color, color

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differences between neighbor pixels and geometry of the areas involved.

The algorithm deals with input images that have been transformed from the standard color space sRGB to the device independent color representation CIEXYZ. Before calculating the color differences between neighbor pixels, the image is smoothed according to the spatial filters that approximate the contrast sensitivity functions of the human vision system in the opponent color space. In this stage, we follow the procedure introduced by Zhang and Wandell in the definition of S-CIELAB extension [9]. The procedure takes into account the viewing conditions of the final image displayed on a (sRGB) monitor. We will consider an observation distance of 18 inches and a resolution of the monitor of 72 points by inch.

The area of the optic cup appears very bright in the images in general, often near to saturation. Taking the pixel color with the highest value of luminance and minimum chromaticity - usually in the yellowish white region- as a seed, the color differences using the CIELAB ΔE equation (alternatively, other metrics such as CIEDE2000 can be used) are calculated between this seed color and the color of the other pixels of the image. The pixels that obtain the smallest color differences from the seed are assigned to the optic cup in first approximation. The final segmentation of the cup is completed by applying morphological operations [10].

The outer contour of the neuroretinal rim is determined in a different way. It does not appear as a continuous shape, but, on the contrary, it is crossed by retinal veins and arteries. For this reason, our algorithm has to approximate the occluded zones of the neuroretinal rim contour. Figure 2 shows a rough scheme based on the color differences between neighbor pixels that we apply to the region of interest. Since the optic disc is nearly round shaped, a new image is generated in polar coordinates (Figure 2b). Since the center and the corners of the image of Figure 2(a) are not interesting for our purpose of finding the rim contour, we just pay attention to the band limited by dashed lines in Figure 2(b). The top and bottom files of this new array correspond to the center of the temporal side where blood vessels are rare and where the contrast between the neuroretinal rim and the rest of the eye fundus -in terms of color difference units- appears most sharpened. In the array of Figure 2(b), the contour sought appears close to a right vertical line (not drawn) within the band limited by dashed lines. This means to consider a circular geometry for the disc boundary in first approach.

The proposed algorithm starts from both the top and the bottom files of the array and looks for the pixel in the file with highest color difference between its (a,b) neighbors placed at both sides, several pixels far from that one (Figure 2c). The differences of color ΔE, luminance ΔL, chroma ΔC, and hue Δh are estimated and considered to select the initial points in the rim contour and eye fundus. These pixels at the top and the bottom files of the array belong to the contour. The following pixels of the contour are found among those with similar characteristic to the former ones that are contained in certain vicinity. If these new pixels cannot be found because of the presence of a blood vessel, then the vicinity is enlarged to embrace a bigger area and the algorithm jumps beyond the vessel (Figure 2d). Finally, the different segments of the contour are linked by interpolation and the neuroretinal rim is completed.

Once the optic disc and cup have been contoured, the cup to disc ratio can be calculated and the sign of damage in glaucomatous eye can be estimated.

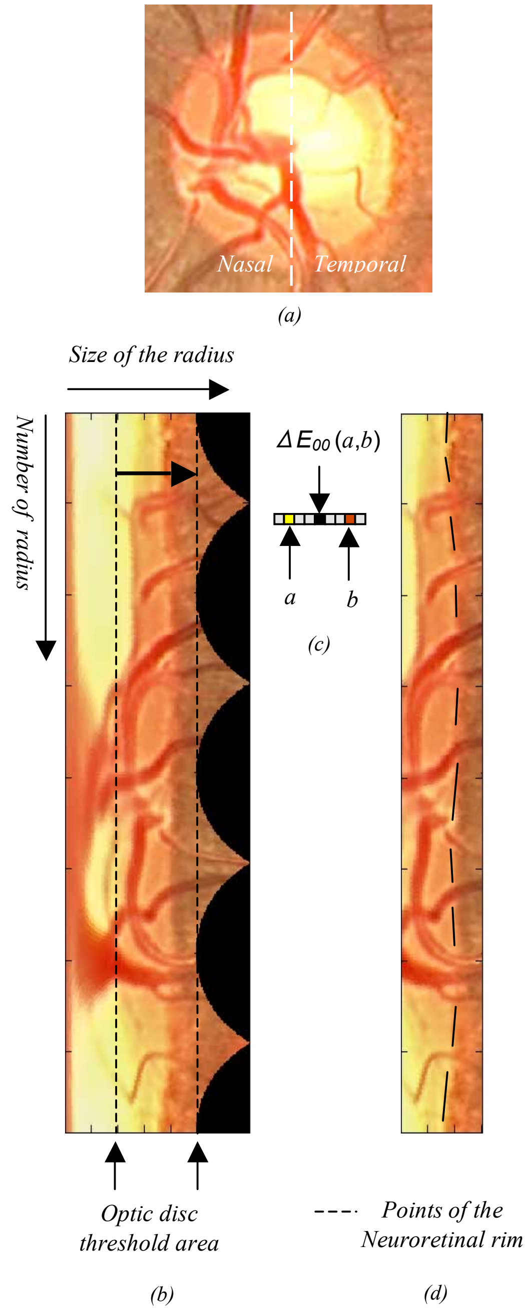

***Figure 2**. Scheme of the algorithm to mark the neuroretinal rim boundary.*

Results

We have applied the algorithm to 50 images of the optic disc obtained by the non-mydriatic retinal camera. The images corresponded to a variety of people, including normal eyes to moderate glaucomatous eyes. These images were also affected by noise, uneven illumination, blur, and noticeable colour and shape variations between individuals. The images can be used to show the robustness and the weakness of the method.

Figure 3 shows a selection of some original images of the optic disc and their corresponding results after applying the proposed algorithm. A red line segments the cup and the blue line corresponds to the disc boundary. These results have been compared with the qualitative assessment by an experienced specialist. A variety of situations concerning dynamic range, noise level, and disc to fundus contrast are shown in Figure 3. Figure 3(a), for instance, has low noise and moderate saturation. The resulting cup and disc segmentations are good. Figure 3(b) shows a neuroretinal rim with a boundary very difficult to appreciate. However, the result is good and the boundary acceptable. Since this optic disc does not show cup, there is no red contour. Figure 3(c) shows an optic disc with a double ring in the boundary of the rim. In this case, the algorithm detects the highest colour difference and follows this contour without deviating to the other ring. The resulting disc boundary (blue line) is good. However, the extension of the cup should be greater, particularly in the nasal zone, than the region segmented by the red line. Figure 3(d) is somewhat dark. The disc boundary is reasonably good, although it tends to be rather circular (instead of elliptical) in the bottom part of the figure. Figures 3(e) and (f) show optic discs that achieve good results.

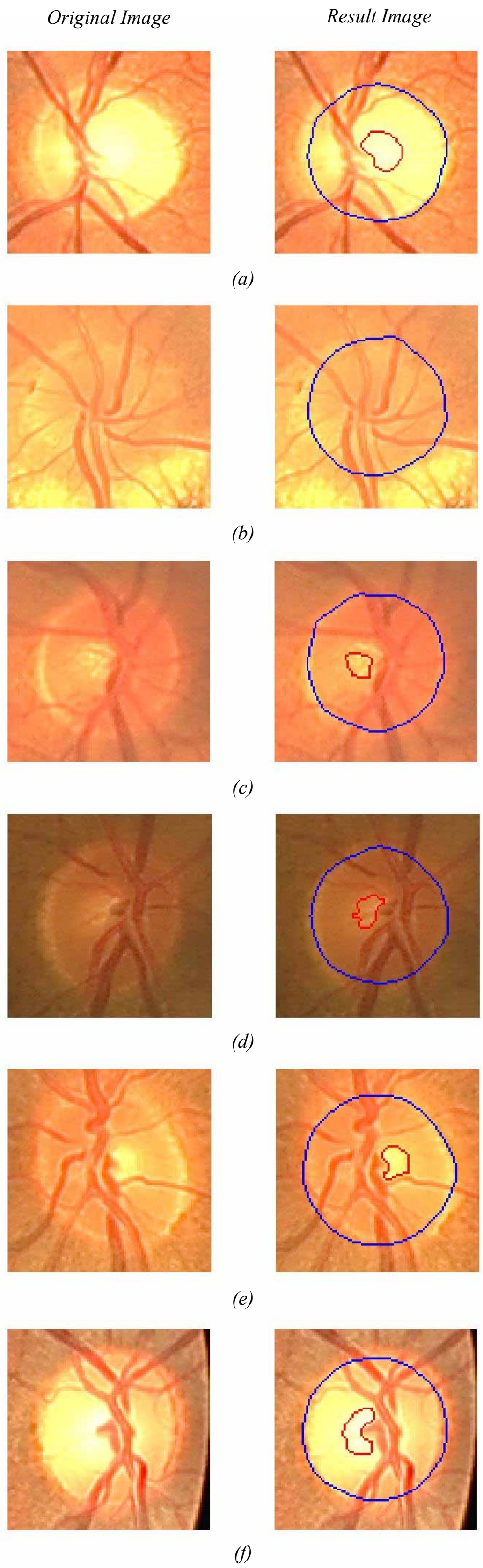

***Figure 3**. Results of cup (red line) and disc (blue line) segmentation.*

Conclusions

The algorithms for the automatic boundary detection of both cup and disc in the optic nerve head have been developed and applied to a set of real images obtained by using a non-mydriatic retinal camera. They are intended to assist the specialists in the cup to disc ratio estimation, which is an important metric for the early detection of glaucoma risk. The algorithms are based on the analysis of the colour content of the region and the colour differences between neighbour pixels. Some considerations about smoothness and round shape of the optic disc boundary have been taken into account too. The method shows a feasible way for complex optic disc images analysis and feature extraction. Further tests should be carried out to contribute to further improvements on the algorithms.

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