

Efficient Methodology for the Enhancement of Color Retina Images

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Abstract. The main objective of this work is the enhancement of eye fundus images. The methodology is based on the Phong specular reflection model and the Euclidean distance to generate a lighting function that is able to mitigate the dark areas on the periphery of the retina image, due to the natural concavity of the retina, starting from a 2D surface which serves as model compensation. At the same time, the methodology takes into account the non-centered illumination of the light source used during image acquisition. The methodology includes a procedure based on mathematical morphology techniques to attenuate the reflections that appear around the vertical thick vessels of the retina.

Keywords: Image enhancement; Retina analysis; Phong specular reflection model; Eye fundus analysis.

1. Introduction

Enhancement of images of the human retina is a useful preprocessing step prior to performing segmentation and analysis, either of the anatomic elements of the retina or the symptoms related to diseases that could be present.

The processing of eye fundus images has to take into account the semi-spherical shape of the retina, which causes reflectivity to be no homogeneous at all points captured by a camera. As a result, the area of the periphery of the image is darker than the central area (Fig. 1). The implementation of the lighting function seeks to attenuate the existing dark areas on the periphery of the retina that cause the background to be no homogeneous. As a result, the anatomic elements of the retina and pathologies (affections) in the retina will become more visible. For this purpose was developed the following procedure:

This lack of homogeneity is also manifested due to the lack of perpendicularity with respect to the geometric center of the retina. In addition, the majority of retinal images exhibit unwanted reflexes around the vertical thick vessels of the retina.

Numerous techniques for improving the quality of human retina images have been proposed, including methods that normalize lighting and contrast [2], histogram equalization [6], [7], contrast stretching [14], [12], [13], the application of the

transformation contourlet [1], techniques based on wavelets [3], [4], [5], multi-scale retinex with color restoration technique [11] and genetic algorithms [8].



Fig. 1. Fundus image with a non-homogeneous background with dark areas on the periphery

The method presented in this paper is particularly effective for the enhancement of human retina images because it takes into account the geometric characteristics mentioned above.

2. Proposed Methodology

Figure 2 shows the general block diagram describing the methodology used. First, images of the retina are converted from RGB color space to HSI color space, from which the intensity channel is selected (a). Then a morphological filter is applied in order to reduce additive noise without greatly altering the high frequency variations in the image (b). This involves the application of a close-open morphological filter followed by an open-close filter, both with a small square structuring element of 2×2 pixels centered in (0,0).

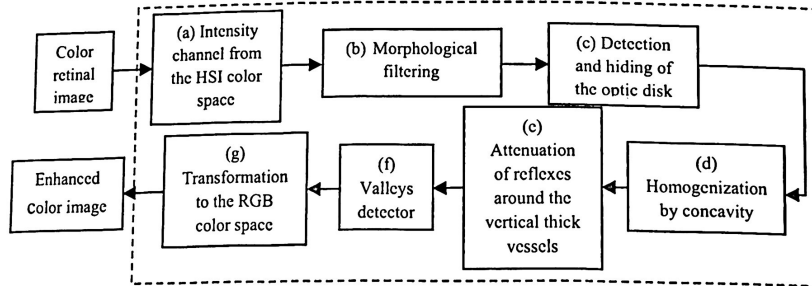


Fig.2. Block diagram of the methodology

A small structuring element is necessary to achieve a compromise between noise reduction and keeping the small features or symptoms that may be contained in the

image being analyzed, such as small microaneurysms and exudates, as well as the edges, borders, etc. of the different objects in the image.

The detection of the optic disk (or optic papilla) (c) is done via a morphological dilation with a square structuring element of 3 x 3 pixels and centre in (1, 1), in order to identify the brightest areas in the image [10]. Once located the optic disk it is hidden with a black disc which can cover more fully as possible the optic disc, in order to subsequently apply homogenization by concavity which will be explained below. So we can find the clearest area of the new image caused by the light source used for the capture, without taking into account the own luminance of the optic disk.

Subsequently, the non-uniform brightness of the retina is homogenized by taking into account the natural concavity that is present when you look through the pupil (d). To do this we applied in a reversed form the result of the illumination model based on the specular reflection model of Phong [9] (Fig. 3). The image on the left shows the Phong's model for a given lighting direction and the image on the right is the compensation image to be applied to the retinal image for its enhancement.

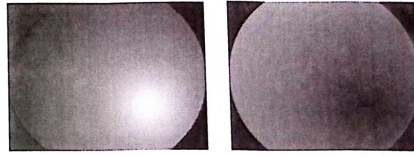


Fig. 3. On the left is the specular reflection model of Phong and on the right the reversed lighting function

Note that at first glance the image on the right is more like a sphere, although in reality it is a 3D surface created from a 2D surface, which has been modeled in agreement with a given direction of the illumination source.

Subsequently, (e) indicates the attenuation of the reflections that occur around the vertical blood vessels (Fig. 3a). These reflections are present in a meaningful way in most of the retinal images, especially the healthy ones. For this, the operations in Equation 1 will be performed:

$$g(x, y) = \text{SumScaled}([\delta_b(f)]^c, CIHC) \quad (1)$$

$b \in B$

Where:

1. - f is the filtered intensity channel from the HSI images obtained from the original color image.
2. - $g(x, y)$ is the output image.
3. - B is the square structuring element of 9 x 9 pixels.
4. - SumScaled is the function that adds two input images and returns an image.
5. - $CIHC$ is the intensity channel homogenized by concavity.

Firstly, the image of the intensity channel obtained after the transformation of the original image to the HSI model is dilated (Fig. 4a); then it is complemented to obtain

the first parameter of the function *SumScaled* (Fig. 4b); the second parameter is the intensity channel homogenized by concavity (Fig. 4c). Fig. 4d shows the output of the procedure with the reduction of reflexes around the thick vertical vessels.

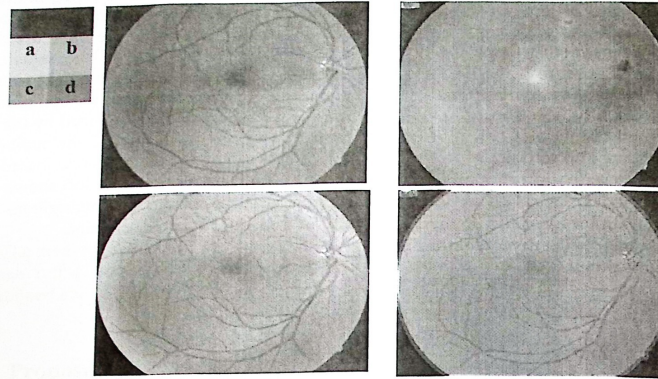


Fig. 4. (a) Original image with the reflexes around the thick vertical vessels; (b) First parameter of the SumScaled function; (c) Second parameter of the SumScaled function; (d) Output of SumScaled function

This procedure reduces the reflections around the thick vertical vessels which facilitates segmentation.

Subsequently, the morphological operator named valleys detector (Bot-Hat) is applied (f), to bring out the arterial and venous networks which appear as dark object in the image and reduce the longitudinal reflections that appear on its center due to its tubular shape and its nature, occurring during the acquisition of the image.

Finally, the improved intensity image is converted from the HSI color space back to RGB (g). This provides the final enhanced color image.

3. Lighting Function

According to Fig. 5, using the term for calculating the Euclidean distance and based on the specular reflection model of Phong [9], we formulated the following equation:

$$I(x, y) = (1 - \cos \theta) \left[(x - s)^2 + (y - t)^2 \right]^{-1/2} \quad (2)$$

Where:

$1 - \cos \theta$ is the constant that will remove the gloss on the periphery of the retina image.

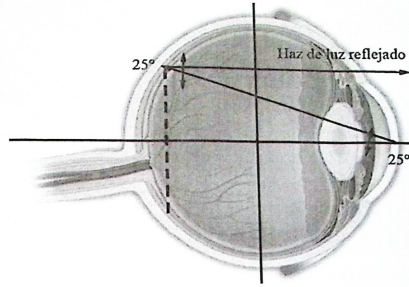


Fig. 5. Furthest angle from the center of the image

θ is the angle between the emitted and reflected light beams, this last parallel to the axis of the ophthalmoscope. We discarded all others.

x, y are the coordinates of the cap formed by the retina.

s, t are the mobile coordinates of the modeled surface.

The term $(1 - \cos \theta)$ is taken based on the expression $(\cos^\alpha \theta)$, where α is the coefficient of secularity or brightness concentration and whose exponent we have removed ($\alpha = 1$) because we are not trying to model the lighting at some specific point, but rather we want to get a function that compensates for the effects of the semi spherical shape of the retina. In the axis parallel to the ophthalmoscope, the Phong model gives the maximum value. It is precisely at this point where it is necessary to obtain the minimum value for the compensation of the curvature; for this reason the cosine function is subtracted from the unit.

In Fig. 5 is shown that the furthest angle from the center of the image is 25° , so the equation 2 will have now the next form:

$$I(x, y) = (1 - \cos 25^\circ) [(x - s)^2 + (y - t)^2]^{1/2} \quad (3)$$

The equation 3 will be used as the lighting function.

4. Results and Discussion

Figures 7, 8, 9, 10, 11 and 12 show the results for various types of retinal images, both normal and pathological. In each case, we show the original image to be improved, the lighting function calculated; the enhanced color image; the histogram of the three color planes R, G and B of the original image, and the histograms of the three color planes R, G and B of the enhanced image.

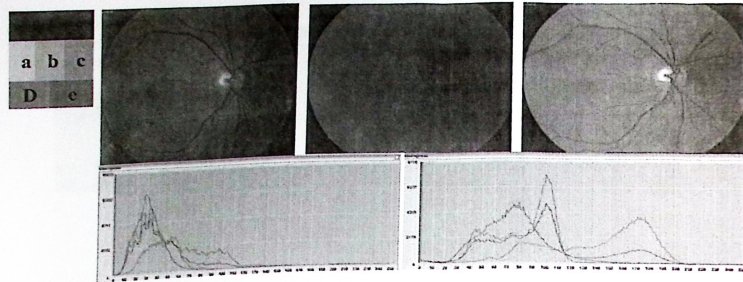


Fig. 7. (a) Original image; (b) Lighting function; (c) Enhanced image; (d) Histogram of the original image; (e) Histogram of the enhanced image

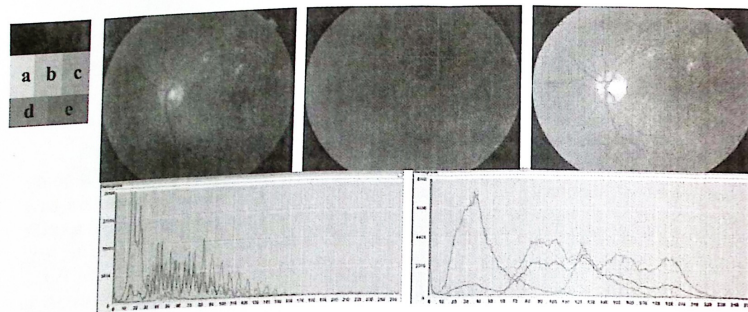


Fig. 8. (a) Original image; (b) Lighting function; (c) Enhanced image; (d) Histogram of the original image; (e) Histogram of the enhanced image

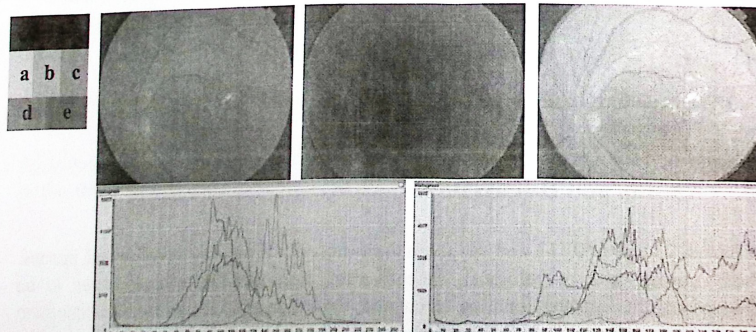


Fig. 9. (a) Original image; (b) Lighting function; (c) Enhanced image; (d) Histogram of the original image; (e) Histogram of the enhanced image

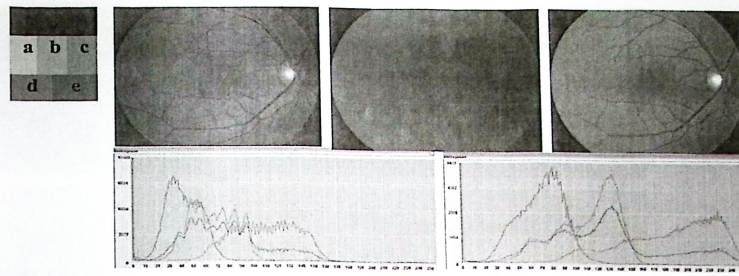


Fig. 10. (a) Original image; (b) Lighting function; (c) Enhanced image; (d) Histogram of the original image; (e) Histogram of the enhanced image

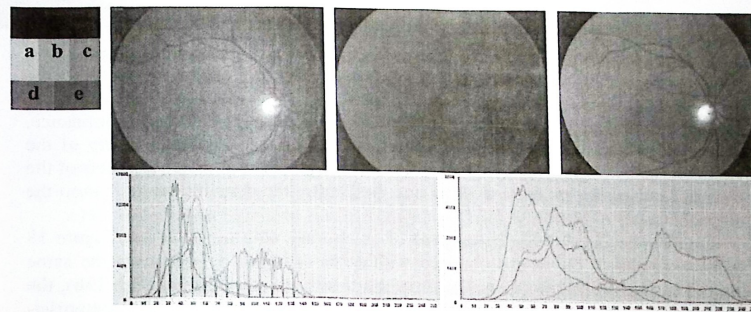


Fig. 11. (a) Original image; (b) Lighting function; (c) Enhanced image; (d) Histogram of the original image; (e) Histogram of the enhanced image

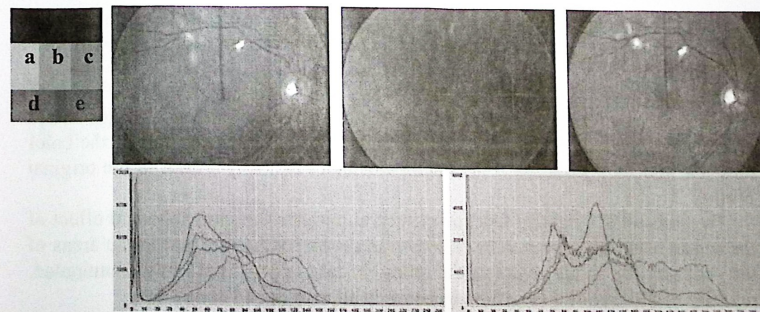


Fig. 12. (a) Original image; (b) Lighting function; (c) Enhanced image; (d) Histogram of the original image; (e) Histogram of the enhanced image

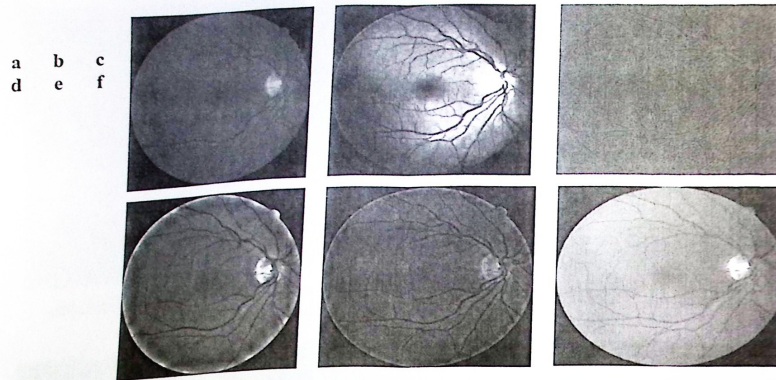


Fig. 13. (a) Original image; (b) Histogram equalization; (c) Local normalization; (d) Wavelet-based; (e) Contourlet-based; (f) the proposed methodology.

In all previous examples it can be seen that due to the homogenization of luminance, the enhanced image is now more homogeneous and clearer on the periphery of the retina than in the original image. In all cases the histograms of all color channels of the enhanced images appear more uniform and uses better the dynamic range than in the original images.

On the other hand, with the purpose of comparing with our solution, Figure 13 shows examples of the results obtained with other solutions applied over the same image (reported by [1]); it shows images of the histogram equalization (Fig. 13b); the local normalization (Fig. 13c); wavelet-based enhancement (Fig. 13d); contourlet-based enhancement [1] (Fig. 13e), and the result obtained with the proposed methodology (Fig. 13f).

5. Conclusions

The methodology proposed in this paper for the improvement of retina images shows satisfactory results, as demonstrated by the uniformity of the histograms of the color channels without degradation of the small pathologies that may appear in the original images.

The proposal of a lighting function created to mitigate the semi spherical effect of the human retina has proven to be effective, as shown by the fact that in the areas of the periphery and in the center of the retina, images appear uniformly illuminated, resulting in a background more homogeneous in all images.

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