COMPUTER-AIDED CATARACT DETECTION USING ENHANCED TEXTURE FEATURES ON RETRO-ILLUMINATION LENS IMAGES

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ABSTRACT
Cataract is a leading cause of blindness worldwide. Computer-aided cataract detection is two-fold significant. Firstly, it will be helpful in mass screening. Secondly, it can be used as the preprocessing step for computer-aided grading. In this paper, the enhanced texture feature is proposed based on the graders’ expertise of cataract and the characteristics of the retro-illumination lens images. The statistics of the enhanced texture feature is used to train the linear discriminant analysis to detect the cataract. The accuracy of 84.8% is achieved on a clinical database that contains 4545 pairs of images. It demonstrates that the proposed method is promising for mass screening and as the preprocessing step for computer-aided grading.

Index Terms— computer-aided cataract detection, feature extraction, texture analysis

1. INTRODUCTION
Cataract is a clouding in the lens which is normally transparent. The function of lens is to converge the light to the retina. As the light is blocked by the cataract, the vision is affected. Cataract remains the leading cause of blindness in the world today. In the developing countries, half or more of the blindness is caused by cataract [1]. Most of the cataract is age-related. With the aging of the population, the ratio of cataract will increase. Currently, cataract is identified by doctors or graded by well-trained graders [2], which is expensive and time-consuming. Computer-aided cataract detection and grading will be helpful for mass screening and etiologic research.

There are mainly three types of age-related cataract, nuclear cataract, cortical cataract and posterior subcapsular (PSC) cataract. Nuclear cataract can be identified on slit-lamp images while cortical and PSC cataract can be detected on retro-illumination images [3]. Retro-illumination images are obtained from the light reflected from the retina through the lens [4]. In this paper, we focus on the automatic method to detect cortical and PSC cataract using retro-illumination images.

In the nineties, Nidek has developed a global thresholding method to detect opacity on retro-illumination lens images [5]. The method has an inherent limitations as uneven illumination is common for the retro-illumination images. An improved method using contrast based thresholding is proposed in [6]. Recently, Li et al [7, 8] proposed automatic detection and grading methods for cortical and PSC cataract, respectively. The methods show very promising results on a small database.

In this paper, we focus on the cataract detection in retro-illumination lens images. Based on the observation of the images and the graders’ expertise on cortical and PSC cataract, an enhanced texture feature is proposed and used to classify the cataract images from the non-ccataract images. The linear discriminant analysis (LDA) method can achieve 84.8% accuracy which shows that the method is promising for mass screening. It can be also used as the preprocessing step in an automatic grading system. The database we used contains 1449 cataract image pairs and 3096 non-ccataract image pairs from SiMES study [9].

2. THE PROPOSED METHOD
A normal lens is transparent and the retro-illumination image of a normal lens is homogeneously gray. Cataract is the opacity in the lens and will show as dark region in the retro-illumination images. Generally speaking, cortical cataract starts from the equator of the lens and grows toward to the central part of the lens, it shows spoke-like structures. PSC cataract starts from the central part of the lens and generally appears in a patch. In general, two retro-illumination images are taken for each lens. One focuses on the anterior cortex of the lens and the other one focuses 3 – 5mm more posteriorly and close to posterior capsule. Anterior image is sharper especially for cortical cataract while posterior image is generally blur except for PSC cataract. Examples are shown in
Fig. 1. Examples of retro-illumination images. (a) and (c) are the anterior and posterior images of a normal lens. (b) and (d) are the anterior and posterior images of a lens with cataract.

The darker cross in the clear lens is common due to the system characteristics [10]. Artifacts such as debris on the cornea also can mimic lens opacities. Due to the above uneven illumination and noise, global and local thresholding does not work well. Edge detection may also fail in the blur region. The setting of the threshold of edge detection is still an open problem as we don’t know if there is cataract or not beforehand. Based on the observation of the images and the graders' expertise on cortical and PSC cataracts, it is found that non-cataract regions are homogeneous and the uneven illumination transits smoothly, while cataract regions are rich of texture. Therefore, we apply the texture filter to suppress the non-uniformity and artifacts while highlighting the cataract. Texture can be computed through several existing methods such as local entropy, local standard deviation and co-occurrence matrix etc. In this paper, local entropy is used to compute the texture of the lens image. In information theory, entropy is a measurement of the uncertainty of a random variable, or the information contained in a message. Given a discrete random variable $X$ with possible values $\{x_i, i = 1...n\}$, and probability mass function $p$. The entropy $H$ is defined as follows [11].

$$H(X) = - \sum_{i=1}^{n} p(x_i) \log_b p(x_i).$$

(1)

In an image, the local entropy is a measurement of the roughness in the local context of the image. The local entropy of the $2m + 1$ by $2n + 1$ neighborhood is defined as follows.

$$H(i, j) = - \sum_{u=i-m}^{i+m} \sum_{v=j-n}^{j+n} p(I(u, v)) \log_b p(I(u, v)),$$

(2)

where $I(i, j)$ is the intensity of the pixel $(i, j)$ in the image. $p(I)$ is the probability mass function of the image intensity within the local window.

Fig. 2 shows the texture images of Fig. 1 (a) and (b). The texture image is homogeneous for the clear lens with uneven illumination while it detects the structure of the opacities very well. However, for the dense patch which is common for PSC cataract, the inner of the opacity is homogeneously black and the texture may be even lower than the background. Two examples are shown in Fig 3.

Fig. 3. Two lens images shown in (a) and (b) have dense PSC cataract. The corresponding texture images are shown in (c) and (d), respectively. The texture within the opacity patch is even lower than the background due to the smooth dark intensity inside the opacity patch.

To solve the above problem, we propose an enhanced texture measurement. As the intensity represents how dark the
opacity is, the inverse of the intensity will highlight the dark region. Taking the inverse intensity as the weight of the texture, the darker region will gain more weight in the texture image. The enhanced or weighted texture is computed in the following way.

\[ \tilde{H}(i, j) = H(i, j) \ast w(i, j), \]  

(3)

where \( w \) is the inverse of the intensity. Fig. 4 shows the enhanced texture images corresponding to the lens images shown in Fig. 1 (a) and (b) and Fig. 3 (a) and (b). In the enhanced texture images, the inner side of the PSC opacity is well boosted while the unevenness in clear lens is also increased in the weighted texture images. As the unevenness normally appears in the border of the lens and PSC opacity usually appears in the central part of the lens, we can partition the lens image into two parts, central part and outer part. The central part is the central ellipse subfield and the outer part is the rest of ring region in the lens. From the pathological point of view, the location of the cortical and PSC cataract is different and the severity of the two types is also different. PSC cataract which generally appears in the central part of the lens affect the acuity of the eyesight severely. Any appearance of the PSC opacity will grade the lens into grade 2 or 3 of PSC cataract, while the grade 2 of cortical cataract is defined as the area of cortical opacity is greater than 5%. Furthermore, cortical cataract generally starts from the rim of the lens. When cortical cataract grows into the central region, it implies the severity of the cataract. Therefore, it is reasonable to partition the lens into central part and outer part and treat each region differently. As cortical is clear in anterior images and PSC cataract is clear in the posterior images generally, the texture of the anterior image is computed as the features in the outer part, and the enhanced texture of the posterior images is computed within the central part.

To reduce the dimension of the features, we calculate the mean, standard deviation, skewness and kurtosis as the final features. Finally, the LDA is trained and tested. The diagram of the feature extraction algorithm is shown in Fig. 5 and the detail steps of the methods are summarized as follows.

1. For the anterior and posterior image pair, apply ellipse fitting method to get the ROI of the lens images [7].
2. Compute the texture of the ROI image pair through local entropy filtering.
3. To compensate the window processing of the local entropy filtering, smooth the posterior image with a Gaussian lowpass filter. Then get the inverse intensity of the smoothed image as the weight image.
4. For the posterior image, multiply the texture with the weight of the posterior image to get the enhanced texture measurement.
5. Divide the lens region into central part and outer part.
6. Normalize the texture measurement and the enhanced texture measurement and compute the statistics of these measurement in the central part of the posterior enhanced texture image and the outer part of the anterior texture image, respectively.
7. Train an LDA classifier using the statistics as the input features.
8. Test the performance of the classifier on the rest of the database.

3. RESULTS

In the proposed method, the lens region is obtained by edge detection and ellipse fitting method proposed in [7]. The window size of the local entropy filtering is \( 5 \times 5 \) and the corresponding window size of the Gaussian filter is \( 9 \times 9 \) with the standard deviation 1.5. The radii of the central part are half of the axes of the ellipse. To exclude the iris part and the border effect of the lens, the outer radii is 90% of the axes of the ellipse when calculating the outer region.

The database tested in this paper is a population-based cataract study in Singapore, which contains 1449 cataract pairs and 3096 non-cataract pairs. Each pair includes the anterior image and the posterior image of the same lens. According to Wisconsin protocol [2], both the cortical and PSC cataract have 3 grades. We use \( C_p \) to represent the cortical grade and \( P_p \) to represent PSC grade. Grade 1 means normal. Thus, \( C_1P_1 \) represents the non-cataract lens. The statistics of the database is shown in Table 1.
Table 1. Number of Image Pairs for Each Categories of the Database.

<table>
<thead>
<tr>
<th>Numbers</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>3096</td>
<td>136</td>
<td>91</td>
</tr>
<tr>
<td>C2</td>
<td>663</td>
<td>103</td>
<td>107</td>
</tr>
<tr>
<td>C3</td>
<td>278</td>
<td>37</td>
<td>34</td>
</tr>
</tbody>
</table>

We randomly select 80% of the data in each category to train the LDA and use the remaining 20% of the data to test the trained classifier. The results of the detection are listed in Table 2. The results are the averages of 100 runs of the experiment.

Table 2. Accuracy of the Cataract Detection.

<table>
<thead>
<tr>
<th>Accuracy (%)</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
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</thead>
<tbody>
<tr>
<td>C1</td>
<td>87.8</td>
<td>60.3</td>
<td>87.0</td>
</tr>
<tr>
<td>C2</td>
<td>70.5</td>
<td>92.4</td>
<td>89.9</td>
</tr>
<tr>
<td>C3</td>
<td>90.7</td>
<td>96.7</td>
<td>85.2</td>
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</tbody>
</table>

In the training, the error rate is 16.7%. In the testing, the total sensitivity is 78.5% and the specificity is 87.8%. The accuracy is above 85% for all the categories except C1P2 and C2P1. As C1P2 and C2P1 is less severe than the other cataract categories, the proposed method is useful for mass screening as it is sensitive to the severe cases.

The feature dimension of the proposed method is 8. If we use all the statistics information from the intensity, texture and enhanced texture in the outer and central regions in both the anterior and posterior images, the feature dimension will be 48, which can be used as the baseline for the proposed method. The error for the complete feature set is 13.7% in the training. The specificity is 91.0%, and the sensitivity is 81.4% in the testing. Comparing to the results obtained by the proposed 8 features, only a marginal increase is obtained.

4. DISCUSSIONS

The proposed method achieves good performance for the severe cataract and the non-cataract images. However, it obtains 60.2% sensitivity for the C1P2 category and 70.5% sensitivity for the C2P1 category, which is not satisfactory. It may be due to the following reasons. Firstly, the P2 grade is very strict. Any appearance of PSC opacity will be graded into P2. It is hard to differentiate a starting PSC cataract even for an untrained human with normal eyesight. For the classifier, it is difficult to differentiate the small PSC cataract from the noise. It remains as an open problem. Secondly, the cortical cataract concentrates in the border of the lens, which may be masked out in the proposed method. When graders grade a lens, they don’t fit an ellipse into the lens. The irregular shape of the lens will not affect the final grading. To further improve the performance of the proposed automatic method, a better lens detection method needs to be used to define the lens region accurately, for example, active shape models (ASMs).

5. CONCLUSION

In this paper, we proposed an new method to classify the cataract lens from the non-cataract lens. Based on the graders’ expertise on the cortical and PSC cataracts and the observation of the database, an enhanced texture analysis method is proposed. The statistics of the enhanced texture information is used as the features and an LDA is trained to classify the database. The result shows that the proposed method is useful for mass screening.

6. REFERENCES