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Automated Drusen Detection Technique for Age-Related Macular Degeneration

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ABSTRACT

Age-related macular degeneration is one of the leading cause of vision loss and blindness among people of age 50 and higher. Macular degeneration is usually characterized by drusen. Drusens are accumulation of lipids, fatty proteins that appears as abnormal white-yellow deposits on the retina. Detection of these lesions using conventional image analysis methods is quite complicated and time taking mainly due to non-uniform illumination and the variability of the pigmentation of the background tissues. This paper presents an automated technique for segmentation and quantitative analysis of drusen in publicly available retinal images i.e. Structured Analysis of retina (STARE) and Automated Retinal Image Analysis (ARIA), acquired with the aid of a digital fundus camera. The present methodology emphasizes on quantitative analysis of drusen based on: First, region-based statistical analysis which corrects the non-uniform illumination of background, enhances local intensity, minimizes image noise, segment image through Otsu's threshold in addition with morphological operation and hence compute area and edge of the detected drusen. Second, pixel-wise feature extraction which extracts the feature of overlapped components through weighted centroid and standard deviation, makes counting of number of drusen easy. Hence, this system can provide vital information about the quantity of drusen and can aid clinicians in their diagnosis to evaluate the stage of age-related macular degeneration.

Keywords: Age-related macular degeneration, non-uniform illumination correction, image denoising, morphological operation, area based analysis, region based properties, fundus images.

1 Introduction

Age-related macular degeneration (AMD) is a common eye condition, main cause of irreversible blindness in the developed countries and a third main cause of blindness in the whole world [1]. It is characterized by drusen or yellow pigmentation. Drusen is basically accumulation of fatty deposits, lipids and waste material from different layers of the retina. AMD is classified into two types: wet and dry. Dry, or atrophic, macular degeneration are characterized by drusen and wet or exudative macular degeneration are also known as late AMD. About 10 percent of people who have macular degeneration have the wet form which will deteriorate the macula i.e. central vision [2]. Currently, no treatment exists for late AMD. However, early detection and quantitative mapping of retinal abnormalities can provide timely treatment and also the progression of disease may be slow down. Number and area of drusen are used to grade AMD [3]. Manual calculation of drusen is time consuming, labor-intensive, difficult to

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reproduce and may lose important information. Thus there are various methods have been used to detect drusen automatically or semi-automatically based on thresholding [4, 5], feed forward neural network [6, 7], template matching [8], spatial histogram [9], drusen modelling [8] and Hybrid classifier [10, 11]. However, none of these methods have achieved accurate result in counting exact number of drusen. An alternative method based on region based statistical properties has been implemented to improve the identification of exact number of drusen by decomposing the overlapped components through their weighted centroids.

This paper present an automated retinal fundus drusen detection system with an ultimate goal being to automatically assess the risk for development of AMD. First, it plays an important role for reliably localize drusen against the varying lesions present in background. Second, to correct the non-uniform illumination due to uneven surface of retina. Third, it improves image noise, count total no. of drusen, its area and edge. In this paper edge of the drusen is detected by canny edge detector. It is widely used in computer vision to locate sharp intensity changes and to find object boundaries in an image which makes edge of the drusen sharp.

2 Materials and method

Materials

2.1 Retinal fundus imaging:

Two publicly available datasets i.e. STARE and ARIA are used to test the performance of applied drusen detection method. The STARE dataset consists of 36 normal and 47 AMD images acquired with TOPCON fundus camera with 35 degree field of view and a resolution of 700 x 650 pixels. The ARIA dataset consists of 101 normal and 60 AMD images acquired with Carl Zeiss Meditec camera with 50 degree field of view and a resolution of 768 x 576 pixels [16, 17].

Method

2.2 Region based statistical analysis

As illustrated in Figure 2, the integrated image analytics of applied system consists of several image processing procedures. These include retinal fundus image as an input. In order to detect drusen, green channel is selected because it having better contrast than other channels, correction of non-uniform illumination by creating an approximation of the background through morphological opening and then subtract this approximated image from original image, enhancement of image is done by automatic contrast enhancement, segmentation of image is done by Otsu's threshold, noise is removed by morphological operation. A label matrix is created after segmentation to visualize the drusen as a pseudo color indexed image. Decomposition of overlapped components in an image is obtained by calculating the object properties which is based on pixel-wise feature extraction through weighted centroid of mass. Weighted centroid is also used to locate the exact the position of spot that has been blurred over an image region by the image acquisition process. Edge of the drusen is detected by canny edge detector which classifies a pixel as an edge if the gradient magnitude of the pixel is larger than those of pixels at both its sides in the direction of maximum intensity change.

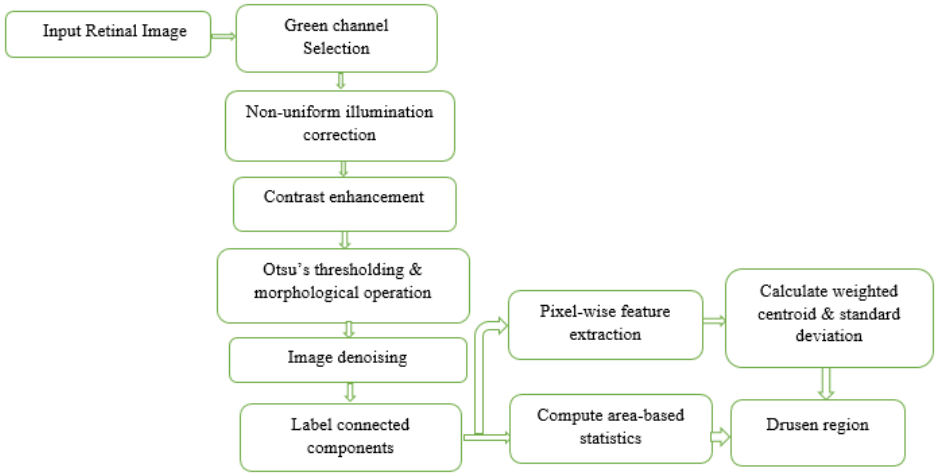

Figure 1: Flow chart of proposed automated drusen detection system

2.2.1 Selection

Green channel is selected from color retinal fundus images because it gives better contrast which helps in extracting brightest region from the background [12].

2.2.2 Non-uniform illumination correction

Retinal images having non-uniform illumination because these are acquired with digital fundus camera, which captures the illumination reflected from the retinal surface. There are also several other factors like curved surface of retina, pupil dilation, cataract & unexpected movement causes severe distortions in the resulting image.

Background of an image having non-uniform illumination hence to make background illumination more uniform, create an approximation of the background as a separate image by removing all the foreground using morphological opening. When this approximate image view as a surface it shows the variation of illumination. Now subtract this approximated image from the original image which will give a uniform image. Morphology is a tool for extracting image components that are useful in representation and description of region shape [13]. The opening operation has the effect of removing objects that cannot completely contain the structuring element, in this erosion is followed by dilation [14].

$$Dilation, (I_m \oplus S_t)(x, y) = \max_{i,j}[I_m(x - i, y - j) + S_t(i, j)] \quad (1)$$

$$\text{Erosion}, (I_m \ominus S_t)(x, y) = \min_{i,j}[I_m(x + i, y + j) - S_t(i, j)] \quad (2)$$

$$Opening, \quad I_i \circ S_t = (I_m \ominus S_t) \oplus S_t \quad (3)$$

Where I_m is image on which we have to do the operation & S_t is the structuring element. I_i is the resultant image after opening operation. (x, y) is the co-ordinate of an image and (i, j) is the coordinate of structuring element.

2.2.3 Contrast Enhancement

Necessity of contrast enhancement arises due to non-ideal acquisition during imaging hence Automatic contrast enhancement is used. It is a technique for mapping an image's intensity value to a new range. In this technique the values in the intensity image $g(x,y)$ is transforms to values in $f(x,y)$ by mapping values between low and high to the values between bottom and top

[1]. The values below low and above high are clipped i.e. values below low map to bottom and those above high map to top.

2.2.4 Drusen detection

To efficiently detect drusen, a combination of mathematical morphology and Otsu's algorithm is used. Binarization of the retinal image is done by using Otsu's algorithm [15], to separate complex regions from the smooth ones. This technique partition the image into two classes $w_0 = \{0,1,2, \dots t\}$ and $w_i = \{t+1, t+2, \dots L-1\}$ at a gray level t, where L represents the total no. of gray levels of the image. Let n_i be the number of pixels at ith gray level, and the total no. of pixels in a given image be n. the probability of occurrence of gray level i is defined as $P_i = n_i/n$. The probabilities of the two classes w_0 and w_i are $q_1(t)$ and $q_2(t)$ are calculated, as shown in Eq. (4)

$$q_1\,(t) = \sum_{i=0}^{t} p_i \ , q_2(t) = \sum_{i=i+1}^{L-1} p_i \tag{4}$$

The mean of the classes are then computed as

$$\mu_j(t) = \sum_{i=0}^{t} iP_i/q_j(t) \tag{5}$$

Let σ_B^2 and σ_T^2be the between-class variance and total variance respectively. An optimal threshold t^* can be obtained by maximizing the between-class variance as given in Eq. (6).

$$t^* = Arg\left\{\begin{matrix} max \\ 0 \le i \le L-1 \end{matrix} (\sigma_B^2/\sigma_T^2)\right\} \tag{6}$$

After applying segmentation the largest connected region is marked as a candidate for drusen. The image obtained after segmentation having objects which can be referenced separately as shown in Eq. (7). Otsu's global thresholding technique has been used to make the proposed system robust and prevents the user intervention during the execution.

$$I_i(r,c) = \begin{cases} 1, & if\ I(r,c) \in object\ labeled\ 'i' \\ 0 & otherwise \end{cases} \tag{7}$$
$$where, r \in [0 \dots Height-1] and\ c \in [0 \dots Width-1]$$

Background noise will be removed through mathematical morphology as given in Eq. (1) and (2). Mathematical morphology also helps to remove the irrelevant vessels from the drusen region. A structuring element is used by selecting the size and shape of the neighborhood. In an image to add the pixels to the boundaries, dilation is used and to remove the pixels from the boundary erosion is used.

The shape and size of the structuring element determines the number of pixels added or removed from the image. After detecting drusen a label matrix is created to display it as a pseudo colour indexed image. Pseudo colour is used to compute total no. of drusen present in an image and then find area of each object through Eq. (8).

$$\text{Area,} \qquad A_i = \sum_{r=0}^{H-1} \sum_{c=0}^{W-1} I_i\,(r, c) \tag{8}$$

The area A_i is measured in pixels and it indicates the relative size of the object.

2.2.5 Pixel-wise feature extraction

In this step object properties is calculated by weighted centroid using pixel value of gray scale image. The (gray value weighted) center of mass is often useful to locate the exact position of a spot that has been 'blurred' over an image region by the image acquisition process. This will also help in decomposition of overlapped objects into individual particle. Hence exact number of drusen can be evaluated by an Eq. (9) and (10).

$$\bar{r_i} = \frac{1}{A_i} \sum_{r=0}^{H-1} \sum_{c=0}^{W-1} r I_i\,(r, c) \tag{9}$$

$$\bar{c_i} = \frac{1}{A_i} \sum_{r=0}^{H-1} \sum_{c=0}^{W-1} c I_i(r, c) \tag{10}$$

The Eq. (9) and (10) corresponds to the row and column where the centre of mass is located. This attribute will help to locate the objects in a bi-dimensional image.

$$f(x, y) = \sqrt{\frac{1}{mn-1} \sum_{(r,c)\in w} [g(r, c) - \frac{1}{mn-1} \sum_{(r,c)\in w} g(r, c)]^2} \tag{11}$$

Eq. (11) is used to calculate standard deviation. It is used for custom calculation based on pixel values of the original grey scale image. The 'pixel values' property returns a vector containing the greyscale values of pixels in a region. Where, $f(x, y)$ is the grey image on which standard deviation is represented. $g(r, c)$ is the binary image on which standard deviation is calculated, mn represents the size of the image.

Conventional edge detector is used to find the edge of the drusen which is basically canny edge detector.

3 Results and Discussion

This algorithm is tested on 36 images, publically available datasets i.e. STARE and ARIA, acquired by the Fundus camera. It is observed from the Figure 2 that the green channel is selected for further processing because it having better contrast than the other channels.

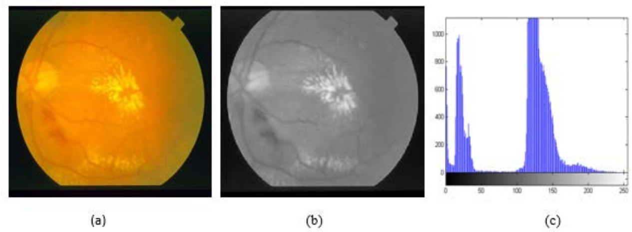

Figure 2: Green channel selection, (a) color retinal fundus image from STARE dataset, (b) green Channel of fundus image, (c) histogram of green channel having better contrast.

Central part of the retina is focused by defining a rectangle at the right or left side of the optical nerve (right or left eye, respectively). Figure 3. Presents example of gray-scale version (green band) of the original color image. Drusen show up as bright blobs, but automatic extraction of these pathological features is difficult, since drusen vary in shape and size and tend to spread (varying brightness) around their location. Additionally, small bright regions of the background tend to create larger than can be mistaken as large drusen hence to remove such type of false negative, an approximation of background as a separate image is considered by using morphological operation. A surface plot of background is shown in Figure 3 to visualize the variation of background. After subtracting this approximated image from the original image a uniform image is obtained which shows the variation in drusen and background.

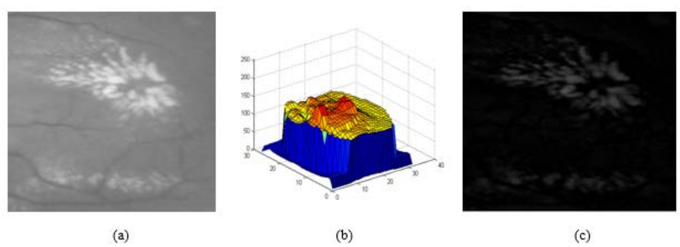

Figure 3: Result of non-uniform illumination and contrast enhancement, (d) test image from Original gray image, (e) surface plot of approximated background, (f) image with uniform illumination after subtracting approximated image from original image

Contrast of an image has been enhanced by using automated contrast enhancement technique which enhanced the local intensity globally. Segmentation of an image is done by Otsu' threshold which ideally locate candidate region of drusen and with the help of morphological operation noise can be removed. There is no vague results found. Pseudo color indexed image is used for visualization of no. of drusen present in retinal fundus images as shown in Figure 4.

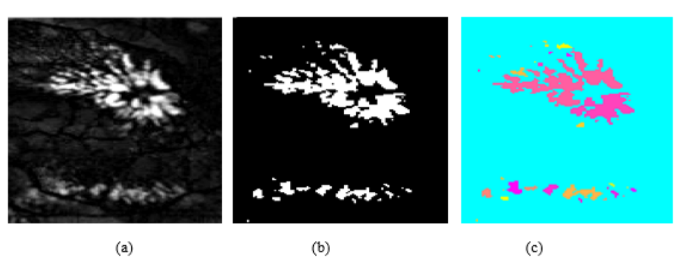

Figure 4: Result of segmentation, (a) enhanced image, (b) binarization of image using Otsu's thresholding (c) Pseudo color indexed image

Pixel-wise feature extraction is done in binarized image to identify the total number of drusen present in image. As drusen varies in its shape and size which may be overlapped on each other. Therefore pixel-wise feature extraction is used because which is based on calculation of weighted centroid and standard deviation of individual pixels. As in Figure 5. Weighted centroid and standard deviation of individual components can be visualize by above mentioned Eq. (10, 11). Graph shows the regional maximum intensity with respect to standard deviation which shows the intensity of individual components.

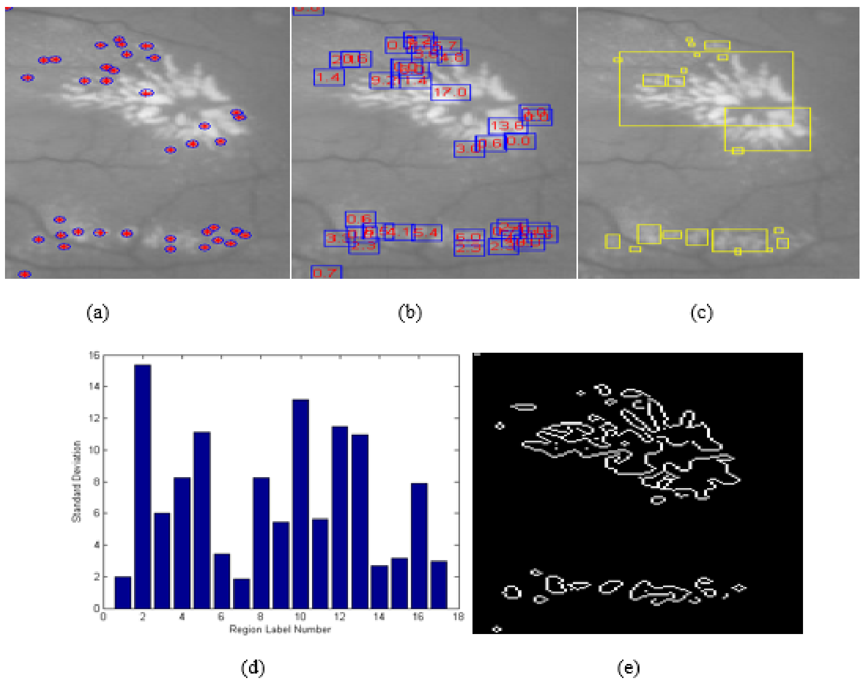

Figure 5: Results of drusen detection, (a) weighted centroid of components, (b) standard deviation of objects in image, (c) components with standard deviation>2, (d) regional label no. w.r.t standard deviation, (e) edge of drusen through conventional edge detector.

Canny edge detector is used to detect the edge of each individual drusen. The canny edge detector is widely used to locate the sharp intensity changes and to find object boundaries in an image. It classifies a pixel as an edge if the gradient of the pixel is larger than those of pixels at both its sides in the direction of maximum intensity change. Area is calculated by an Eq. (8) in pixels. The total area affected by drusen is in pixels. The proposed algorithm has been tested on an image as shown in Figure 5. (e) Which shows the edge of the drusen and its total area in pixels is 1698 pixel.

4 Conclusion

Early detection of drusen may reduce the progression of disease and also provide timely treatment. In this work, an automated detection of drusen using publicly available retinal fundus images is proposed. It analyzes region and custom properties of image by extracting the feature from the pixels of fundus images. This algorithm will help in computing the total area affected by drusen in pixels with its edge. Centre of mass (weighted centroid) with standard deviation is used to separate out different objects which helps in calculating total number of drusen present in image. Use of the proposed detector may reduce false negatives and give reliable results in both area and number of drusen.

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