Automated processing of retinal images

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Abstract

The problem of automated processing of retinal images for semi-automatic diagnosis of retinal diseases is considered in this paper.

The main aspects of retinal image processing are discussed. Methods for non-uniform illumination correction, blood vessel detection and macula and optic disc segmentation, finding dark and light spots in the macula area are suggested.

Keywords: retinal image processing, eye fundus, telemedicine.

1. INTRODUCTION

Automated analysis of retinal images using software programs makes it possible to perform mass diagnosis (screening) without involving a medical officer. This is very important in terms of time saving and health budget economy and gives a possibility to make the criteria of detection of the most dangerous retinal diseases more objective and to detect retinal diseases at early stages.

The following major task groups can be marked out in the problem of automated processing of retinal images:

1. Preprocessing of retinal images.

2. Segmentation of retinal objects which include blood vessels, macula — the central part of the retina and the optic disc (optic nerve head).

3. Detection and assessment of pathologies.

2. PREPROCESSING OF RETINAL IMAGES

Image preprocessing consists of correction of non-uniform luminosity, color normalization and contrast enhancement. Methods of general image enhancement (sharpening of blurred images, noise suppression, etc.) can be added to this list.

In this work we use a method of luminosity correction that is based on segmentation of background pixels and subsequent computation of luminosity function based only on the background image [1]. The advantage of this approach is that it does not produce ringing effect.

The algorithm consists of two steps:

1. First we segment background pixels based on analysis of statistical values. For each pixel of the image we compute mean value $\mu(x, y)$ and standard deviation $\sigma(x, y)$ within a window of a fixed size, then we compute Mahalanobis distance as follows:

$$D(x, y) = \left| \frac{I(x, y) - \mu(x, y)}{\sigma(x, y) + \sigma_\varepsilon} \right|,$$

where $I(x, y)$ — value of the pixel with coordinates (x, y), $\sigma_\varepsilon > 0$ — small coefficient.

The pixel is classified as the background pixel if $D(x, y) < D_T$. We use $D_T = 0,7$.

2. The second step consists of luminosity correction as

$$I_C(x, y) = 128 \frac{I(x, y)}{\mu_C(x, y) + \mu_\varepsilon},$$

where $\mu_C(x, y)$ is the mean intensity value of background pixels in the neighborhood of the pixel at (x, y), $\mu_\varepsilon > 0$.

Fig. 1 illustrates the proposed method of luminosity correction.

a) original image   b) result
Fig 1: Example of correction of the non-uniform luminosity

3. OBJECT SEGMENTATION IN RETINAL IMAGES

3.1 Vasculature segmentation

There are several general approaches to automated vessel segmentation [2]: matched filtering; ridge detection; vessel tracking that allows connecting disjoint parts of the vessel; pixel-based classification; mathematical morphology.

In the proposed method we apply morphological amoebas to the result of Gabor filtering of the image.

3.1.1 *Gabor filtering*

2-D Gabor filtering is a convolution with a kernel that can be formulated as

$$g(x,y;\lambda,\theta,\psi,\sigma,\gamma) = \exp\left(-\frac{x_\theta^2 + \gamma^2 y_\theta^2}{2\sigma^2}\right)\exp\left(i\left(\frac{2\pi x_\theta}{\lambda} + \psi\right)\right),$$

where
$$\left.\begin{array}{l} x_\theta = x\cos\theta + y\sin\theta \\ y_\theta = -x\sin\theta + y\cos\theta \end{array}\right\}$$
is the rotation operation. In these notations, the parameter λ defines the wavelength of the sinusoidal factor, θ sets the orientation of the filter, ψ is the phase offset, σ is the scale of the filter and γ specifies the ellipticity.

Values of the parameters λ, θ and σ are chosen in order to detect parts of vessels of different directions and widths. We use 6 directions from 0° to 150° with a step of 30° and 4 values for parameter σ: $\frac{1}{4}\sigma_0, \frac{1}{2}\sigma_0, \frac{3}{4}\sigma_0$ and σ_0, where σ_0 is the maximum vessel width. Other parameters are set to: $\lambda = 3\sigma$, $\psi = \pi$, $\gamma = 1$.

The result is the maximum modulus of the filtering over all angles for multiple scales.

Fig. 2 illustrates vessel enhancement by Gabor filtering.
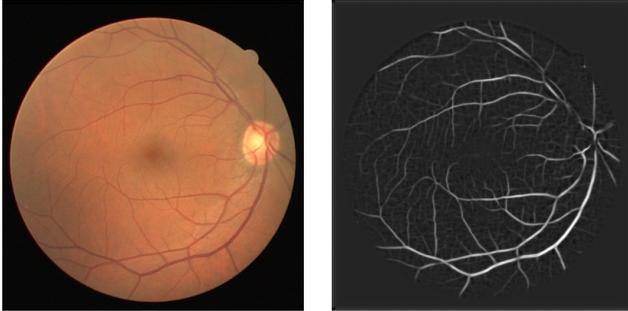
Fig 2: Result of vessel enhancement using Gabor filtering.

3.1.2 Morphological amoebas

The segmentation method is applied to the result of the Gabor filtering. Thresholding does not produce satisfying results, yielding to either a lot of false positive responses or loss of significant amount of smaller vessels. Mathematical morphology allows to enhance thresholding methods.

For segmentation of retinal vasculature we use morphological amoebas, described in [3,4], with modified amoeba distance function. The general idea of morphological amoebas is that the shape of the structuring element is adapted for each pixel of the image.

For each pair of adjacent pixels the distance based on pixels' intensities is computed. We use the following distance function:

$$d((x_0,y_0),(x_1,y_1)) = \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2} + $$
$$+ \lambda\sqrt{(I(x_0,y_0))^2 + (I(x_1,y_1))^2}, \quad \lambda \geq 0.$$

The summand $\lambda\sqrt{(I(x_0,y_0)^2 + I(x_1,y_1)^2}$ makes the distance shorter in dark areas and longer in light areas. It restricts the amoeba expansion only inside the vessel. Parameter λ defines the cost of expansion. The summand $\sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2}$ does not allow the amoeba to grow indefinitely in case of a constant image.

The structuring element for the pixel (x_0,y_0) consists of all pixels with the shortest path to the pixel (x_0,y_0) not exceeding the given threshold.

The examples of amoebas' shapes are given in Fig. 3.
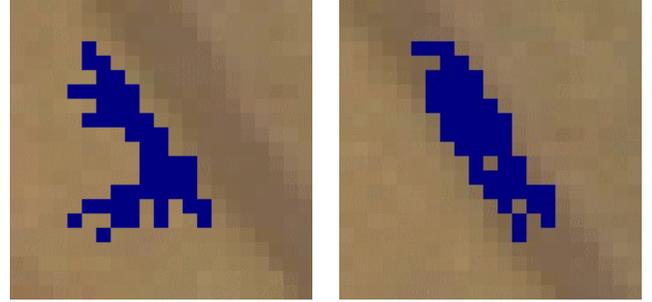
Fig 3: Examples of shapes of morphological amoebas. Pixels that form the structuring element are marked in blue.

The algorithm of segmentation using morphological amoebas consists of the following steps:

1. Via thresholding of the result of Gabor filtering the set M_0 that consists only of vessel pixels is produced.

2. The set of vessel pixels is morphologically dilated using morphological amoebas. The set is then eroded using circular structuring element and is joined to the set from the previous step:

$$M_{n+1} = M_n \cup Erosion(AmoebasDilation(M_n))$$

3. The process terminates when $M_{n+1} = M_n$.

The result of the segmentation using morphological amoebas is shown in Fig. 4.
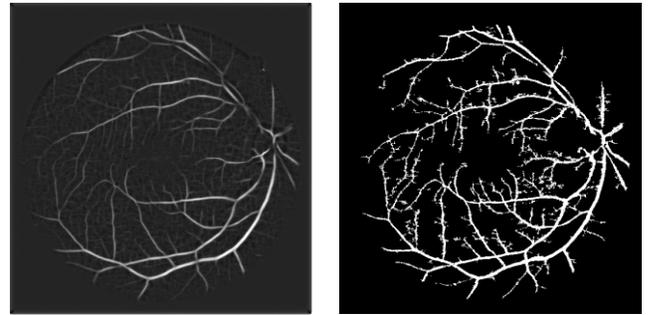
Result of Gabor filtering   Result of segmentation

Рис 4: The result of the vessel segmentation using morphological amoebas.

3.2 Macula and optic disc segmentation

The localization of macula and optic disc can be performed via analysis of the vasculature.

We find these regions in assumption that form of the major vessel arcades is close to circle, the center of this circle is the center of the macula and the circle crosses the optic disc.

Let $\{P_k = (x_k, y_k)\}$, $k = 1,...,K$ be a set of coordinates of major vessel pixels. The resulting circle is the one that minimizes the dispersion of distances from pixels P_k to the circle boundary.

The macula region is taken as a circle with 1/3 of the radius of obtained circle and the same center.

A bright region on the circle boundary is taken as the initial approximation of the center of optic disc that is further used for detection of its boundary.

Example of macula and optic disc localization is shown in Fig. 5.
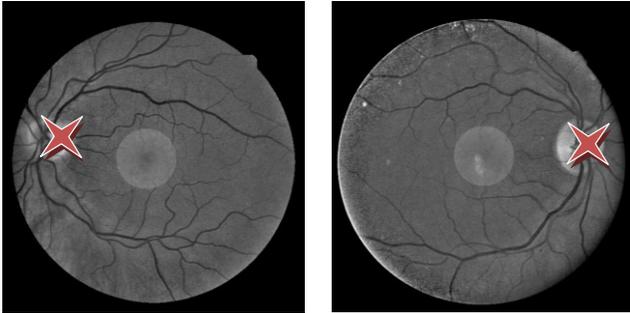
Fig 5: Result of macula and optic disc localization. The macula region is highlighted in the center of the image.

4. DETECTION AND ASSESSMENT OF PATHOLOGIES

4.1 Finding spots in the macula area

Appearing of dark and light spots in the retina can be an indication of the retinopathy.

4.1.1 Light spot detection

We perform the detection of lesions in the macular area.

The green channel of the preprocessed image is used for the light spot analysis. Morphological closing and opening is performed to exclude blood vessels from the image. The size of the structuring element is chosen in accordance to image size. Then we calculate dispersion values in every pixel of the image, apply thresholding and find coordinates of light spot candidates.

Next to distinguish between light spots and outliers we fill every light spot candidate area with the value taken from surrounding background pixels, then subtract this image from the original one and apply the threshold to find light spots.

An example of light spot detection is shown in Fig. 6.
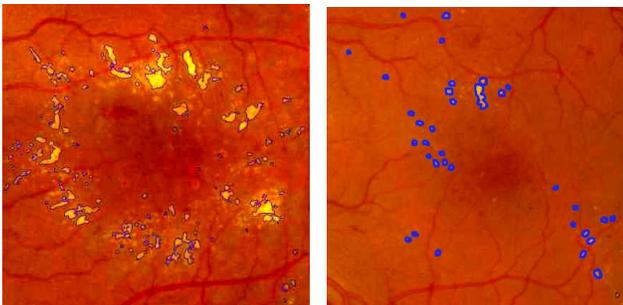
Fid 6: An example of light spot detection in retinal images.

4.1.2 Dark spot detection

Like for the light spot detection, the green channel of the preprocessed image is used for dark spot detection. We perform median filtering, then apply thresholding to find dark spot candidates. Next dark spots are separated from outliers. We calculate proper-

ties of the candidate areas which include compactness, ellipticity, dispersion, average intensity in red and green channels. The first property is used to exclude large blood vessels. The remaining small vessels are segmented from dark spots using the SVM (Support Vector Machines) method.

An example of dark spot detection is shown in Fig. 7.
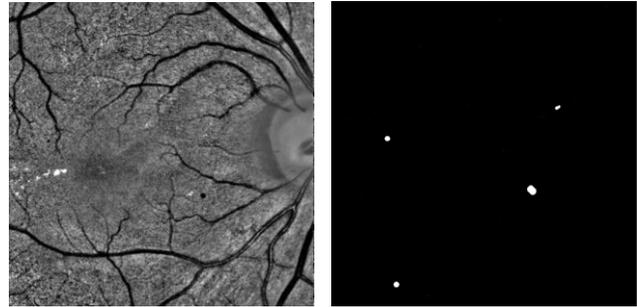
Fig 7: An example of dark spot detection.

4.2 Finding optic disc boundary

The analysis of optic disc boundary is important for glaucoma diagnosis. To find its boundary the method based on active contours was developed [5].

At the preprocessing step the blood vessels are removed from the image using morphological closing and opening in CIE Lab color space. [6]. Next the blood vessel map is constructed from the difference of the obtained image and the source image. Then the edge map is calculated as the modulus of the intensity gradient. Using the Hough transform, the initial contour best approximating the optic disc boundary is taken. The external force field Gradient Vector Flow (GVF) [7] which is used in active contours method is constructed from the boundary map.

Fig 8: An example of morphological preprocessing. Left: the source image; middle: the result of blood vessel removal; right: the blood vessel map.

At the next step, the preliminary result is calculated. This result is usually inaccurate and the deviation of the obtained boundary from the true optic disc boundary is usually observed at intersections of the optic disc boundary with blood vessels.

At the last step, the correction of the obtained boundary is performed. We construct the ellipsis approximating the obtained boundary. Every point of this ellipsis is assigned a weight depending on the edge map and the blood vessel map. The external force attracting the contour to this ellipsis is added. Another force (the pressure force) directed along the external contour normal is added to the points of intersection of the contour with blood vessels.
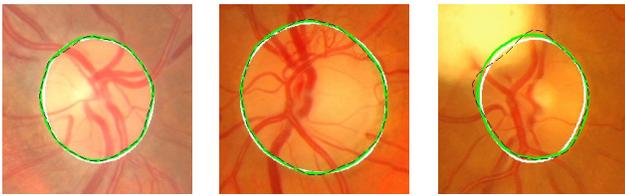
Fig 9: Examples of optic disc detection. True contours are shown by white color. The results of the proposed method are shown by green color. Black dashed lines are the preliminary results (without applying active contours).

The following performance values were obtained on DRIVE and MESSIDOR bases: average overlap – 0.89, sensitivity – 94.1%, specificity – 98.4%. This confirms the effectiveness and the reliability of the proposed method.

5. CONCLUSION

The proposed in the paper algorithms for non-uniform illumination correction, blood vessel detection, macula and optic disc segmentation in retinal images, finding light and dark spots in the macula area compose the basis of the telemedicine system of retinal image analysis developed by the authors group.

The target of the future work is creating the integrated software system based on the optimization and coordination of the work of the proposed algorithms.

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