AUTOMATIC OPACITY DETECTION IN RETRO-ILLUMINATION IMAGES FOR CORTICAL CATARACT DIAGNOSIS

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ABSTRACT

Computer aided analysis of medical images, a unique type of non-text media, can facilitate clinical diagnosis. As an example, an automatic opacity detection approach is proposed in this paper to grade cortical cataract more objectively. The automatic pupil detection is performed by detecting the strongest edges on the convex hull and ellipse fitting using nonlinear least square method. The cortical opacity is detected by radial edge detection and post-processing. The automatic grades are assigned following Wisconsin cataract grading protocol. The accuracy of pupil detection is 98.2%. The mean error of opacity area detection is 7 percent compared with the result of human grader. And 86.3% accurate grades of cortical cataract are achieved. This is the first time that the spoke-like feature is utilized in the automatic detection of cortical cataract to separate from other opacity types. The encouraging results show that it is probable to apply the proposed approach to clinical diagnosis later.

***Index Terms*—** medical image, opacity detection, cortical cataract.

1. INTRODUCTION

Medical images are a unique and important type of non-text media. It is one essential means to facilitate clinical diagnosis. Currently most of the medical images are analyzed by human graders. There are two main issues for such analysis. One issue is that the grading is usually subjective, which means the inter-grader reliability is low. Time-consuming is another problem that bothers human grader for quantitative measurement. Computer aided analysis of medical images can help in some way to resolve these two challenges. In this paper, automatic detection of opacity for cortical cataract grading is proposed as an example of computer aided diagnosis based on medical images.

Cataracts are the leading cause of blindness worldwide. It was reported that 47.8% of global blindness is caused by cataract [1]. A cataract is due to opacity or darkening of crystalline lens. Cataracts are classified into three types according to the location of opacity: nuclear cataract, cortical cataract, and posterior subcapsular (PSC) cataract. Cortical cataract which occurs in the cortex (or periphery) of the lens is reported to be the most prevalent type (44.7%) of cataract in some studies [2]. Retro-illumination images are taken for grading cortical and sub-capsular cataracts.

There are multiple grading systems established [3-4], which are based on similar principle. A standard set of images with increasing cataract severity are assigned consecutive integer grades. Ophthalmologists compare the picture observed with the standard set to assign a reasonable grade, which is termed as clinical grading or subjective systems. In order to classify the lens opacity more objectively, human graders are trained to classify cataracts based on photographs or digital images [5-6], which is termed as grader's grading or objective system. But studies showed that the reproducibility of intra-grader and inter-grader measurement is still not high [5].

Some efforts have been put in the development of automatic systems to improve grading objectivity. For nuclear cataract classification, automated systems were proposed using slit-lamp images [7-8]. For cortical cataract and PSC, the current methods employed so far are relatively simple. Nidek EAS-1000 software [9] extracts opacities based on the global threshold principle, with the threshold value picked as 12% from the highest point. There is no distinction between opacity types and its pupil detection is manual. The user may manually select the threshold value if automatic detection is not satisfactory. Opacity detection by global thresholding is often inaccurate due to non-uniform illumination of the lens. There is an upgrade of the software by researchers [10]. First improvement is to detect pupil automatically as a circle of 95% of the maximal radius detected. Second improvement is the opacity detection by contrast based thresholding. This contrast based approach has its limitation too when opacities are so dense that the contrast in the opacified areas is no longer high. Still there is little effort made in the separation of the opacity types.

An automatic opacity detection approach is proposed in this paper for the purpose of objective grading of cortical cataract. The workload of graders can be saved as well in the aspect of opacity measurement, which is quite time-consuming.

2. METHODOLOGY

To develop an automatic cortical cataract grading system, the region of interest (ROI) needs to be identified first. The cortical opacity will be determined only within the ROI. Cortical cataract is graded based on the measurement of cortical opacity.

2.1. Pupil detection (ROI detection)

The pupil detection (refer to Fig. 1), which is the ROI detection, looks obvious at first sight. After observation of more images and trying straightforward methods, experimental results show that simple thresholding or edge detection and circle fitting cannot work well for a large amount of retro-illumination images. We conclude that the followings are the challenges for automated pupil detection:

a. Severe opacity, which will affect both edge detection and thresholding approaches;

b. Heavy reflective noises outside the pupil. It is difficult to differentiate those noises from the real pupil;

c. Oblong lens rather than circular shape, which is surprisingly very common in retro-illumination images.

After trying different techniques, we propose an automatic pupil detection algorithm based on convex edge detection and non-linear least square ellipse fitting. The original image is processed by morphological transformation of repeat open and close functions first. Canny edge detection is applied on both original and morphologically closed image to detect the strongest edges. The edges detected on both images are selected to rule out external reflective noise. The edges detected within the lens are filtered out by extracting only the edge on the convex hull, which solves the problem of opacity edge due to severe cataract. Using these edge pixels, non-linear least square fitting by the Gauss-Newton method is applied to extract the parameters of the best fitted ellipse. This is an iterative approach to determine the four parameters (r, a, b, k) that best fit the sets of edge pixels (x_i, y_i) to the elliptical equation:

$$y = b \pm k\sqrt{r^2 - (x-a)^2} \tag{1}$$

Thus the pupil is automatically detected by an estimated ellipse.

2.2. Cortical opacity detection

After proposing an algorithm to extract ROI from retro-illumination images, our next objective is to detect cortical opacity. In order to obtain robust detection, several issues need to be resolved: non-uniform illumination, heavy opacity, and presence of non-cortical opacities especially PSC. An algorithm based on radial edge detection is proposed here to detect cortical opacity.

It is observed that the main difference between cortical cataracts and the remaining cataract types would be its spoke-like nature (refer to Fig.1). Hence a logical and quantitative way to measure cortical severity would be the roughness of the lens in the angular direction. So we propose to transform the retro-illumination images to the polar coordinate in order to ease the information extraction in the angular direction. The transformation is illustrated in Fig.2. This is the first time that the feature of spike shape is utilized in the cortical cataract detection, which makes it possible to separate cortical opacities from subcapsular opacities.

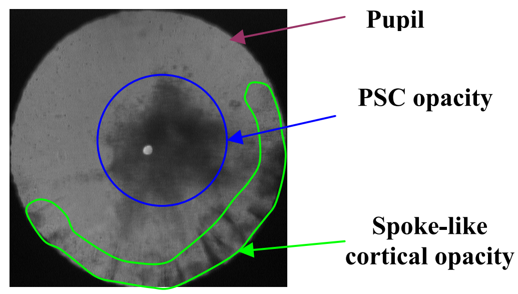
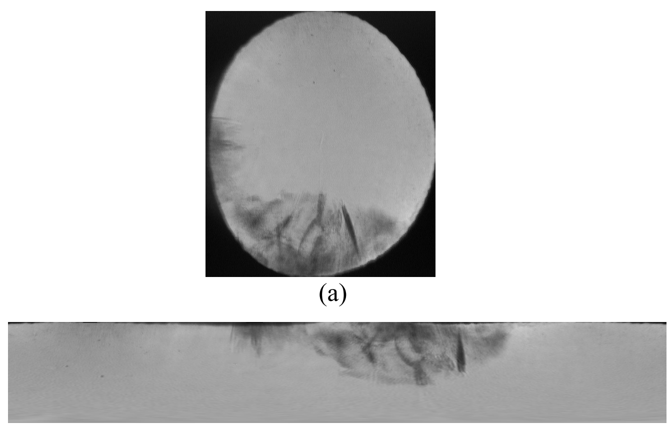


Fig.1 An example of retro-illumination image with different types of opacities



(a)

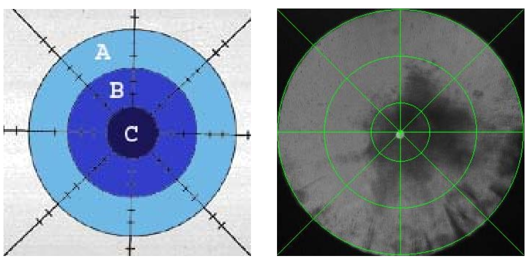
(b)

Fig.2 Transformation of retro-illumination image to polar coordinate. (a) Original retro-illumination image; (b) Polar plot of image (a).

Vertical Sobel edge detection is applied to the polar image to detect the edges in the radius direction. The ideal result would contain all cortical edges and some strong PSC edges. The horizontal Sobel edge detection is further employed to remove the angular edges attributed by the PSC opacity. Cortical opacity regions are obtained by radial closing in the polar plot followed by hole-filling after the image is converted back to Cartesian coordinates. The detected opacity is further measured as described in below section 2.3.

2.3. Grading of cortical cataract

Based on the cortical opacity detected, our automated grading of cortical cataract follows widely accepted Wisconsin cataract grading protocol [5]. A measuring grid is used which divides a lens image into 17 sections as seen on Fig 3(a). The grid is formed by three concentric circles: a central circle with radius 2mm, an inner circle with radius 5mm, and an outer circle with radius of 8mm. Equally spaced radial lines at 10:30, 12:00, 1:30, 3:00, 4:30, 6:00, 7:30, and 9:00 divides the zones between the central and inner circles and between the inner and the outer circles into eight subfields each.



(a) (b)

Fig.3. Measuring grid overlaid over a retro-illumination image. (a) Measuring grids; (b) grids on a lens image.

The percentage area of the detected cortical opacity in each area (Area A, B, and C in Fig. 3(a)) is calculated. The total percentage area of cortical opacity is calculated according to the following equation [5]:

Total area% = area% in A*0.0762 + area% in B *0.0410 + area% in C *0.0625 (2)

The automated grading of cortical cataract is according to the total area calculated based on equation (2). Greater grades indicate severe cortical cataract.

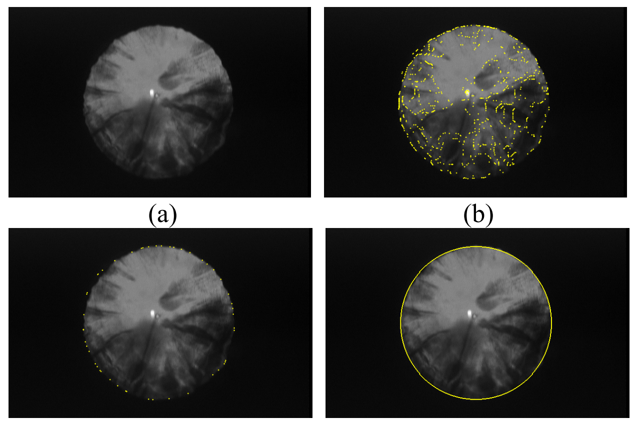
Table 1 Cortical cataract grading protocol

Grades of Cortical Cataract	Description
1	Total Area < 5%
2	Total Area 5 – 25%
3	Total Area > 25%

3. RESULTS AND DISCUSSION

The proposed automatic opacity detection approach is tested using retro-illumination images obtained from a population-based study: The Singapore Malay Eye Study (SiMES). A Scheimpflug retroillumination camera, Nidek EAS-1000, were used to photograph the lens through the dilated pupil. The retro-illumination images were captured in gray image and were exported from EAS-1000 software. They are saved in the format of bitmap with the size of 640 * 400 pixels.

Our automatic pupil detection algorithm was tested using 607 images. Fig.4 illustrates the processing steps. It can be noted that convex hull method can remove most of the edges due to opacity and the final ellipse fitting is satisfactory. Another example of pupil detection is shown in Fig. 5. We can see that the pupil detection algorithm is quite robust even in the case of reflective noises. 607 images were tested and evaluated visually. The success rate is 98.2%. The only 11 images with inaccurate detected ROI are all due to the heavy presence of reflective noise.



(a) (b)

(c) (d)

Fig.4 Example of automatic pupil detection. (a) Original image; (b) Edges detected; (c) Edges on the convex hull; (d) Ellipse fitting result.

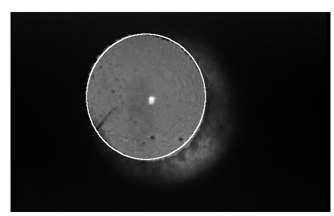


Fig.5 Well detected ROI despite reflective noise and elongated shape.

To test the robustness of our cortical opacity detection, 102 images with grader's grading result were selected, which has an even distribution within each grade of severity. Two examples are illustrated in Fig 6. Only the area cropped around ROI is shown in the figure. The example in Fig. 6(a)-(b) shows that the radial edge approach is capable of capturing small cortical cataracts. The feature of spoke is considered in the radial edge detection, which makes the algorithm not sensitive to other opacity type, PSC in particular. Fig. 6 (c) – (d) is such an example.

The total area of detected cortical opacity is calculated according to section 2.3. Comparison is performed with the total area graded by the human grader according to the same protocol. Fig. 7 indicates the comparison results. The mean error is 7 percent. The linear regression is performed and the fitting coefficients are 0.78035 and 0.070712 respectively.

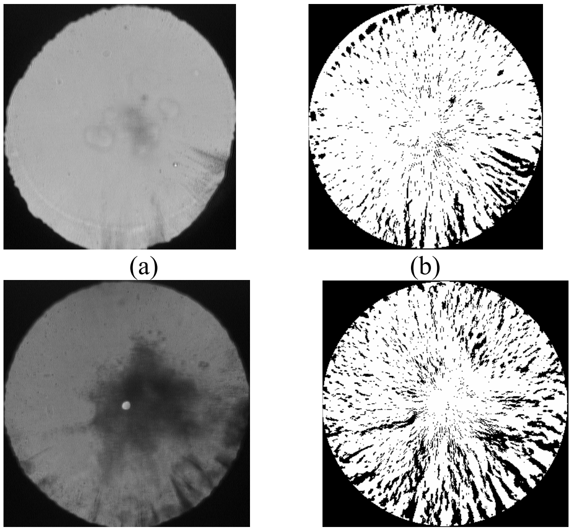


Fig. 6 Examples of cortical opacity detection by radial edge detection. (a) Original image with minor cortical cataracts; (b) Detection result of (a); (c) Original image with PSC; (d) Detection result of (c).

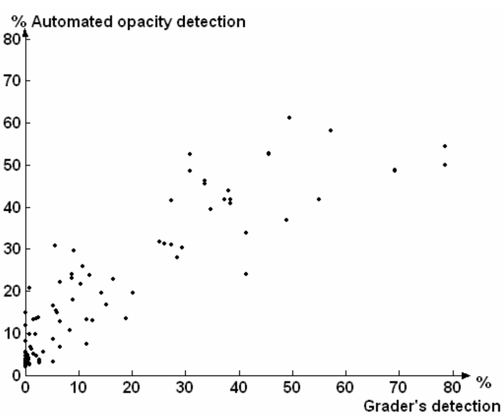


Fig.7 Comparison of automatic cortical opacity area detection with that of human grader.

Table 2 Comparison with the grader's grades

Graders grades	**Automated Grades**		
	1	**2**	**3**
1	44	6	0
2	5	18	2
3	0	1	26

The automated detected area was fitted and grades of cortical cataracts are assigned according to Table 1. Comparison between the automated grades of cortical cataract with that of human grader was also carried out. The results are shown in Table 2. The un-weighted Kappa is 0.78, and 95% CI is (0.68, 0.89). The success rate is 86.3%, which we think is promising for automatic grading.

4. CONCLUSION

An approach to detect cortical opacity automatically in retro-illumination images is investigated. To detect the region of interest, the strongest edges on convex hull are detected and further fitted by an ellipse. The image is transformed to polar coordinates and vertical edge detection is performed to detect cortical edge and rule out the edges attributed to PSC. This is the first time that the spoke-like feature is employed in the automatic cortical cataract detection to separate from PSC. The proposed approach was tested by images from a population study and the results are promising for future clinical diagnosis.

5. ACKNOWLEDGEMENT

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