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Image Based Diagnosis of Cortical Cataract

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Abstract—**An automatic approach to detect cortical opacities and grade the severity of cortical cataract from retro-illumination images is proposed. The spoke-like feature of cortical opacity is employed to separate from other opacity type. The proposed algorithms were tested by images from a community study. The success rate of region of interest (ROI) detection is 98.2% for 611 images. For 466 images tested, the mean error of opacity area detection is 3.15% compared with human grader and 85.6% of exact cortical cataract grading is obtained. The experimental results show that the proposed approach is promising in clinical diagnosis.**

I. Introduction

POPULATION aging is a global trend. Associated with aging, age-related cataract remains to be the leading cause of blindness in all region of the world except for the most developed countries [1]. For example, 35% of cataract prevalence was reported in Chinese people over 40 years old in Singapore [2]. Similar estimates were obtained from the Beaver Dam Eye Study in Wisconsin [3]. A cataract is clouding or opacity of the eye's natural clear lens, which usually results in a loss of clarity or blurring in vision. Cataracts can form in any of the three layers of the lens and are described based on its location in the lens: nuclear cataract, cortical cataract and posterior capsular cataract (PSC). The image based diagnosis of cortical cataract will be investigated in this paper.

Nuclear cataract is diagnosed by slit-lamp imaging, while cortical cataract and PSC are examined by retro-illumination images. One example of retro-illumination image is illustrated in Fig. 1. In clinical grading of cortical cataract, frontal view of the patient's eye is observed via retro-illumination to be compared with a set of standards, and a grade is assigned accordingly. There are several grading systems available such as LOCS III system [4] and the Oxford System [5]. An example of a standard used in the LOCS III system [4] is shown in Fig. 2. These clinical grading systems are quite subjective and inconsistent. To improve the grading objectivity, cortical cataract is graded based on the area of opacity coverage on the lens by trained graders according to Wisconsin protocol [6]. Study showed that the estimation of opacity area is not identical between graders and not from time to time for the same grader. The within-grader agreement and between-grader agreement are both between 73.5% and 82.45 [6]. It is also time-consuming for this grader's grading. The average grading time for a retro-illumination image by a well-trained grader varies from 5 to 10 minutes depending on the severity of the opacity.

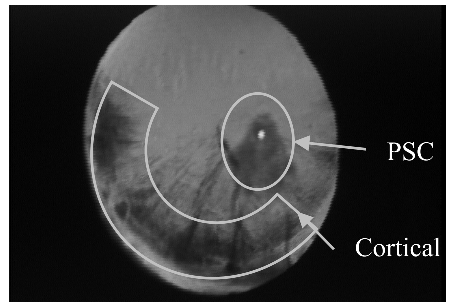

Fig. 1. Retro-illumination with presence of cortical opacity and PSC

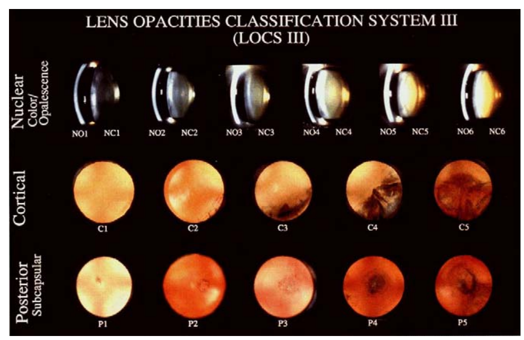

Fig. 2 The LOCS III grading system [4]

There have been attempts towards computerized cataract detection recently. However there is no fully automatic grading system that targets only cortical opacity yet. There are mainly two previous works on computer aided retro-illumination image analysis: Nidek EAS-1000 [7] available in the market and its upgrade [8] currently in research stage. In many retro-illumination images, both cortical opacity and PSC are presented. The work in [7] and [8] extracts all types of opacity together and the processing is not fully automatic. Hence there is need to investigate automatic detection of cortical opacity to make the grading procedure more objective and specific to cortical opacity.

An automatic algorithm is developed in this paper to detect cortical opacities from retro-illumination images, and to grade the severity of cortical cataract objectively. The comparison with the prior-arts is described in table 1.

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Table 1. Comparison with prior-arts

	Technology	Limitation	Separate opacity type	Automatic pupil detection
Nidek EAS-1000 [7]	Global threshold	Fail for non-uniform illumination	×	×
Nidek upgrade [8]	Contrast threshold	Fail for large opacity	×	Not robust
Proposed method	Radial-edge & region growing		✓	✓

II. METHODOLOGY

A. ROI detection (pupil detection)

The first step of the automatic processing is to extract the region of interest (ROI) in the input image. In our application, it is the detection of pupil. The combination of canny edge detection, Laplacian approach and convex hull approach is applied to detect the edge pixels. The detected pixels are further fitted to an ellipse by non-linear least square fitting.

The procedure can be illustrated in Fig. 3. Canny edge detection and Laplacian filter are applied to the original image respectively. The edge pixels detected by both of the methods are selected to remove the external reflective noise. The edge pixels on the convex hull are further chosen to eliminate the edge pixels due to severely opacities. The pupil is estimated as an ellipse by fitting the chosen edge pixels using non-linear least square fitting.

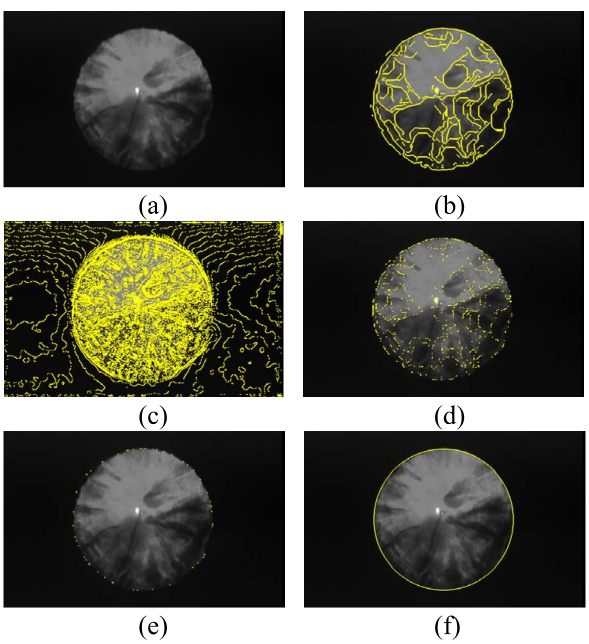


Fig. 3 Processing steps of ROI detection. (a) Original image; (b) Canny edge detection; (c) Laplacian edge detection; (d) Edge detected by both Canny and Laplacian; (e) Convex hull pixels; (f) Non-linear least square ellipse fitting.

B. Cortical opacity detection by radial edge and region growing

Observing the retro-illumination images (refer to Fig. 1), it can be seen that the characteristic of cortical opacity would be its spoke-like nature and its general spatial location at the rim of the lens. PSC is characterized by its smoother texture, more circular shape and central location. In order to detect cortical opacity specifically, the spoke feature is employed to separate from other opacities such as PSC.

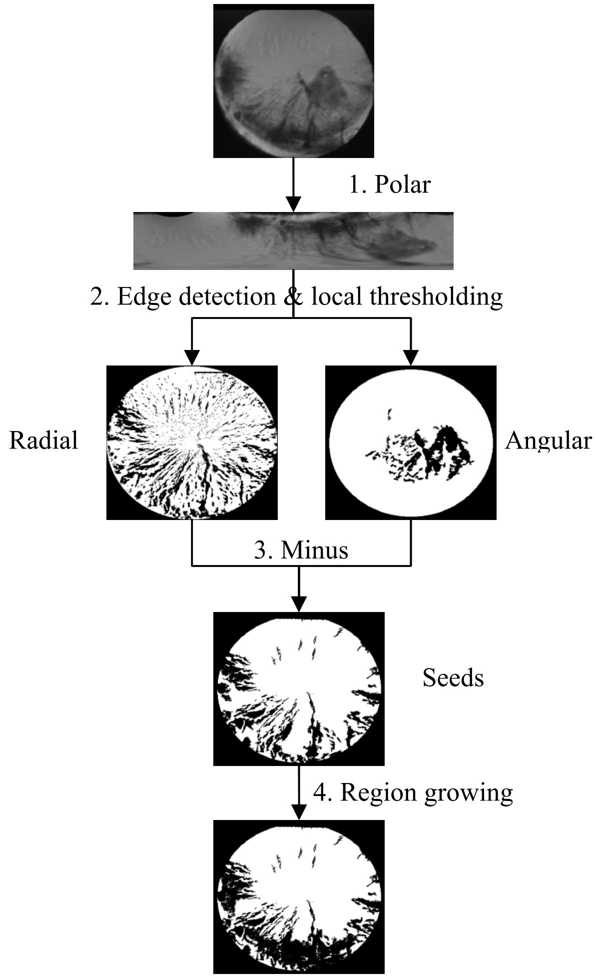


Fig. 4 Procedure of cortical opacity detection

The diagram of cortical opacity detection algorithm is shown in Fig. 4. First, an input image is converted to polar coordinates to ease the process to extract cortical opacity in the radial direction and rejecting PSC opacity in the angular direction. Next, local thresholding and edge detection are applied in both radial and angular direction to detect opacity centers and opacity edges respectively. Vertical and horizontal windowing elements are applied to the polar plot in local thresholding to obtain the radial and angular opacity center correspondingly. Vertical and horizontal Sobel edge detection is employed to detect opacity edges in radial and angular directions correspondingly. The detection results of local thresholding and edge detection in each direction are merged. Ideally the opacity in the radial direction should correspond to cortical opacity, while the opacity in angular direction would correspond to PSC. The detection results in both directions are reverted to Cartesian plot thereafter. Thirdly, angular opacity is subtracted from radial opacity to retain only the cortical opacities as cortical seeds. The last step is to region grow cortical opacity with previously obtained seeds. Spatial and size-filters are further applied to remove noises.

Once the cortical opacity is extracted, the percentage area of cortical coverage on the lens can be computed and the cortical cataract can be graded automatically according to the protocol.

III. RESULTS AND DISCUSSION

A. Data description

611 retro-illumination images from a community study, the Singapore Malay Eye Study (SiMES), were used to test the proposed automatic grading algorithm. They have been taken via Nidek EAS-1000 [7] to obtain gray-scale images of 640x480 pixels.

For each image, a grade for cortical severity was obtained from a trained grader according to the Wisconsin protocol [6], which is based on an estimation of the total percentage area of cortical coverage on the lens. A measuring grid is used to divide a lens image into 17 sections as seen in Fig. 5. The percentage coverage of cortical opacity is estimated by human grader manually in each sub-section. The total cortical opacity percentage is then calculated according to equation (1).

$$\text{Total \% area} = \text{\%Area in A} \times 0.0762 + \text{\%Area in B} \times 0.0410 + \text{\%Area in C} \times 0.0625 \quad (1)$$

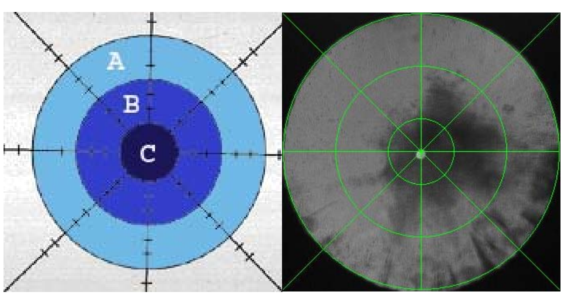


Fig.5 Wisconsin grading protocol

A final grade for each lens image is given according to table 2.

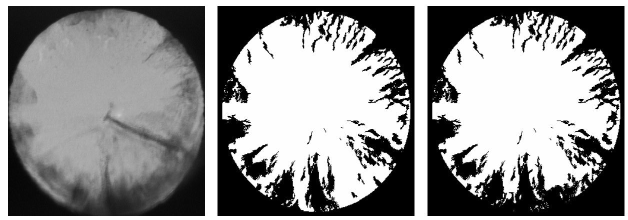
Table 2: Wisconsin grade

Wisconsin cortical Grade	Total % area coverage
1	0 – 5%
2	5 – 25%
3	25 – 100%

B. Automatic detection and grading result

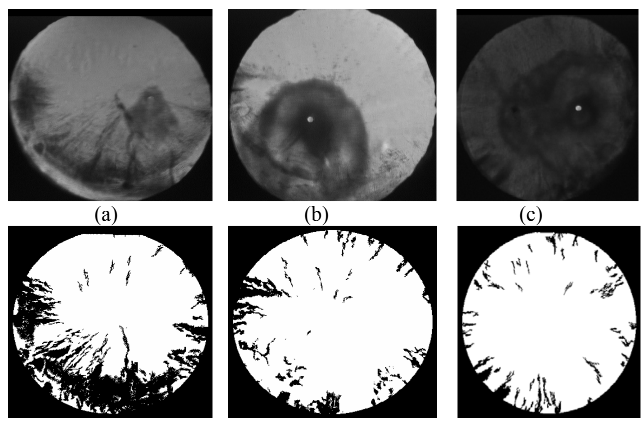
The automatic ROI detection algorithm was tested first. The estimated ellipse of pupil was evaluated visually. Success rate of 98.2% in the 611 images was achieved. Only 11 images have less optimally-detected ROI, and they are all due to the heavy presence of reflective noise.

For cortical opacity detection, one example is illustrated in Fig. 6. Some more examples are shown in Fig. 7. From the experimental results, it is noted that the proposed algorithm can detect most cortical opacity well. It is robust to extensive cortical opacities (Fig. 7(d)) and robust to most PSC (Fig.7(e) and 7(f)) and poor contrast (Fig. 7(f)).



(a) (b) (c)

Fig. 6 Cortical opacity detection result by region growing. (a) Original image, (b) Detected cortical seeds, (c) Cortical opacity detection by region growing.



(a) (b) (c)
(d) (e) (f)

Fig. 7 More examples of cortical opacity detection results. (a)-(c): Original images, (d)-(f) Cortical opacity detection result of (a)-(c).

Observing 611 images, it was found that except for PSC, a wide range of noise and other unknown variation affects a large portion of the images, which includes non-cortical spokes, artificial implants, obscured lenses and etc. as shown in Fig 8. Thus 466 images without variations were selected for this preliminary study. In the visual evaluation of cortical cataract detection, the obtained binary image of cortical opacity is compared with the corresponding original image to observe the agreement of cortical opacity detection. Experimental results show that the automatic cortical opacity detection in 94.4% of the images is successful by visual evaluation.

In order to evaluate the cortical opacity detection quantitatively, the automatic detection is compared with the grading results by trained human grader. The comparison of automatic cortical opacity percentage with that obtained by human grader is illustrated in Fig. 9. The mean absolute error is 3.15%. The automatic grades are assigned according to Wisconsin protocol similarly as the human grader. The comparison of the automatic grades and manual grades is described in Table 3. The exact agreement with the human grader is 85.6% for the 466 lens images tested. The results are very promising to provide objective grading of cortical cataract in clinical diagnosis.

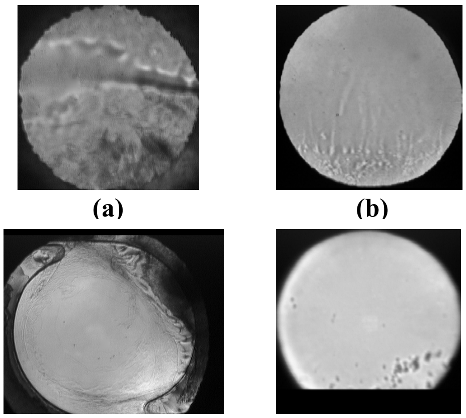


Fig. 8 Original images with various noises. (a) Unknown variation, (b) Non-cortical spokes, (c) Artificial implants, (d) Obscured lens.

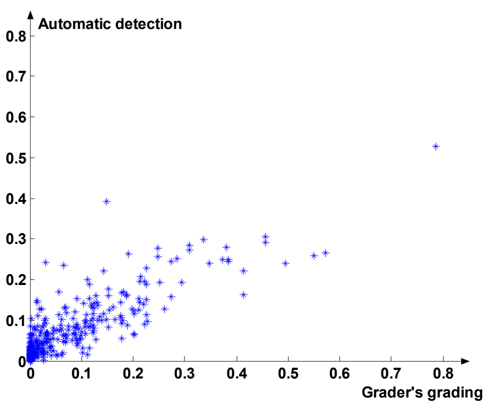


Fig.9 Comparison of automatic cortical opacity percentage with that of human grader.

Table 3: Automatic grading result

Automatic Grading (466 images)			
Manual	Automatic grading		
	1	2	3
1	277	38	0
2	15	109	4
3	0	10	13

For the images with variations, further investigation is necessary to distinguish cortical opacity from various types of unknown variations, especially those with spoke-like noise. This will make the system more robust to noises.

C. *Processing speed*

The automatic grading approach takes an average of 6 seconds to process each image, which is in contrast to 5~10 minutes on average for manual Wisconsin grading.

IV. Conclusion

An automatic approach is proposed in this paper to detect cortical opacities and grader cortical cataract from retro-illumination images. The novelty lies in utilizing spoke-like features to separate cortical opacity from other opacity types, especially PSC. The proposed approach is tested using images from a community study. The experimental results show that the success rate for automatic ROI detection is 98.2%. Compared with human grader, 85.6% of exact agreement is achieved for the 466 testing images. The preliminary results indicate that it is possible to provide objective grading to clinical diagnosis using the approach. Further investigation should be performed to make the detection more robust.

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