Computerized Systems for Cataract Grading

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Abstract— Cataract is the leading cause of blindness worldwide. Two automatic grading systems are presented in this paper for nuclear cataract and cortical cataract diagnosis respectively. Model-based approach was applied to detect anatomical structure in slit-lamp images. Features were extracted based on the lens structure and severity of nuclear cataract was predicted using Support Vector Machines (SVM) regression. For cortical cataract, the opacity was detected using region growing. The seeds were selected by local thresholding and edge detection in radial direction. Cortical cataract was graded based on the area of cortical opacity. Both of the systems were tested by clinical data and results show that the automatic systems can provide objective grading of cataracts.

Keywords—automatic diagnosis, nuclear cataract, cortical cataract

I. INTRODUCTION

Cataract, cloud or opacity of the human lens, causes half of the blindness worldwide [1]. Most of the cataracts are related to aging. For example, a population-based study reported a cataract prevalence of 35% in Chinese Singaporean over 40 years old. Cataract was shown in 7% of people in their forties, and 37.5%, 80.4%, 93.3% of people in their fifties, sixties and seventies respectively [2-3]. According to the location of opacity in lens structure, age-related cataract can be classified into three types: nuclear cataract, cortical cataract, and posterior sub-capsular cataract (refer to Fig.1).

Accurate diagnosis via grading cataract according to its severity is important. Clinically, cataract is graded by comparison with standard photographs of different grades. Examples are the Lens Opacities Classification System III [5] and the Oxford Clinical Cataract Classification and Grading System (OCCCGS) [6]. The grading rules of these systems are similar.

With the advance of image processing and machine learning techniques, computer aided diagnosis can facilitate clinical diagnosis and study in several ways. Compared with manual grading, it has the advantage of objectivity and reproducibility. Automatic grading systems were investigated in [7] for nuclear cataract and in [8-9] for cortical cataract grading. Most of the systems are still in research stage and are lack of validation with a large amount of clinical data.

In this paper, two automatic grading systems for nuclear cataract and cortical cataract are investigated. New algorithms to detect opacity in the lens images are proposed.

II. AUTOMATIC GRADING SYSTEM FOR NUCLEAR CATARACT

A. Data Description

Slit-lamp camera is widely used for grading opacity of nuclear cataract. By changing the width of the beam, detail about each eye structure can be captured. A digital slit-lamp camera (Topcon model DC-1 with FD-21 flash attachment) was used to photograph lens through the dilated pupil. The slit beam was adjusted to completely fill the pupil and focus was placed on the sulcus of the lens. The images were saved as 1536 *2048 color images.

The testing images were obtained from a population-based study, The Singapore Malay eye study (SiMES) [10]. The study sampled all Malays aged 40-79 living in the designed study area in Singapore.

Clinical grading of nuclear cataract followed the Wisconsin cataract grading system [11], which is considered ground truth here. The range of the grades is from 0.1 to 5, in which the grade less than or equal to 3 is defined as normal case.

B. Methodology

The computer-aided diagnosis system mainly includes two parts: feature extraction and grade prediction. In both steps, model-based approach is chosen to apply domain knowledge. The diagram of the system is shown in Fig.2 [12].

The lens is located using thresholding and horizontal and vertical profile clustering for ellipse estimation first. Active shape model is further applied to extract the contour of lens. The shape of the lens is denoted by twenty-four landmark points as shown in Fig 2. Here ten images were used as the
training set and the landmark points in the training set were labeled manually. A statistical description of the shape and its variations was obtained using principal component analysis (PCA) on the training shapes. The learnt shape model is able to deform in a way that reflects the variations in the training set. Active Shape Model (ASM) method is an iterative searching procedure to fit the shape model in a new image to find the contour of lens.

Figure 2. Diagram of nuclear cataract grading system.

Based on the landmark detected using ASM method, features were extracted following previously published clinical work [5, 11]. Six-dimensional feature was selected: mean intensity inside lens, color on posterior reflex (HSV color space), mean intensity of sulcus, and intensity ratio between anterior lentil to posterior lentil. The last two features were obtained via visual axis profile analysis, which is the intensity distribution on a horizontal line through central posterior reflex.

Support Vector Machines (SVM) regression was employed to train a grading model and predict the grade for a testing image. One hundred images were selected as the training set. Twenty images from each grading group (0-1, 1-2, 2-3, 3-4, 4-5) were selected as the training set.

C. GUI of the System

The user interface is illustrated in Fig.3. The main menu includes: Load Image, Feature Extraction and Predict Grade. By using these three menus step by step, a slit-lamp image can be loaded and its automatic grading result can be displayed. The interface is convenient for clinicians to use and the whole processing is fully automatically.

D. Experimental Results

Two thousand slit-lamp images from SiMES study [10] were tested. The automatic grading results were compared with the clinical grading ground truth as shown in Fig. 4. The errors were further analyzed statistically and Fig. 5 shows the histogram of the errors. The mean grading error is 0.37. The grading error is less than one grade for 96% of the testing images and 72% of automatic grading error is less than half grade, which shows the system is promising for clinical usage.
III. AUTOMATIC GRADING SYSTEM FOR CORTICAL CATARACT

A. Data Description

A Scheimpflug retro-illumination camera (Nidek EAS-1000) was used to photograph lens through dilated pupil. A first image is taken when the iris margin is in sharp focus for grading cortical cataract. The camera is advanced 2.9~3.4 mm to image posterior sub-capsular opacities [10]. In this paper, only the first image is used for cortical cataract grading. 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.

B. Methodology

An automatic system to detect cortical opacities and grade the severity of cortical cataract from retro-illumination images is proposed. The diagram of the system is illustrated in Fig 6 [13].

Canny edge detection and Laplacian edge detection were employed to detect the region of interest (ROI). The edges detected on the convex hull by both detectors were selected and fitted to an ellipse for ROI detection.

To detect the cortical opacities in ROI, spoke-like features were utilized to distinguish cortical opacities from the posterior sub-capsular opacities. An original image is converted to polar coordinate first. Local thresholding and edge detection were applied in both radial and angular directions. Angular opacities were subtracted from radial opacities to retain only the cortical opacities as cortical seeds. Region growing was then applied to detect the cortical opacities. Spatial and size filters were used to remove noises as a post-processing step.

The total area of cortical opacities is calculated and a grade is assigned according to the rule in Table 1 [11]. Grade 1 is considered as normal case and Grade 2 and 3 are significant cortical cataracts.

Table 1: Cortical cataract grading rule

<table>
<thead>
<tr>
<th>Cortical Grade</th>
<th>Total Opacities (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 – 5%</td>
</tr>
<tr>
<td>2</td>
<td>5 – 25%</td>
</tr>
<tr>
<td>3</td>
<td>25 – 100%</td>
</tr>
</tbody>
</table>

C. GUI of the System

The user interface is illustrated in Fig 7. Cortical cataract can be automatically graded using the system. The main menu includes: Load Image, ROI Detection, Opacity Detection, and Predict Grade.

D. Experimental Results

Three hundred retro-illumination images from the SiMES study [10] were tested by our system, among which 149 images are with grade 1, 128 images with grade 2 and 23 images with grade 3. The total opacity percentage obtained by the system is compared with the clinical ground truth and the mean absolute error is 3.5%. The histogram of the errors is shown in Fig. 8. The error is less than 5% for 81% of the testing images. For the automatic grades, the exact agreement with clinical grades is 89.3% as shown in Table 2. Compared with clinical grading, in which within-grader agreement and between-grader agreement are both between 73.5% and 82.45 [11], our system can facilitate clinical diagnosis by providing objective grading of cortical cataract.

Figure 6. Diagram of cortical cataract grading system

Figure 7. GUI of cortical cataract grading system

Figure 8. Error histogram for automatic cortical opacity detection.
Table 2. Automatic grading results of cortical cataract

<table>
<thead>
<tr>
<th>Clinical Grades</th>
<th>Automatic Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>148</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

This paper presents two computer-aided diagnosis systems for cataract grading. Novel approaches to measure opacity in the lens nucleus and cortex are proposed in slit-lamp images and retro-illumination images respectively. Images from population-based study were tested by the automatic systems and promising results were shown.

Further improvement will include user interaction function in the system for a user to edit the automatic detection. One of the drawbacks of automatic systems is that they cannot handle exceptions. By adding user interaction, the system will be more accurate and more suitable for clinical diagnosis.

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REFERENCES