A Simple and Robust Method to Screen Cataracts Using Specular Reflection Appearance

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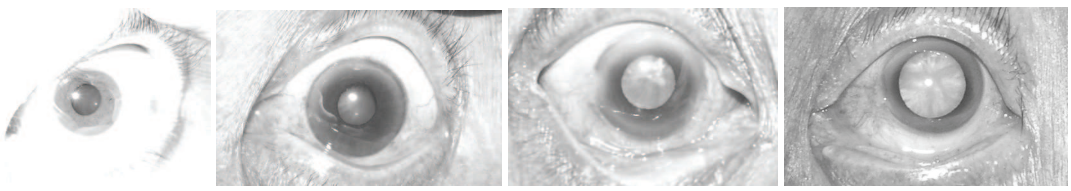
ABSTRACT

The high prevalence of cataracts is still a serious public health problem as a leading cause of blindness, especially in developing countries with limited health facilities. In this paper we propose a new screening method for cataract diagnosis by easy-to-use and low cost imaging equipment such as commercially available digital cameras. The difficulties in using this sort of digital camera equipment are seen in the observed images, the quality of which is not sufficiently controlled; there is no control of illumination, for example. A sign of cataracts is a whitish color in the pupil which usually is black, but it is difficult to automatically analyze color information under uncontrolled illumination conditions. To cope with this problem, we analyze specular reflection in the pupil region. When an illumination light hits the pupil, it makes a specular reflection on the frontal surface of the lens of the pupil area. Also the light goes through the rear side of the lens and might be reflected again. Specular reflection always appears brighter than the surrounding area and is also independent of the illumination condition, so this characteristic enables us to screen out serious cataract robustly by analyzing reflections observed in the eye image. In this paper, we demonstrate the validity of our method through theoretical discussion and experimental results. By following the simple guidelines shown in this paper, anyone would be able to screen for cataracts.
Keywords: screening, cataract, specular reflection analysis

1. INTRODUCTION

A cataract is a clouding of the lens in the eye that interferes with vision. The World Health Report published in 2001 estimated that there were 20 million people who are bilaterally blind (i.e., eyesight less than 3/60 in the better eye) from age-related cataracts and the number will have swelled to 40 million by the year 2020 [1]. Developing countries like Indonesia have the highest number of cases. On the other hand, Indonesia has only about 750 eye specialists for a population of more than 200 million (one for every 350,000 people) many of whom have no access to eye care because of geographic conditions[2]. For tele-medical environments like in Indonesia, it is crucial to implement a compact screening system for several diseases common there.

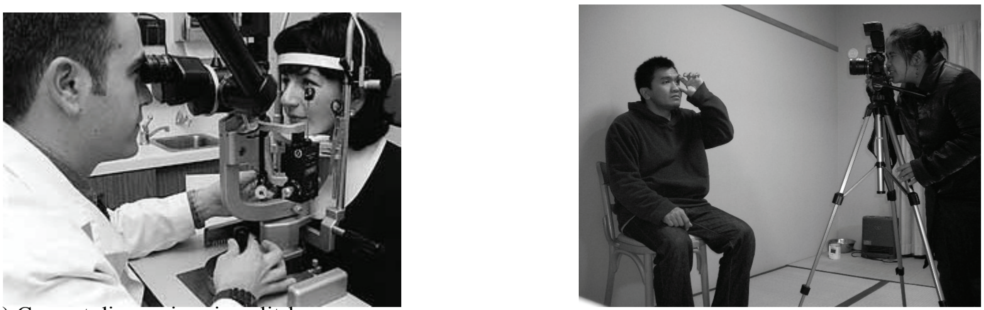
In current diagnosis, eye specialists focus on the pupil region to get information about cataracts using a slit lamp camera to get clear information about any whitish color inside the pupil. Three classes of cataract, immature, mature and hypermature, differ in seriousness as shown in Figure 1. An immature cataract shows appearance of a whitish color inside the pupil, but less so than the mature or hypermature types, and is usually not yet a serious condition. Hypermature cataracts show much whitish color inside the pupil and can cause the eyeball to break if surgery is not carried out. This condition is very dangerous.



Normal Immature Mature Hypermature

Figure1. Examples of eye conditions

In this paper, we describe the development of an automatic detection method for screening cataracts by easy-to-use and low cost imaging equipment such as a compact camera. This equipment has many advantages: it is small and easily carried to an outpatient department, an operation room or an emergency clinic; it is easily used by anyone without special training where specialists are unavailable; it is cheaper than a slit lamp camera (about US$475 vs. about US$30,000). Figure 2 shows the current diagnosis by slit-lamp camera and our proposed system using a commercially available digital camera.



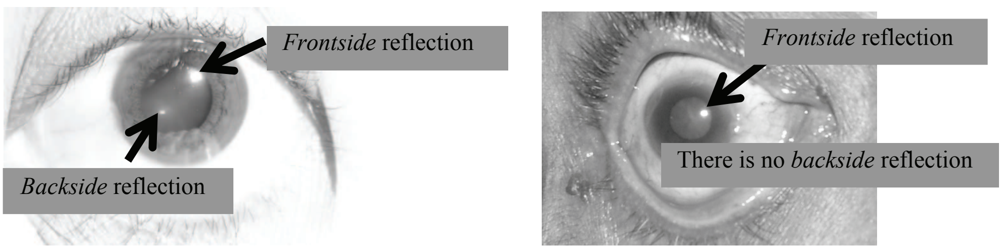
(a) Current diagnosis using slit-lamp camera
(Source: http://www.mrcophth.com/examinationtechniques)

(b) Our system using commercially available digital camera

Figure2. The different equipment in current diagnosis and our system

Currently there are many projects to develop telemedicine in order to improve health service in developing countries. A typical example is proposed by Soegijoko [3]. Our method can be applied to a telemedicine system and is expected to assist its functionality.

However, images taken by a compact camera are not of sufficient quality, and illumination is not controlled. It is therefore very hard to analyze color information from inside the pupil. For example, because some images in Figure 13 are taken under bright illumination, we have high intensity values inside the pupil. If we employ intensity value for screening for cataract, i.e. higher intensity corresponds to a serious condition; it would fail for the images in Figure 13**.** To solve this problem we propose a new method for cataract diagnosis. Using specular reflection inside the pupil, we solve the problem of illumination and poor image quality. This method is based on the effect of light on the eye, as depicted in Figure 4. Principally, light enters the pupil and makes a reflection on the frontal surface of the lens of the pupil area, called the *frontside reflection*; also the light enters the rear side of the lens. Usually, a normal eye will have no clouding in the lens, so the light will make a reflection on the rear side of the lens, called the *backside reflection*. But with a serious cataract condition, since there is much clouding in the lens, we cannot observe a *backside reflection*. We can thereby distinguish between serious and normal (not serious) conditions. Referring Figure 1, the serious condition of cataracts is including mature and hypermature classes because there is no backside reflection appearance inside pupil. Otherwise normal conditions are including normal and immature classes because there is backside reflection appearance inside pupil. Figure 3 shows the appearance of a *frontside reflection* and a *backside reflection* on a normal and cataract images taken by a compact camera.



(a) Normal Condition

(b)Serious Condition

Figure3. *Frontside* and *backside* reflections appearance in an eye image

Specular reflection appearance is always brighter than the surrounding area so we can compare the intensity between specular reflection and pupil without dependence on illumination and poor image quality. The system can be used anywhere by anyone and is therefore suitable for developing countries or rural areas where specialists are not found.

Basically, we just take a photograph with a compact camera and enter it into a system that will automatically screen for cataract conditions.

2. RELATED WORKS

Cataract is a common disease of human eye and there is much related research. We classify the research into three categories. The first category is research about the statistics and the causes of cataract. For example, Lewis [4] studied development of granting acuity in children treated for dense congenital unilateral or bilateral cataract and examined how variations in treatment affect grating acuity during early childhood. Sasaki [5] surveyed cataract epidemiology using application of photo documentation. Lin [6] assessed the relationship between myopia and age-related cataract in a defined older population.

The second category is research about diagnosing cataract. For example, Sugata [7] examined normal and cataract lenses and suggested the possibility of diagnosing by measuring the attenuation characteristic of the lens. Biwas [8] discovered the role of catalin in the prevention of posterior capsular opacification (OPA) conducted an experimental study on rabbit. Garif [9] applied speckle technologies and measured retinal angular resolution by laser retinometer at the stage of preoperative cataract diagnosis. Frohn [10] introduced the beam-deflection method to evaluate vision impaired by cataract. Babizhayev [11] introduced the Halometer for measuring intraocular light scattering in the presence of human cataract. Roizenblatt [12] analyzed verification of iris identities after intra-ocular procedures when individuals were enrolled before the surgery.

The third category is research about eye image processing especially for localizing the pupil. For example, Beeswax [13] proposed an algorithm for windowing around the pupil image on the basis of a difference pupil detection method, which works on a relatively cheap construction. Xhifei [14] proposed a method for estimating the center and radius of the pupil. Funahashi [15] proposed a system for extracting eye gaze information and introduced a system for supporting a video conference system. Wan [16] proposed a novel iris quality assessment based on Laplacian of Gaussian operators.

3. CONTRIBUTIONS

Basically our research is included in the second category but it appears that all research in this category was devoted to eye specialists who usually used special equipment requiring training and some knowledge about cataracts. Those studies are valuable if implemented in conditions where there area enough eye specialists and health facilities are equally distributed. In our research, we dedicate our system to rural areas where eye specialists and health facilities are limited as in developing countries. A part of our research also belongs to third category because basically we also use image processing in our method. We implement image-processing techniques for localizing pupil and specular reflection, but unfortunately we could not find related works about implementing image-processing technique for cataract diagnosis. To the best of our knowledge our research is the first work that discusses this topic. We develop a simple method for cataract detection using low-cost and easy-to-use equipment; also the system can be used by anyone and anywhere. Our method will diagnose cataract automatically based on specular reflection appearance inside the pupil image.

4. SPECULAR REFLECTION ANALYSIS FOR CATARACT DIAGNOSIS

The core of our method is detecting *frontside* and *backside* reflection. Specular reflection is the perfect, mirror-like reflection of light from a surface, in which light from a single incoming direction is reflected into a single outgoing direction. We develop our algorithm based on the reflection theorem, which states that the direction of incoming light and the direction of outgoing light reflected make the same angle with respect to the surface normal. Thus the angle of incidence equals the angle of reflection, and this is commonly stated as

$$\theta_i = \theta_r \tag{1}$$

Figure 4 described the simulation of our method based on the reflection theorem. Light enters the lens through the pupil. It will make a reflection on the frontal surface of the lens of the pupil area and the rear side of the lens. The direction of the normal vector always go to the center of pupil, so when we look at the image appearance we can find the relationship of location between the two reflections and the center of the pupil; they are on a single line. We already done the experiment for 80 normal images and all of them have both of reflections in a single line.

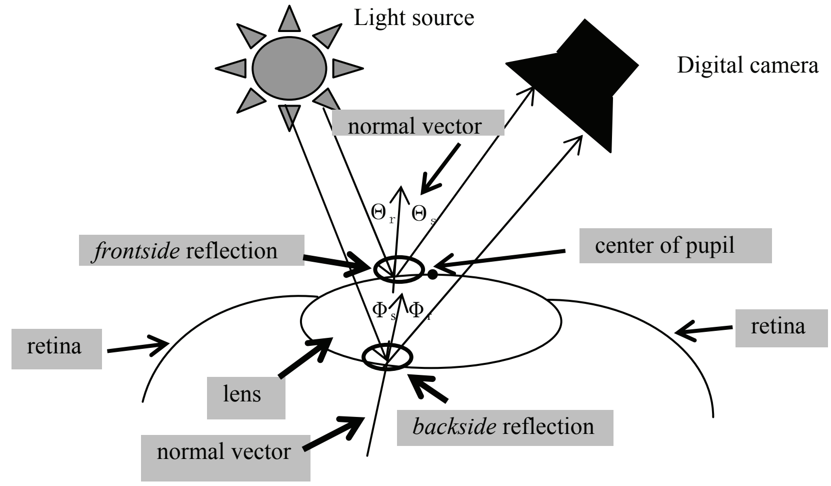
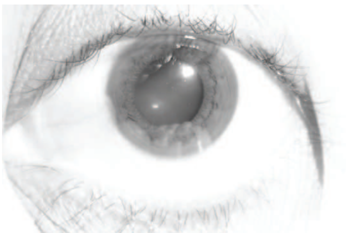
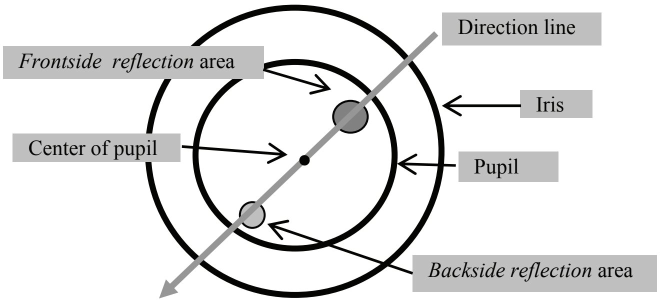


Figure4. Model of reflection theorem and geometrical characteristic in the eye

Figure 5 shows the image appearance both in the actual image and the model image. The pupil is the variable sized, black circular or slit shaped opening in the center of the iris that regulates the amount of light that enters the eye. The shape of the pupil varies between species. Common shapes are circular or slit-shaped, although more convoluted shapes can be found it. In current research we assume the pupil has circular shape. Also referring to Figure 4, the relationship of location between the *frontside* reflection, center of the pupil and backside reflection is located in a single line caused by the direction of the normal vector always goes to the center of the pupil as discussed in the above paragraph.



(a) Actual image



(b) Model of pupil image

Figure5. Relationship between a *frontside* and a *backside* reflection area

Using the relationship between both reflections, we conducted a search to find the backside reflection, as depicted in Figure 6. Using coordinate of the center and the radius of *frontside* reflection, we then searched for the *backside reflection* by searching for areas of higher intensity beside *frontside* reflection compared with their immediately surrounding areas. A detailed algorithm will be shown in Section 5 but principally if the difference was great enough, we assumed that we had found a *backside reflection*. This would indicate that the condition was normal condition. Otherwise is a serious condition. The appearance of the normal condition and serious condition was shown in Figure 4. The experimental proof of this algorithm is described in Section 7.

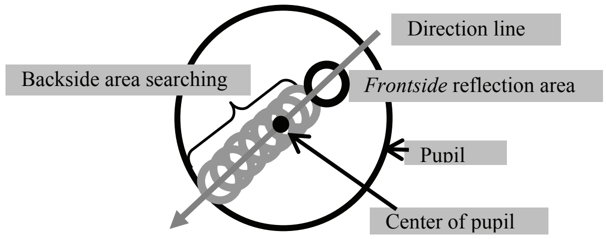


Figure6. *Backside reflection* area searching

5. ALGORITHM

To realize cataract diagnosing based on specular reflection appearance we designed algorithm as shown in the figure 7.

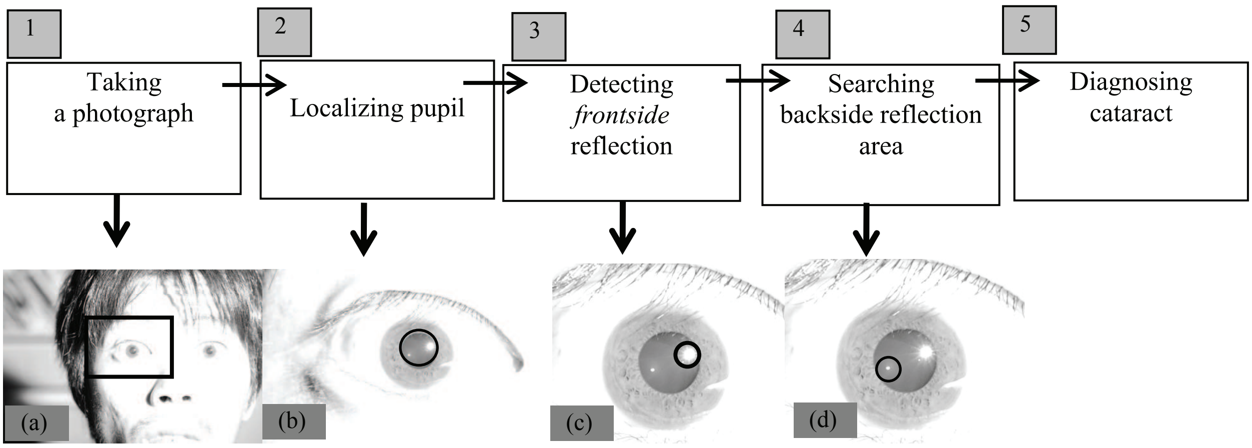


Figure7. Flow chart of our system

5.1 Taking a photograph

The first step in our method is taking a photograph. Usually the focus position of the portable digital camera is in the center automatically. Based on the fact, the simple way to take a photograph using a compact camera is arranging the object in the center of image, because we don't need to arrange the focus position of camera. In current implementation, we assume that the pupil will be investigated always located in the image center so when we take a photograph should be arranging the focus of camera always in the center. Using this assumption, we divide image into nine areas as shown in the Figure 8 and assume that eye area will be investigated always located in area E. The system will crop automatically by shown only area E as an input image for localizing pupil.

To avoid noise caused by occlusion we ask the patients to open their eye by hand manually as shown in Figure 2(b). We got the size of pupil is around 27 pixels to 78 pixels. Also in current research we take a photograph without asking the patient to enter the dark room, while in the current diagnosis patient should be entering the dark room to get a bigger size of pupil then the eye specialist will investigate using special equipment as shown in Figure 2(a). In the future we should consider about this phenomena. Beside that, also we consider about angle and distance during taking a photograph that will discuss in Section 6. The rectangle shown in Figure 7(a) indicate the part of cropping automatically

In current experiment, the experimental images for normal eyes were taken in Japan using Nikon D40X while images for cataract were taken in Indonesia before patient's surgery using Nikon Coolpix L4 and Kodak Z650 and we use grayscale image during taking photographs for both conditions.

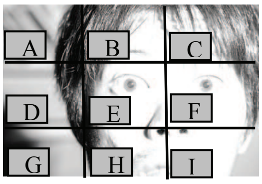


Figure8. Process of cropping eye area automatically

5.2 Localizing pupil

The second step of our system is localizing pupil. We should be localizing the pupil because our algorithm is based on the information availability inside the pupil. In the current research we assume that the pupil has a circle shape and we implement Hough transform to get a circle shape. The main advantage of Hough transform is the robustness to discontinuous pixels and noise in real world images so it can identify positions of arbitrary shapes.

In current research we use gray-scale image as an input image (a). After that we convert to binary image based on global threshold using Otsu method (b) that usually used in the reduction of intensity image to a binary image as introduced by Otsu [17]. To get a clear image in this paper, we enlarge the size of image indicated by rectangle in Figure 9(c) and presented in Figure 9(d). During experiment we still get some noise and to reduce it we implement erosion operation for one time (e). We implement Sobel edge detection to get edge image (f). After that we implement Hough transform to get circle shape (g). We use this circle as a mask image and multiply with input image. Finally we get pupil localization (h). Figure 9 described step by step of pupil localization.

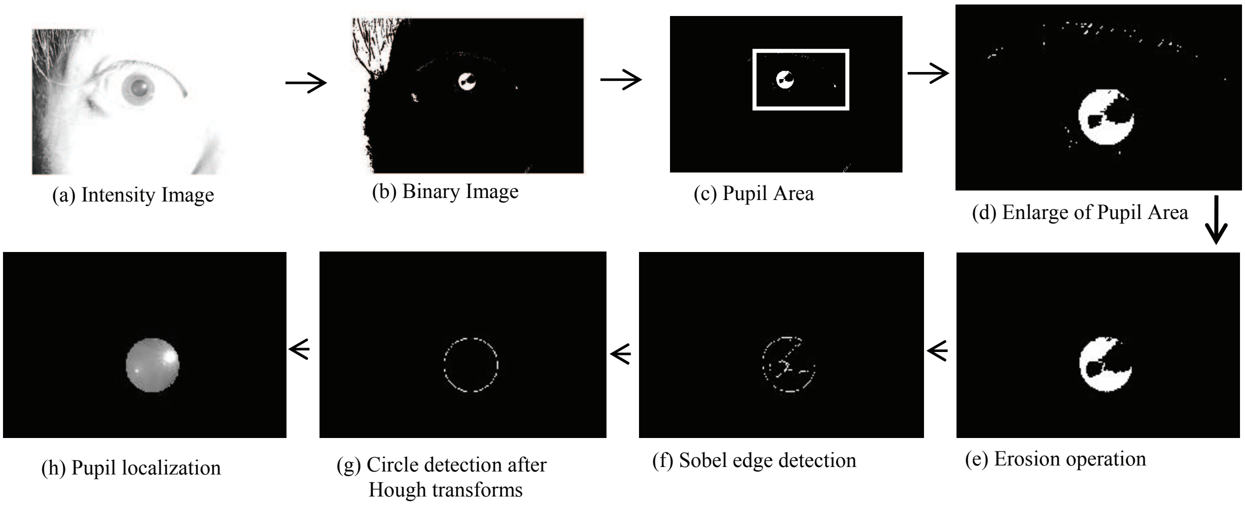
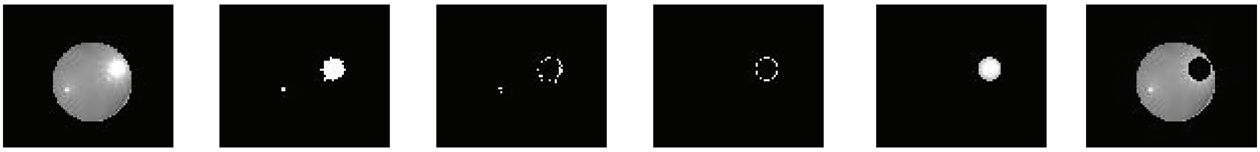


Figure9. Process of pupil localization

5.3 Detecting *frontside* reflection

The third step in our system is detecting *frontside* reflection. We use the result of pupil localization as an input image (j). Based on the result experiment as described in Section 6, we found that the intensity of specular reflections always have the intensity value more than 200, so in the current implementation we assume this value as a threshold for converting input image to the binary image (k). Then we implement Sobel edge detection (l) and implement Hough transform to get a circle shape (m). Based on the preliminary result we found that radius of frontside reflection is around 7 pixels to 15 pixels, so we entering this value during finding circle image by Hough transform. We get frontside reflection localization (n) and remove it from pupil (o) for tracking intensity in order to search backside reflection that will be clarified in Subsection 5.4.

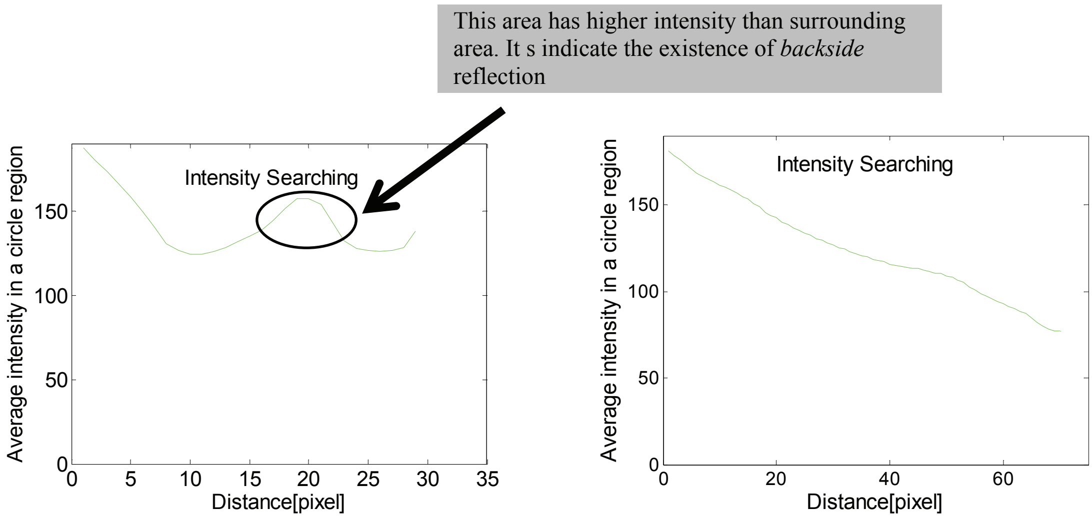


(j) input image (k) binary image (l) edge image (m) circle detection after Hough transform (n) localization (o) output image

Figure10. Process of *frontside* reflection localization

5.4 Searching backside reflection

The fourth step of our system is searching for *backside* reflection availability. This is the core of our method, because the result of this step will be used as a basis to diagnose cataract. Principally, we were searching intensity along the direction line start from the center of the *frontside* reflection pixel by pixel. During intensity tracking, we measure average intensity in a circle area around a focused pixel. The radius size of it is same as one of the *frontside* reflection. . Actually, in the fact the size of backside reflection is smaller than *frontside* reflection (less than 7 pixels), but now we do not consider yet. In the future research we should consider about radius size of *backside* reflection. Figure 11 show the examples result of intensity tracking for normal and cataract eye images. Referring Figure 11 (a), during intensity searching, we found areas with a higher intensity than the surrounding areas. This indicated the existence of *backside reflections*.



(a) Normal eye image (b) Cataract eye image

Figure11. Example result of intensity graph for both eye images conditions

Referring Figure 11(b), during intensity searching we didn't find an area that have a great increasing intensity than the surrounding area, which means that there was no *backside reflection.*

Based on the results depicted in Figure 11, we got the characteristics for both conditions. The main characteristics of both conditions depend on the presence of *backside reflection* in an image that shown by increasing intensity in an area during intensity searching. Also we note in here these characteristics are independent of the illumination condition.

5.5 Diagnosing Cataract

The fifth step or the last step in our system is diagnosing for cataract. Based on the intensity tracking that was done in section 5.4, we implement a differential function in a discrete system to develop an automatic screening between the normal and serious condition.

$$D(s) = I(S) - I(S-1) \qquad (2)$$

Where I is intensity, S is distance between the center of *frontside* reflection and the next circle that will be investigated. During intensity searching, if D(s) > 0 it means there is an increasing intensity value. Otherwise, if during intensity searching D(s) < 0 it means there is a decreasing intensity value. Based on the discussion in Subsection 5.5, normal conditions always have a great increasing intensity that indicated existence of *backside* reflection but it doesn't mean that serious conditions didn't have increasing intensity during tracking intensity. Sometimes serious conditions have increasing intensity that maybe caused by noise. Based on the fact we compute the accumulation of D(s) > 0 and assume if there are a lot of numbers D(s) > 0 it is indicated existence of *backside* reflection, otherwise is a noise. Because we have variations of the numbers of intensity tracking so we define normalized number of increasing value determined by following equation:

$$P_n = \frac{p}{n} \tag{3}$$

Where n is numbers of intensity tracking and p is the numbers of D(s) > 0. By implementing Equation 4 we will get a value as a threshold to distinguish diagnosing between normal and serious condition. If the experiment gives us value more than threshold result it means that patient has normal condition. Otherwise is serious condition.

6. GUIDELINE FOR IMPLEMENTATION

The examples of experimental images are shown in Figures 13 and 14. As discussed in the section 4, our method focuses on the specular reflection appearance inside the pupil. According to this topic, in order to get a good input image we should consider the angle and distance during taking a photograph.

Figure13. Examples of normal eye images

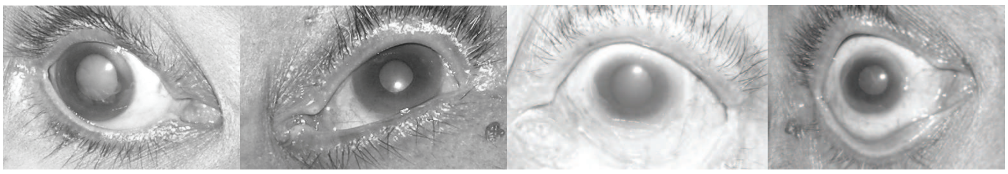


Figure14. Examples of cataract eye images

First we consider angle. As discussed in Section 5 we assume that both of pupil and *frontside* reflection are a circle and we can compute the distance between the center of pupil and *frontside* reflection using Euclidian formulation as described in Equation 4 and Figure 15.

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \tag{4}$$

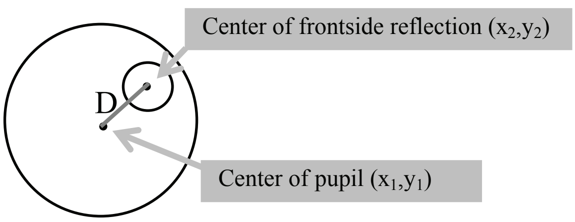


Figure15. Euclidian distance between center of pupil and center of *frontside* reflection

Because the eye images have many variation of pupil size, we make normalization by dividing the distance result with the radius of the pupil r by Equation 5.

$$D_N = \frac{D}{r} \qquad (5)$$

During experiment we found the position of backside reflection depend to the position of *frontside* reflection. For example if the position of *frontside* reflection very close with center of pupil it will effect that backside reflection will be very close with *frontside* reflection and sometimes will be overlap. Therefore, D_N is an important factor in our system especially during taking photographs. Figure 16 described the relationship between backside reflection and *frontside* reflection. Also, based on the experiment we classify the position of specular reflection inside pupil refer to angle consideration as shown in Table 1.

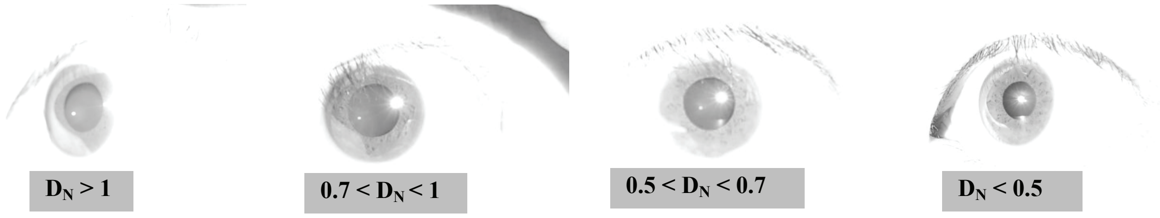


Figure16. The image examples for each classification

Table1. Classification of distance based on angle position

Value of D_N	Characteristic
$D_N > 1$	There is no reflection inside pupil. This condition is **inappropriate** for our system because we could not get specular reflection appearance inside the pupil.
$0.7 < D_N < 1$	Some part of *frontside* reflection is outside of pupil. This condition is **not so appropriate** for our system because we could not get a whole shape of the *frontside* reflection inside the pupil.
$0.5 < D_N < 0.7$	It is **the appropriate** condition for our system. We could get a whole shape of the *frontside* reflection inside the pupil; also this condition has enough distance between the *frontside* reflection and *backside* reflection. Also It is very important because we will make a tracking to detect *backside* reflection availability based on intensity tracking.
$D_N < 0.5$	The whole shape of the *frontside* reflection inside pupil but the position between the *frontside* reflection and *backside* reflection is very close. It is **inappropriate** for our system because sometimes the *frontside* reflection and *backside* reflection will overlap.

We have tried many positions between the camera and light source and the object. The first position is a light attached the camera and it moves smoothly from an angle of 10^o to 170^o. The second position is one in which the camera is fixed at a 90^o angle in the *frontside* of the patient and the light moves smoothly from an angle of 10^o to 170^o. The third position is on in which the light take is fixed position at 90^o angle on the *frontside* of the patient and the camera moves smoothly from an angle of 10^o to 170^o. The first and second positions give us a result suitable for classification described in table 1, while the third position always gives us the value of $D_N < 0.5$. It means that this position is inappropriate for our system. Figure 17 to Figure 19 show a sketch and results of the experiments.

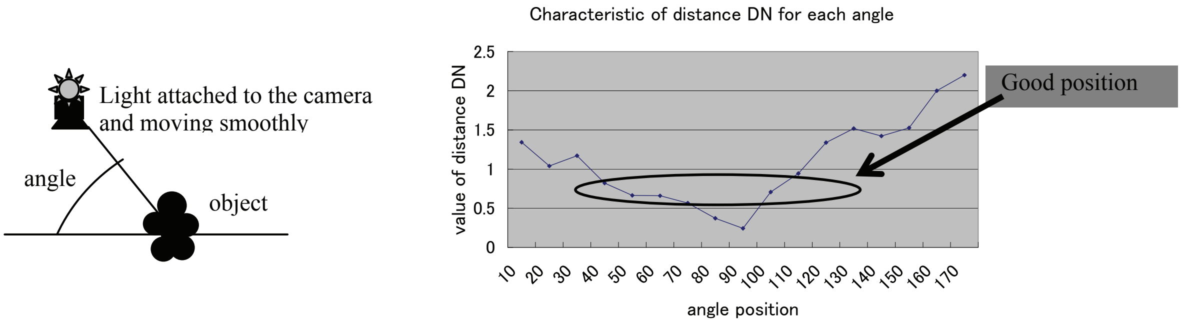


Figure17. Distance characteristic between center of pupil and center of *frontside* reflection if light attached to camera

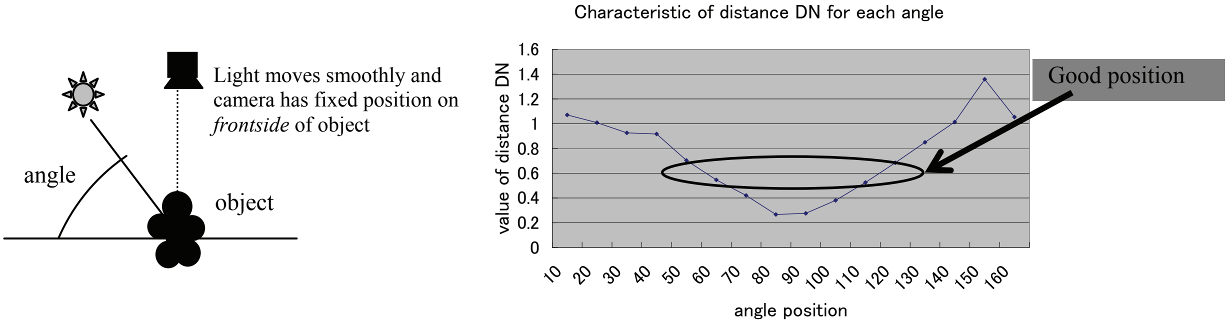


Figure18. Distance characteristic between center of pupil and center of *frontside* reflection if camera has fixed position on *frontside* of object and light source moves smoothly based on angle position

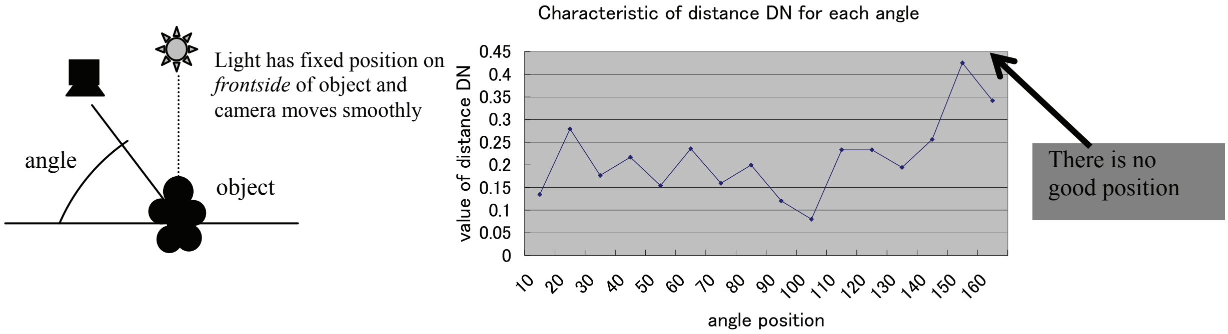


Figure19. Distance characteristic between center of pupil and center of *frontside* reflection if light source has fixed position on *frontside* of object and camera moves smoothly based on angle position

Second we discuss the distance consideration during taking a photograph. We refer to the natural rule about vision. If we look at an object by a close distance, it will appear large but it doesn't mean that we will get clear information about our object. Otherwise, if we look at an object at a far distance, it will appear small but it doesn't mean that we will not get clear information on our object. Based on that fact, we did experiments to get the best distance during taking a photograph. Table.2. shows the effect of distance between camera and light source to the object observed.

Table2. The effect of distance during taking a photograph

Distance	Radius of Pupil	Radius of *frontside* reflection	Average intensity of *frontside* reflection	*Backside* reflection availability
30 cm	**52**	**15**	**252**	**Detected (clear)**
40 cm	**37**	**13**	**249**	**Detected (clear)**
50 cm	**36**	**11**	**245**	**Detected (clear)**
60 cm	**34**	**10**	**242**	**Detected (clear)**
70 cm	24	8	240	Detected (weak)
80 cm	22	7	239	Detected (weak)
90 cm	22	6	229	Undetected
100 cm	20	4	227	Undetected

According to the result shown in table 2, the distance will affect the size and intensity of the object. In this table, the size of the pupil radius and *frontside* reflection radius will decrease following the increasing distance from the object. It also occurs in the average intensity of the *frontside* reflection. The important thing in this consideration is detecting *backside* reflection availability. We take an image from a distance of 30 cm to 100 cm, because it is very hard to take an image with enough content information about the pupil with a distance less than 30 cm or more than 100 cm. The bold type in Table 2 indicates the best position of distance to detect the backside reflection during tracking intensity.

7. EXPERIMENTAL RESULT

This section shows the experimental result of localizing the pupil and screening cataract. We have already done experiments to localize the pupil for 80 images and had success with 75 images, so the performance of the algorithm for localizing the pupil is 93.75%. We failed to localize pupil for some images because of restrictions in our algorithm like restriction of pupil should be located in the image center, using threshold when converting from intensity image to binary image etc. In the future research we should consider a sophisticated algorithm to solve the restrictions. The result of cataract screening is shown in Figure 20.

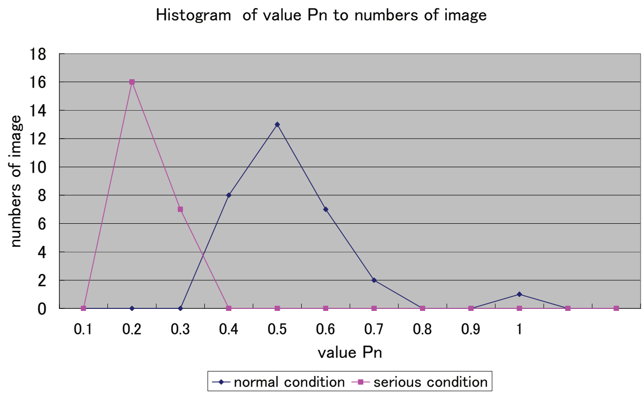


Figure20. Histogram function for both conditions

Referring Figure 20, the threshold value in this experiment is 0.2. So if we get value > 0.2 the system will judge that this is normal condition. Otherwise if the value < 0.2 the system will judge that this is serious condition. Based on the experimental result, we can say that our method is success to distinguish between serious and normal condition although the numbers of data is limited. In the future our method is promising for screening for cataracts.

8. CONCLUSION

Our method is simple and robust for cataract screening because we can distinguish between normal and serious condition based a threshold value as described in Section 7. Also our method does not depend on the illumination condition and poor quality image so anyone would be able to implement our system in anywhere. In the future our method is promising for screening for cataract using a portable compact digital camera. The important part to implement our method is taking a photograph. We should follow the considerations about focus of camera, angle and distance to get a robust screening system. The best angle for taking photograph is 50^o – 70^o and the best distance for taking photograph is 30 cm – 60 cm from the object. In the future research we should consider about the effect of entering dark room before taking a photograph because we have not considered yet about this case. Also regarding the pupil and frontside reflection localization we should consider a sophisticated algorithm for localizing both the pupil and *frontside* reflection. It caused by the fact that current research has a lot of restrictions during localizing pupil and *frontside* reflection like pupil position, threshold etc. Also we should be implementing our method to more data examples in order to develop some improvements.

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