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Cataract Screening Techniques under Limited Health Facilities

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Cataract Screening Techniques under Limited Health Facilities*

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Abstract

In this thesis we developed a cataract screening system using image processing techniques. The goal is to solve problems about cataract diagnosing under limited health facilities. Toward this end, we will use low-cost and easy-to-use equipments such as a digital camera for cataract diagnosis so that anyone can conduct diagnosis easily. The increasing number of cataract sufferers is a serious problem because cataracts are a leading cause of blindness in the world. To avoid blindness from cataracts we need to detect them early. Today, ophthalmologists use slit lamps to diagnose cataracts. This equipment is expensive and requires special training to use it. Unfortunately, a lot of developing countries have a limited number of ophthalmologists and health facilities, while a lot of cataract sufferers live in developing countries. In our system, once a user simply takes a patients photograph of an eye, the system will automatically analyze the image and distinguish between serious and non-serious conditions. In the image analysis, we have to treat images taken under various kinds of conditions and the conditions strongly affect their appearance. Therefore, in order to conduct diagnosis robustly using those images, we take into account the information inside a pupil area including specular reflections and texture appearance. The specular reflections in a pupil area are mainly caused by a flash light attached with a digital camera. They are easily extracted in an image even if illumination conditions are varied. And there is an important characteristic that the number of reflections

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inside a pupil area can be used for screening cataract patients. Finally we exploit not only the specular reflections but also texture appearance in a pupil area and we conduct a robust screening of cataracts. We tested our system using 777 images and the result shows that True-Positive is about 92% and False-Positive is about 18%. This performance is promising for further development although for practical implementation is still needed some improvement as will be discussed in this thesis.

Keywords:

cataract screening, specular reflection, texture analysis , low-cost equipment, limited health facilities

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Contents

Chapter 1

Introduction

1.1. Background

1.1.1 Definition of cataract

Cataract comes from Greek katarrhakies, English Cataract and Latin cataracta, those words meaning waterfall. This is an eye disease that affects vision. Cataract is any cloudiness in the lens that can occur due to the hydration (addition of liquid) lenses, lens protein denaturation, or the result of both. Usually opacities of both eyes and walked progressive or may not experience a change in a long time [78].

Cataracts are common among those over age 50 and are characterized by clouding of the eye lens but can also be due to congenital abnormalities, or chronic eye diseases. Various eye diseases can cause cataracts such as glaucoma, ablation, uveitis, and retinitis pigmentosa. Cataracts can be related to other intraocular disease process,[30]. Although most cataracts are related aging, sometimes cataract can attack everyone including people who less than age 50. Cataract can develop in one or both eyes and there can be more than one type of cataract that develops in the same eye. Over time, many individuals with a cataract in one eye usually go on to develop a cataracts in the other eye as well. Cataract are not painful, they do not cause the eye to tear abnormally and they are not known to make the eye itchy or red. It cannot spread from one eye to the other [32]. It is also a main cause of blindness in the world [40]. Treatment of cataract is surgery. After surgery the lens is replaced with afacia glasses, contact lenses or intraocular lenses planting. There are some classification of cataracts.

The first classification are related aging, there are some types of cataracts [7]:

(a). Congenital
A cataract that a baby is born with. Many congenital cataracts are hereditary. If there is no history in the family, they can be caused by a hereditable mutation in the infant - the infant's future children may be at risk even if there is no previous family history .

(b). Juvenile
A mature cataract with a poorly developed nucleus in a child or young adult. Juvenile cataracts are a known hereditary condition and usually is developing to people who less than age 9. It is a continuation from congenital cataract.

(c). Senile
A kind of cataract associated with aging those over age 50 in which an opacity forms in the crystalline lens of the eye. This is the most common type of cataract.

The second classification are based on location of opacities [30]:

1. Nuclear
Nuclear cataract are the most common of the cataract types. Nuclear cataracts affect the center of the lens, so they interfere with a persons ability to see objects in the distance. This type of cataract is usually the result of advancing age.

2. Cortical
Cortical cataract are most commonly seen in patients who have diabetes. Cortical cataracts begin at the outer rim of the lens and gradually work toward the central core of the lens. This type of cataract resembles spokes of a wheel that extend from the outside of the lens to the center.

3. Subcapsular
Of all cataract types, subcapsular cataracts progress the most rapidly. Subcapsular cataracts affect the back of the lens,causing glare and blurriness. This type of cataract is usually seen in patients who use steroids, or who suffer from diabetes,or extreme nearsightedness.

(a) Non serious condition

(b) Serious condition

Figure 1.1. Example of eye images

Referring to above classifications, we summarize that cataract always exhibit whitish color inside a pupil and cause blindness in all categories of cataracts as discuss above.

Referring to the number of opacities in the eye lens, there is a classification stages of cataract. There are immature, mature and hypermature, which differ in seriousness. In an immature cataract, a whitish color appears inside the pupil but less so than in mature or hypermature cataracts. Usually the conditions is not serious yet. Hypermature cataracts exhibits much whitish color inside the pupil and can cause the lens of the eye to break if surgery is not carried out. This condition is very dangerous. Figure 1.1 shows example of the range of serious and non serious conditions.

The most common symptoms of a cataract are cloudy or blurry vision, colors seem faded, glare, headlights, lamps, or sunlight may appear too bright, a halo may appear around lights, poor night vision, double vision or multiple images in one eye, and frequent prescription changes in eyeglasses or contact lenses [48].

Although the signs of cataracts include physical signs such as the opacities in the eye lens signs and non-physical symptoms experienced by patients such as those mentioned in the paragraph above;however,because we are in the view of engineering, so we emphasize our discussion on the physical signs of cataract as the basis for developing of our screening system.

This thesis will discuss about screening system therefore we emphasize for distinguishing between serious and non-serious condition only. We have not considered yet to classify each stage of cataract because the main purpose of current research is screening cataract to get a rough database of people who require surgery as soon as possible.

1.1.2 Diagnosing cataract

Usually cataract is detected through a comprehensive eye exam that includes:

1. Pupil dilation

Pupil dilation is a common test used in cataract diagnosis. First, the ophthalmologist uses eyedrops to widen pupils. It will take 15-20 minutes for pupils to dilate fully. Then the ophthalmologist will ask patient to stare straight ahead as each eye is examined with a bright light and special lens. Dilating the pupils allows the ophthalmologist to examine the lens and retina for eye diseases.

2. Visual Acuity Test

In the most well-known vision test, the visual acuity test, an ophthalmologist will ask a patient to read letters or symbols of various sizes from a chart. The eyes will be tested individually and together to measure the accuracy of your eyesight at different distances. This test is frequently used to screen for any visual problems including cataract.

3. Tonometry Test

A tonometry test can determine whether or not a patient has a cataract by measuring the fluid pressure inside the eyes. The ophthalmologist will first numb the surface of the eyes using eyedrops. An instrument will be used to place a small amount of pressure on the eye.

Usually ophthalmologists will use various tools to determine the type, opacities and the location of the cataract, and to distinguish it from other eye diseases that have symptoms similar to cataracts. With early diagnosis, the cataract can be monitored whether to continue or will cause complications that must be treated to prevent blindness. Thus, there is not a reason to suspend the examination and treatment if the patient has vision problems interfere with daily activities.

All types of eye examinations which are described in the paragraph above be done before an ophthalmologist using a slit lamp or ophthalmoscope as a main equipments for detecting cataract. A slit lamp is commonly used by an ophthalmologist to see if there are defect or anomalies in the anterior segment which is everything in the eye from the lens forward including the iris, lens, cornea, and conjunctiva. The slit lamp is mounted to a movable table top that includes an integrated chin rest to keep the patient's head stationary. The light source produces a beam of light that is projected onto the area of interest which is in turn viewed by the examiner with the biomicroscope portion of the apparatus. The biomicroscope allows the user to adjust the image magnification from approximately 1.5 up to 4 life size. This equipment is modified for photography by incorporating a beam splitter for the camera and flash system that uses the same light path as the tungsten examination illumination. The slit lamp biomicroscope earns its name by the type of lighting it produces, which is a very thin less than 1 mm beam of light that can be raked across the surface of the eye. This is a specialized form of dark-field illumination that might be considered to be similar to the effect of closely drawn curtains on a sunny day where a thin beam of sunlight reveals every speck of dust floating in the air against a dark background. The slit lamp works the same way on the cornea or lens of the eye which are normally optically clear. The thin slit beam allows the photographer or the physician to visualize any abnormalities or opacities by creating in effect an optical section of the cornea or lens [69].

An ophthalmoscope is an instrument used by optometrists, ophthalmologists and doctors to see inside the eye, particularly the back of the eye, which is called the fundus. The ophthalmoscope also called a funduscope. It is usually comprised of a bright light, mirrors, lenses for magnification and wheels that the doctor turns

(a) Portable slit-lamp camera (b) Opthalmoscope

Figure 1.2. Different equipment for diagnosing cataract

to view different levels and depths of the eye. There are two types of ophthalmoscopes; direct and indirect. Direct ophthalmoscopes are hand-held devices, about the size of an electric tooth brush, and magnify the inside of the eye. Direct is the most common type of ophthalmoscope. Indirect ophthalmoscopes are usually bigger, are worn on the head of the physician doing the exam, and are used in conjunction with a lens that the doctor holds in his hand while looking inside the eye. Indirect ophthalmoscopes are used when an expanded internal view of the eye is needed. An ophthalmoscope can be used together with drops that dilate the pupils, which gives the opportunity for an even bigger opening to see inside the eye [74].

By using this kinds of equipment, lens opacities can be assessed by observing the width of the edge of the iris in a cloudy lens (iris shadow). If the remote location and the large shadow means immature cataracts, if it is a small shadow and close to the pupil occurs in mature cataracts. Figure 1.2 shows a process for diagnosing cataract using a slit-lamp and an ophthalmoscope. It is appears that to use those equipments, we need a special training and knowledges of eye disease.

1.1.3 Condition of health facilities in developing countries

The World Health Report published in 2001 estimated that there were 20 millions people who are bilaterally blind people (i.e.,with eyesight of less than 3/60 in the better eye) whose blindness was caused by age-related cataracts. That number

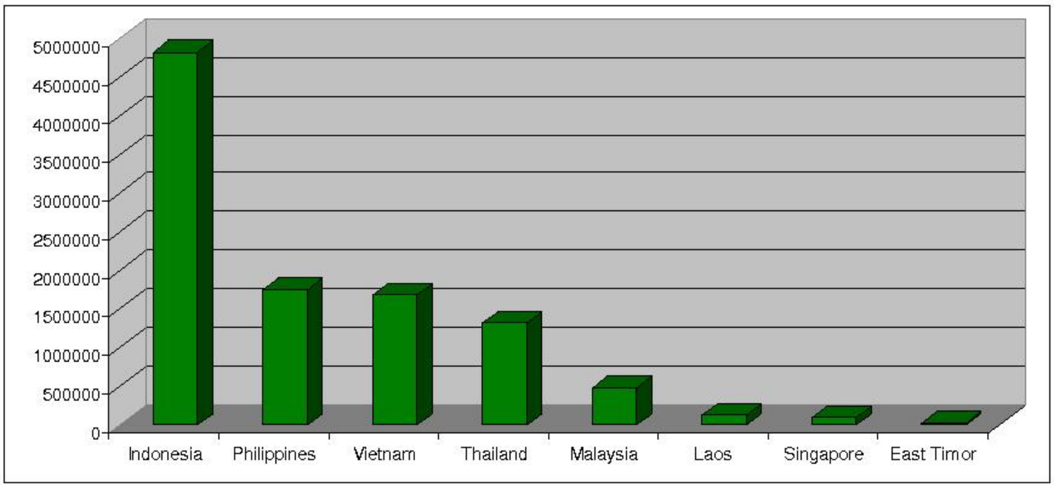


Figure 1.3. Statistic of cataract patients in Southeast Asia (2001)

will have increased to 40 million by the year 2020 [40]. Increasing age is associated with an increasing prevalence of cataracts, but in most developing countries, cataracts often occur earlier in life. One of the developing countries that has the highest number of people with cataract is Indonesia. Figure 1.3 shows a statistic of cataract patients in Southeast Asia in 2001 [47]. In fact, it is estimated the number of cataract patients in Indonesia exceeds the amount which was presented on the graph in Figure 1.3. On the other hand, Indonesia only has about 750 ophthalmologists for population more than 200 millions people (one for every 350.000 people) [35]. In addition, Ophthalmologists are not evenly distributed. Many ophthalmologists are located in the capital city, yet many people have not access to ophthalmologist because of geographic conditions. Regarding these conditions, it is crucial to implement a compact screening system for several diseases common there.

The only way for treating cataract is a surgery. Although surgery is a simple way for cataract treating, the real fact in the developing countries like Indonesia, there are unequal conditions between the number of patients and surgical capacity as shown in the Figure 1.4. The graph in the Figure 1.4 refers to an annual report from Kamandaka eye clinic Indonesia [24]. As discussed in subsection 1.1.1, today ophthalmologist use a slit lamp or opthalmoscope to obtain a clear information about the inside of the lens for detecting eye diseases like cataract,

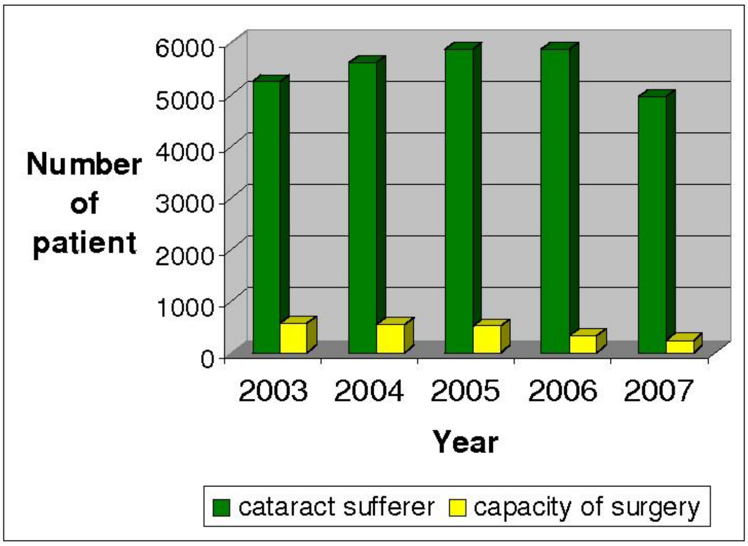


Figure 1.4. Comparison between cataract patients and surgical capacity

but both tools are expensive and require special training to use it. These facts may not be a problem in developed countries like Japan, the USA or the UK, for example. However, this is a problem for some developing countries like Indonesia, Nepal, and Vietnam. According to conditions in developing countries like Indonesia which has limited number of both ophthalmologists and health facilities, implementing equipment with a compact screening system for several eye diseases that are common there is useful.

1.2. Related works and contribution

Cataract is a common disease of human eye therefore a lot of related research about cataract. We classify the research into three categories. **The first category** is research about statistics and causes of cataract. For example, Lewis studied development of granting acuity in children treated for dense congenital unilateral or bilateral cataract and examined how variations in treatment affect granting acuity during early childhood [58]. Sasaki surveyed cataract epidemiology using application of photo documentation [53]. Lin assessed the relationship between myopia and age-related cataract in defined older population [56]. Kadka analyzed the progress of eye care in Gaur Nepal. Their investigation found that the number of cataract patients are increased [11]. Hargaard determined the incident and cumulative risk of childhood cataract in Denmark during 1980 to 2000 [44]. Congdon determined the quantity of association between siblings in age-related nuclear cataract after adjusting for known environmental and personal risk factor [25].

The second category is research about diagnosing cataract. For example, Sugata examined normal and cataract lenses and suggested the possibility of diagnosing by measuring the attenuation characteristic of the lens [99]. Biwas discovered the role of catalin in the prevention of posterior capsular opacification (OPA) conducted an experimental study on rabbit [73]. Garif applied speckle technologies and measured retinal angular resolution by laser retionometer at the stage of preoperative cataract diagnosis [42]. Frohn introduced the beam deflection method to evaluate vision impaired by cataract [39]. Babyzhayev introduced the halometer for measuring intraocular light scattering in the presence of human cataract [1]. Roizenblatt analyzed verification of iris identities after intra-ocular procedures when individuals were enrolled before the surgery [75]. Raitelaitiene measured the attenuation coefficient of the lens and investigated the distribution of its value in different patient group. They used ultrasound examination and calculation of the attenuation coefficient for early stage of cataract detection [71]. Kwok investigated the possible role of accommodative biomechanical forces in the development of human cataract and anterior human lens was modeled using standard engineering membrane theory [57]. Feraro used nonmyadriatic fundus camera for cataract detecting [41] . Aina assessed the association between hormone replacement therapy and cataract [38]. Donnelly created personalized computer eye models to simulate an individual's vision [50]. Rocha analyzed higher-order aberration induced by different types of lenticular opacities and found the functional limitations of patient with senile cataract can be adequately assessed using wavefront analysis in eyes with nuclear and cortical cataract [91]. Tsui explored the feasibility study of using ultrasonic parametric image based on nakagami distribution to quantify the lens hardness [61]. Ansari proposed a new instrument for detecting cataract using dynamic light scattering and coreal topography. This instrument is frequently used in mapping the corneal topography during PRK (photorefractive keratectomy) and LASIK (laser in situ keratomileusis) procedures in shaping of the cornea to correct myopia [72]. Scanlon did a research about the influence of age, duration of diabetes, cataract and pupil size on image quality in digital photographic retinal screening [76]. Forte did a research about contribution of chromatic aberrations to color signals in the primate visual system [28].

We summarize that above works discussed about proposed alternatives method for cataract diagnosing and dedicated to ophthalmologists or a condition in which there are not problems about health facilities. A little difficult to apply these research results in developing countries that have limitations in health facilities.

To solve the problem for diagnosing cataract especially in developing countries which have limitations of health facilities, we propose a cataract screening system using image processing techniques. These techniques support the use of a low-cost and easy-to-use equipment such as digital camera to be used in our research. We chose to use a digital camera as the main equipment with reference to the working principle of the slit-lamp camera and ophthalmoscope in which this equipment using the light to check the condition of the eye lens, so we adopted the use of the slit-lamp camera or ophthalmoscope light with a flash light on digital camera lenses to represent the condition.

In our method, we will extract all information about cataract from pupil area only because all information about cataracts comes from the lens only. This is based on the fact that the opacities as an important sign of cataracts occur in the lens, while based on the anatomy of the eye as described by Makeart [34] and shown in Figure 1.5, it appears that the condition of the lens can only be seen through the pupil; therefore, we need to localize pupil.

In image processing field especially for localizing pupil, there are some studies. We classify this kinds of studies into third category. **The third category** is research about eye image processing especially for localizing pupil. The exam-

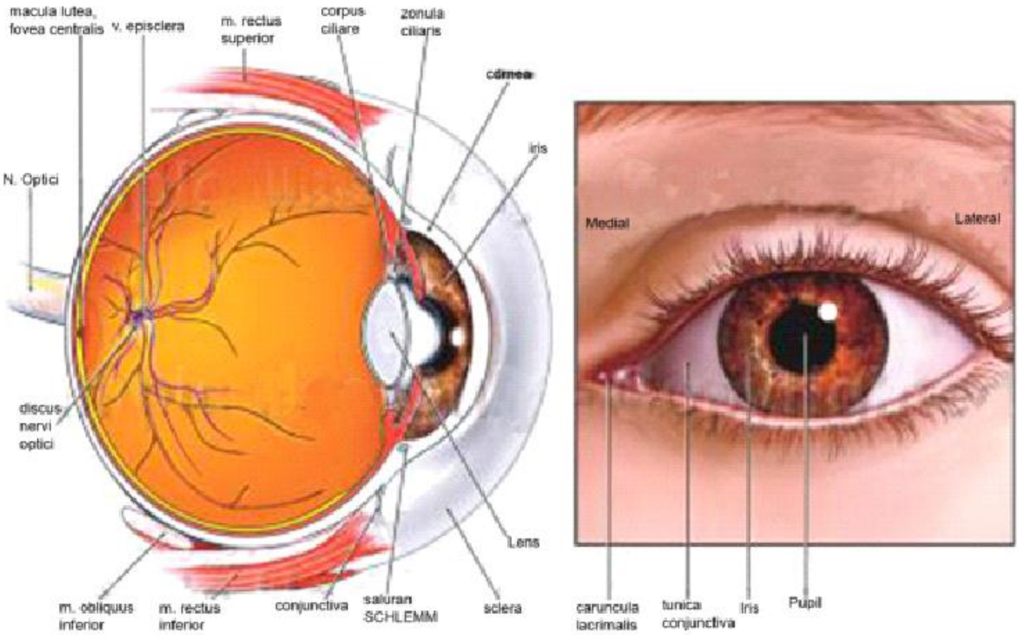


Figure 1.5. Eye anatomy

ples research of this category are: Ebisawa proposed an algorithm for windowing around the pupil image on the basis of difference pupil detection method which works on a relatively cheap construction [98]. Xhifei proposed a method for estimating the center and radius of the pupil [101]. Funahashi proposed a system for extracting eye gaze information and introduced a system for supporting a video conference system [87]. Wan proposed a novel iris quality assessment based on Laplacian of Gaussian operators [95]. Jomier developed a new tool for automatic quantification of the pupil dilation to test the hypothesis that dark adaptation is slowed proportional to the amount of stress that an individual has experienced [51]. Bhuiyan proposed a robust and precise scheme for detecting faces and locating the facial features in image with complex background. Facial features, such as eyes, nose, mouth, eyebrow,etc are localized from face skeleton with the knowledge of the face geometry [10]. Gupta proposed an iris recognition algorithm with the help of corner detection [68]. Cho proposed a method for pupil and iris segmentation in the mobile environment [46]. Yuan proposed a method for localizing pupil in non-ideal eye images [102]. Park proposed a new iris recognition method for mobile phones based on corneal specular reflection [67]. Masek developed an 'open source' iris recognition system in order to verify both the uniqueness of the human iris and also its performance as a biometric [59].

Almost all works in third category discussed about image processing for localizing eye areas including iris and pupil. By adopting some image processing algorithms, we develop a simple algorithm for localizing pupil as will be discussed in Chapter 3 .

Our works discuss about applying image processing techniques in cataract diagnosis field. To the best of our knowledge our research is the first work that discusses this topic. In the early works we found that using specular reflection appears inside a pupil able to distinguish between serious and non-serious condition without depends on the illumination condition [82][81]. However, sometimes we got a problem for distinguishing specular reflection and whitish color, therefore we extract an uniformity texture inside a pupil for improving our method to screen cataract [83][84]. In order to improve our system performance, we extract all information appear inside a pupil including specular reflection and texture for cataract screening [86]. Finally, for giving a guideline about using our system in a real implementation, we did a design and practical data acquisition for getting an appropriate input image for our system [85]. In this thesis we emphasize on the description of the whole part for implementing our method in a real condition including data acquisition, process analyzing and a simple guideline for getting an appropriate input image.

The main purpose of our research is to develop a simple and robust cataract screening system. In real conditions, usually to measure the performance of the newly proposed system is to compare the performance with existing systems. However because our research is the first work that discuss this topic so we do not have another comparison system;therefore we refer to the performance of ideal system only. To test the performance of our system, we use several parameters. The first is True Positive Rate (TPR). TPR determines a classifier or a diagnostic test performance on classifying positive instances correctly among all positive samples available during the test. The second is FPR (False Positive Rate). FPR, on the other hand, defines how many incorrect positive results occur among all negative samples available during the test [89]. A perfect classification will have a TPR value 100% and a FPR value 0%. Referring to the definition of a perfect system, our system is expected to have a TPR and FPR as mentioned earlier. We only use TPR and FPR parameters because these parameters are sufficient to represent the accuracy of a system.

1.3. Contributions of the thesis

In order to get a clear information about our research, this thesis will discuss the whole part of our method for cataract screening as shown in Figure 1.6 and described in the following explanations.

Chapter one will discuss about background of this thesis, including definition of cataract, several kinds of cataract categories, current diagnosing of cataract,

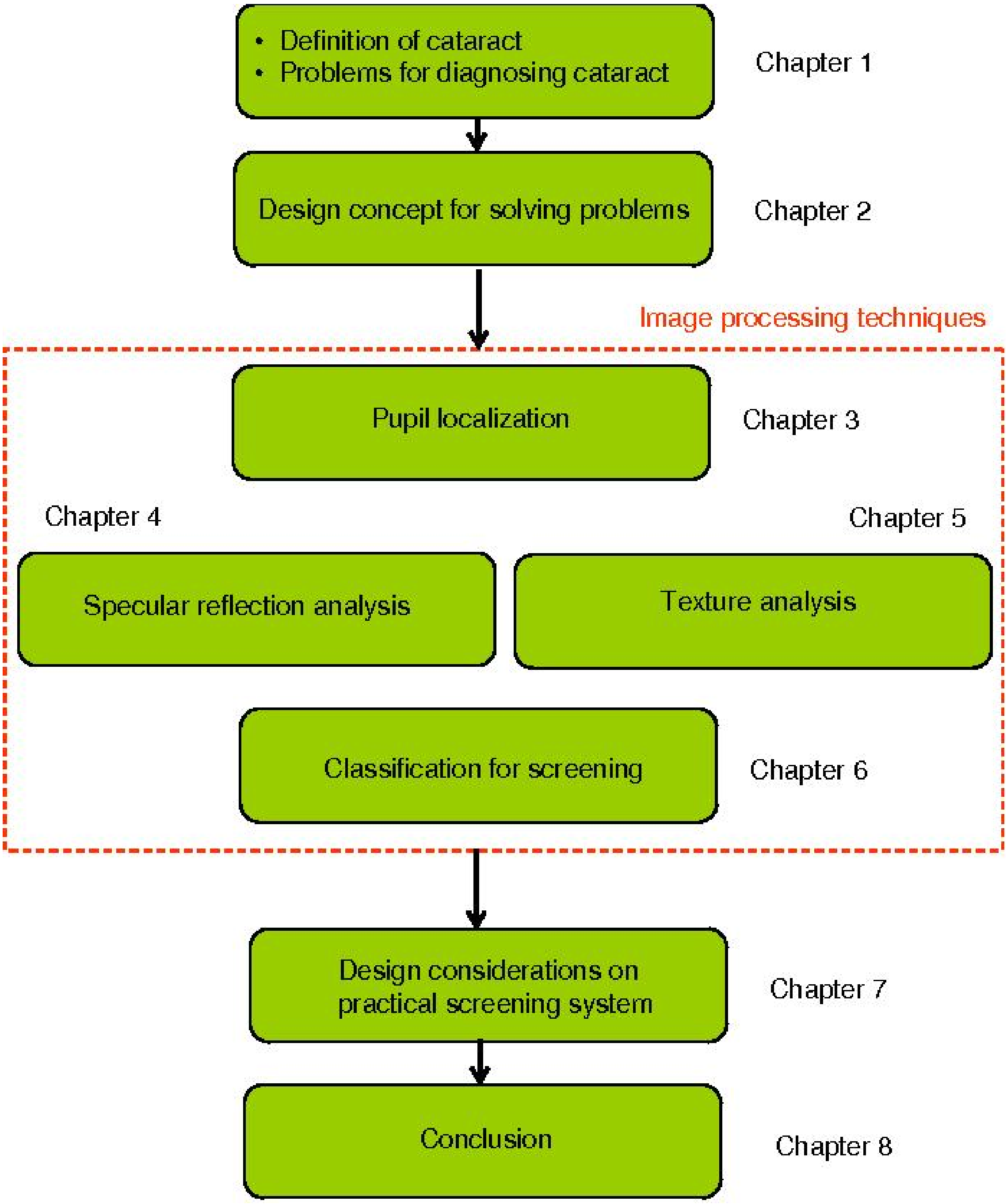


Figure 1.6. Roadmap of the thesis

statistic of cataract, and problem of cataract in developing countries. Also related works about cataract studies in which separating into three categories. The first category is research about the statistic and the causes of cataract. The second category is research about diagnosing cataract. and the third category is research about image processing technique. **Our contribution in this chapter** is finding problems about difficulties for diagnosing cataract under limited health facilities as common in developing countries.

Chapter two will discuss about the whole concept of our research. The main purpose of our research is handling problem about the limitations of both ophthalmologist and health facilities in developing countries. It is based on the problems arise for cataract diagnosing as discussed in chapter one. This chapter shows examples of both conditions between cataract eye images and normal eye images, examples of equipments which usually used for cataract diagnosis. **Our contribution in this chapter** is proposing an alternative method for cataract screening under limited health facilities.

Chapter three will discuss about pupil localization. In our system, all information about cataract is extracted from the pupil only. Basically, a pupil is a black hole in the iris through which one can peer into eye. Although there are a lot of ethnic in the world with many kinds of iris color, however their pupil always black in a normal condition. This chapter shows an example of color of pupil that does not depend on ethnicity. **Our contribution in this chapter** is developing a simple algorithm for localizing pupil in which will be used in our screening system

Chapter four will discuss about specular reflection analysis. This is the core of our system. In this chapter we divide specular reflection into two kinds of reflection. The first is frontside refelection and second is backside reflection. Specular reflection analysis method will detect frontside and backside reflection inside the pupil based on reflection theorem. We develop our algorithm to refer to the working principles of the opthalmoscope and slit lamp. We found a characteristic of serious and non-serious condition by using information about specular reflection inside a pupil. **Our contribution in this chapter** is finding a new method for cataract screening by exploiting specular reflection appearance inside a pupil.

Chapter five will discuss about texture analysis. We extract texture appearance inside the pupil for detecting cataract. First, distribution of whitish color for some serious conditions are uneven so we can exploit an uniformity inside the pupil. Second, we exploit an average intensity features inside the pupil. **Our contribution in this chapter** is considering the use of texture in order to improve the performance of our system despite the fact that information about the texture is not stable because it depends on the illumination conditions

Chapter six will discuss about classification of screening in which our system will distinguish between serious and non-serious conditions. Also, this chapter will show experimental results of our research. **Our contribution in this chapter** is showing the performance of our system is promising for cataract screening under limited health facilities.

Chapter seven will discuss about some of the considerations when our system is applied in the real condition. This refers to conditions in developing countries which have limitations in terms of health facilities that need a simple system design, but effective for cataract screening. The most important is the typical examples of appropriate input images for diagnosis using our system. Also, this chapter describes a guideline for taking photographs in order for getting an appropriate input image. **Our contribution in this chapter** is proposing a simple system design for cataract screening, but effectively applied in developing countries which have limitations in terms of health facilities.

Finally, **Chapter eight** will summarize the work already done in our research include the possibility of open issues still to be developed from our research. The beginning of this chapter will begin with the conclusions of our research. This chapter will close with our plans for future research. We hope our research will be useful tools for cataract screening under limited health facilities.

Chapter 2

Screening Flow

2.1. Flow concept

As discussed in Chapter 1 Section 1.1.3, most of developing countries have limitations both of ophthalmologists and health facilities. On the other hand there are many people with cataract need treatment as soon as possible. This condition requires a simple system for cataracts screening so that people with serious conditions able to get treatment as soon as possible.

In order to solve the problems about limitations of ophthalmologists and health facilities in developing countries, we propose a simple cataract screening system. Referring to the discussion in Section 1.1.2 about equipment for diagnosing cataract, so far the simplest way to detect cataract is using ophthalmoscope. This program still preceded by a preliminary test to find out about the condition of the eye disorder that can only be done by ophthalmologists or medical staff who have received training on how to do preliminary tests for eye diseases. Based on this fact, in our research, we choose digital camera as a main equipment. This option based on the working principle of the slit-lamp and ophthalmoscope in which these devices using the light to check the condition of the eye lens, so we adopted the use of the slit-lamp or ophthalmoscope light with a flash light on digital camera lenses to represent the condition. Also, a compact digital camera 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 spe-

(a) Slit-lamp screening (b) proposed screening

Figure 2.1. Cataract diagnosis using slit-lamp (a) and proposed screening (b)

cial training where specialists are unavailable; it is less expensive than a slit lamp camera. The two types of equipment are shown in Figure 2.1. So that we can formulate the objectives of our research is to develop a robust cataract screening under limited health facilities using a low-cost and easy-to-use equipment.

Our system will distinguish between serious and non-serious conditions only. The reason is this condition is effective to describe the number of people who need immediate treatment, and also it is useful when applied in developing countries who have limitations in terms of health facilities. In this thesis, we have not considered yet to classify each class of cataracts because our main goal is to find people who need surgery as soon as possible. But for the future research we will consider to do the classification for each class. To do this we need to get a similar perception among ophthalmologists therefore our classification can apply to all circumstances.

As discussed in Chapter 1, the only treatment of cataract is surgery; therefore, implementing our cataract screening system in developing countries is useful. For example, in a remote area, although there is not ophthalmologist but local government staff able to perform screening on residents who live in this area, so that can be assembled a database of existing cataract sufferers in the area and which can be sorted in a serious conditions to get treatment as soon as possible. If a patient is in serious condition will be recommended to other areas that have

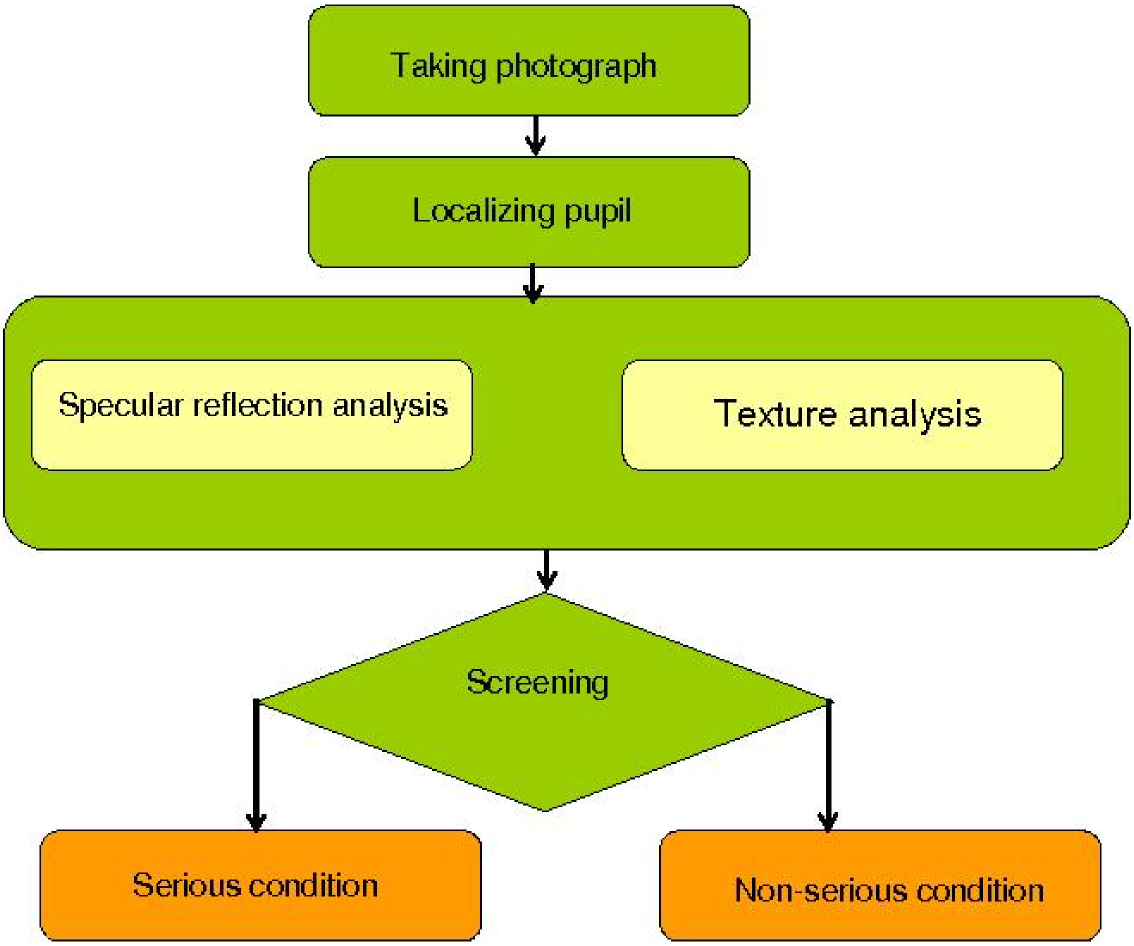


Figure 2.2. Flowchart of proposed screening method

adequate health facilities to get a treatment. If in the area there are a lot of patients who are in serious condition, the local government may submit a request to the health department in central government to send medical staff to the area in order for providing treatment to patients. Thus will speed up the handling of patients who require immediate treatment.

Design concept of our system is described in Figure 2.2. First user simply takes a patients photograph of an eye. By extracting specular reflection and texture appearance inside the pupil, system will analyze the condition of the patient eyes and classified them into two conditions are serious and non-serious conditions.

As discussed in Chapter 1, for doing data acquisition we use a portable digital camera. However, when using a portable digital camera, we found problems such as insufficient image quality and uncontrolled illumination. Figure 2.3 shows some examples of pupil images taken by different cameras. It is appears in here that the average intensity of a serious and non-serious conditions inside the pupil is not clear separately. For example, if we employ intensity value for screening cataract, i.e. higher intensity corresponds to a serious condition, it would fail for a cataract eye image taken under low illumination as shown in Figure 2.4. Its appears that a non-serious condition eye image has an average intensity is about 155 inside a pupil while a serious condition eye image only has an average intensity is about 55 inside a pupil.

Referring to this fact, we decide to use specular reflection analysis as the core of our method. It is based on the characteristics of specular reflection is not depend on illumination conditions. The main characteristic is the intensity of specular reflection always higher than the intensity in the surrounding area. In a specular analysis method, we will investigate an availability of backside reflection. It is a kind of specular reflection that occurred in the rear side of lens. For a non-serious condition there is a backside reflection appears in a pupil, while for a serious condition there is not a backside reflection appears in a pupil. Detail discussion about this method will discuss in Chapter 4.

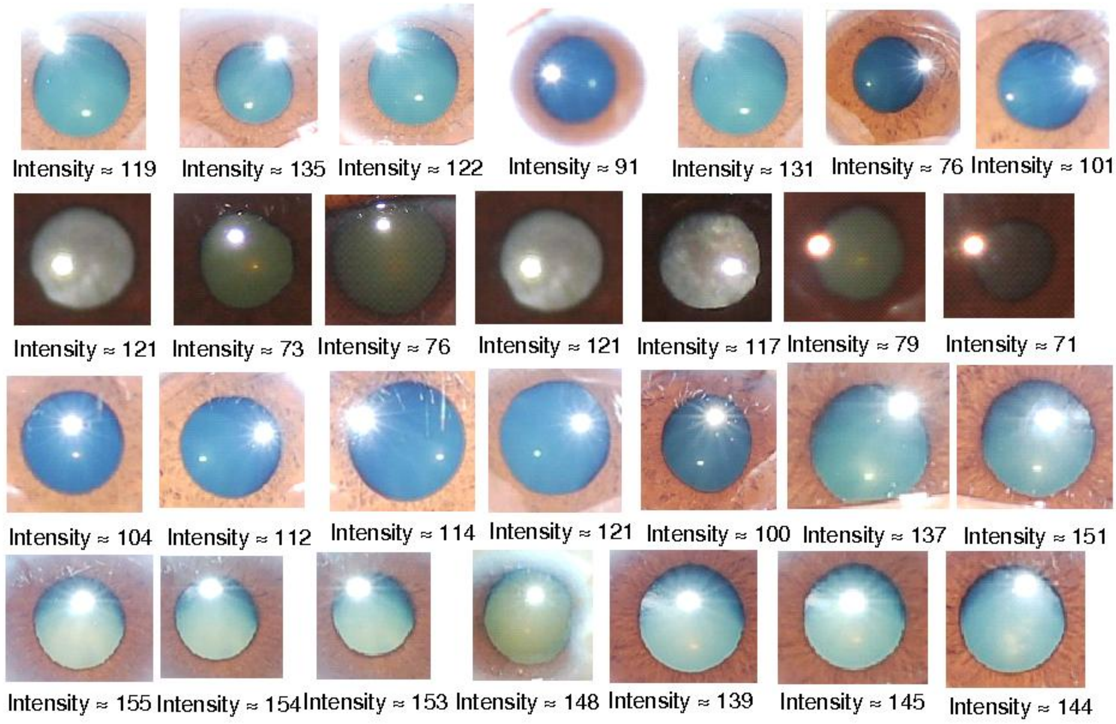
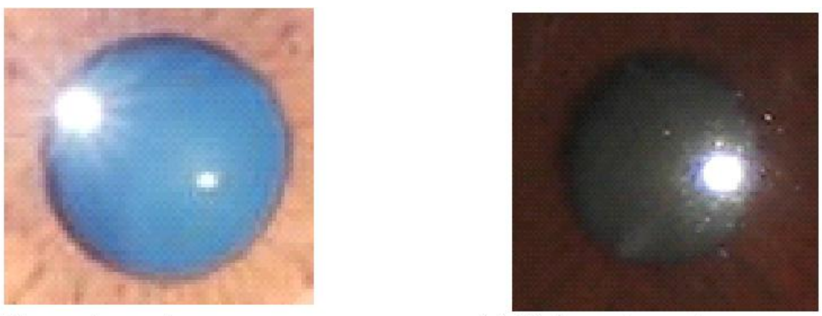


Figure 2.3. Example of pupil images taken by different cameras



(a) Normal eye image
Average intensity inside
pupil area about 155

(b) Cataract eye image
Average intensity inside
pupil about 55

Figure 2.4. Example of photographs under uncontrolled illumination

In the texture analysis method, we extract information about the uniformity and the average intensity inside the pupil. Assuming that a non-serious condition has not whitish color in the lens and the pupil have seen smooth surface so that a non-serious condition has a higher value of uniformity compared to serious condition. On the other hand, a serious condition has a higher value of average intensity than a non-serious condition. **Only, it should be noted here** that these conditions are not stable because it depends on the illumination conditions, while our system does not consider the existence of a controlled illumination conditions. Detail discussion about texture appearance will be discussed in Chapter 5. By combining two types of analysis, our system can distinguish between serious and non-serious conditions.

2.2. Experimental data preparation

Data was collected in Japan and Indonesia, also taken by an amateur photographer using a portable digital camera under uncontrolled illumination. In Japan, data was collected from some locations. **First** is "The house of elder people" (Chomeisho) Ikoma Japan with number of images about 89 images data. However, most of people who stay in this house already got a surgery for their eyes therefore they did not have an original eye lens and we ignore this kind of data. Also, because most of people who stay in this house is elder people so it is little bit difficult to give a direction for elder people to open their eye during taking photograph, therefore some images have bad quality such as their eyes are closed. Regarding this condition, we used 18 images only consist 7 images are serious conditions and 11 images are non-serious conditions. **Second** is Nara Institute of Science and Technology Japan (NAIST). We took photographs of staff in NAIST with number of images about 160 images consists of 122 images are non-serious conditions, 36 images are people who used soft lens and 2 images are people already got surgery. Regarding our research, we ignore images with soft lens and already get surgery; therefore we used 122 images of non-serious condition only. **Third** is Advanced Intelligence Laboratory. We took photographs of members in Advanced Intelligence Laboratory with number of images about 118 images and

all of images are non-serious conditions.
In Indonesia, data was collected in Kamandaka Eye Clinic. We took about 519 images consists of 201 images are serious conditions and 318 images are non-serious conditions. In total, we have about 886 images. However, because we ignore some images as described in above paragraph, therefore we use 777 images only.

Currently, our system is intended for taking images in a room only, therefore, we used the images photographed in a room only. and regarding the environmental condition, we take photograph in many kinds of conditions. As already discussed in the paragraph above, the data acquisition process carried out at four different places namely chomeisho, advanced intelligence laboratory, building of graduate school of information science, and kamandaka eye clinic. In each place we did not set the illumination conditions, so it can be said that each location of data retrieval has different illumination conditions. Also, equipment used in data retrieval is quite different. In the data retrieval in the building of graduate school of information science and some data in advanced intelligence laboratory, we use the equipment as shown in Figure 2.5. Actually we use the same tools that will be discussed in Section 7.2. The difference is we use a factory-made chin rest and commonly used by ophthalmologists and a laser distance meter to measure the angle and distance of the camera placement. This equipment has some advantages as follows [29] :

(i) Precise, fast and reliable indoor measurements
(ii) Easy-to-use and rapid access to frequently used functions
(iii) Measured values can be read even in the dark
(iv) Measure from edges or corners
(v) Stake-out equal distances
(vi) Measure without shake
(vii) indirect height and width measurements for inaccessible positions
(viii)Splash and dust proof

While for data retrieval in chomeisho and kamandaka eye clinic, we use the

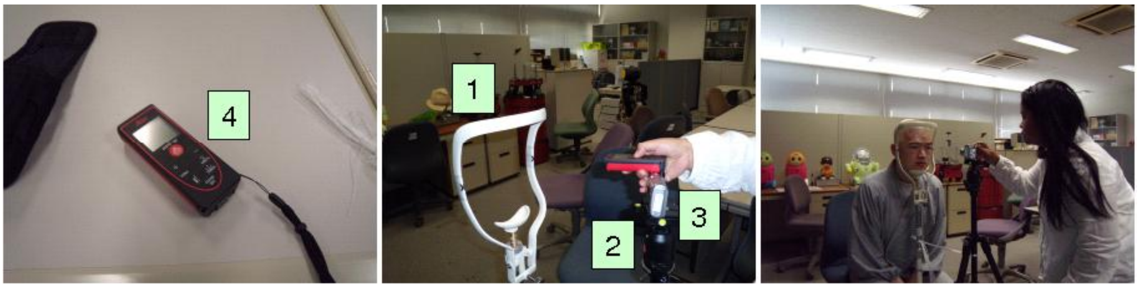


Figure 2.5. Equipment used in the experiment in our laboratory

same equipment as will be discussed in Section 7.2. There should also underlined here, that we use different types and brands of digital camera at each place of data retrieval without camera calibration. This is in accordance with our goal to create a simple system. Effect of different types and brands of digital cameras on screening results will be discussed in Chapter 6.

Chapter 3

Pupil Localization

3.1. Definition of pupil

We extracted all information inside the pupil including specular reflection and texture appearance because all information about cataract is taken from the pupil region only as discussed in Section 1.2. The pupil of eye is simply a hole in the iris through which one can peer into the eye. It appears black because of the darkness inside [33]. Referring to this definitions, we can conclude that the color of the pupil is universal; it does not depend on ethnicity although the color of the iris is different for different ethnicity as shown in Figure 3.1.

Figure 3.1. Color of pupil does not depend on ethnicity

The pupil gets wider in the dark but narrower in light. When narrow, the diameter is 3 to 4 millimeters. In the dark it will be the same at first but will approach the maximum distance for a wide pupil of 5 to 8 mm depending on a person age. In a real condition, we can measure size of pupil and expressing by unit mm, while in an image plane the size of pupil is expressing by pixel. However as discussed in above paragraph, the size of pupil always change while the size of iris always fix; therefore, for getting a universal pupil size we express by a ratio between pupil and iris and indicated by symbol P_r as will be discussed in Section 7.3.

Referring to the related works about pupil localization as discussed in Chapter 1 then we can classify information used for localizing pupil in the existing works. Almost all data acquisition in the existing works using different equipments and conditions with our system. Sometime they use a web camera [87], special cameras [51], or if they use a regular camera but the condition while data acquisition process arranged to be the same illumination condition [98], [95], [46]. However, the input images in our system can not be classified based on the above information because data acquisition process using a variety of types and brands of digital cameras. Also, as has been discussed in Chapter 2, data taken from different places and different illumination conditions as well; therefore, we propose our own algorithm for localizing pupil as will be discussed in the following section.

3.2. Algorithm

3.2.1 Overview of the proposed algorithm

An overview of the proposed algorithm is shown in Figure 3.2. First, entering the image captured by portable digital camera into our system. Input image is R-G-B; therefore, in order to make processing easily then extracting image into red, green and blue component. Subsection 3.2.2 will discuss detail information about extracting image into red, green and blue component. The next step is subtracting red component by green component followed by implementing median filter into image. Using canny edge detector we implement edge detection. However we still get some noises in surrounding predetermined eye area therefore the next step is reducing noise. Finally, by applying circular Hough transform we got a center coordinates and radius of pupil.

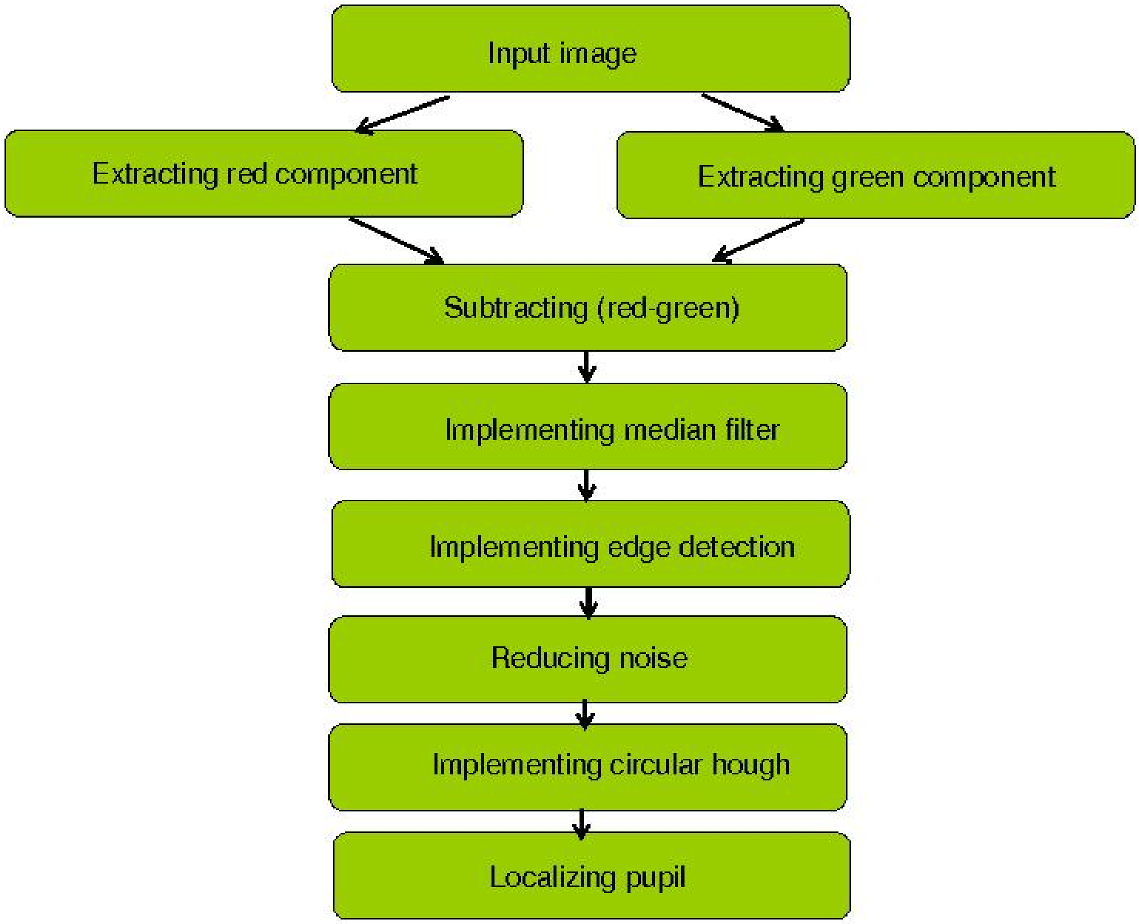


Figure 3.2. Flow chart of the proposed algorithm

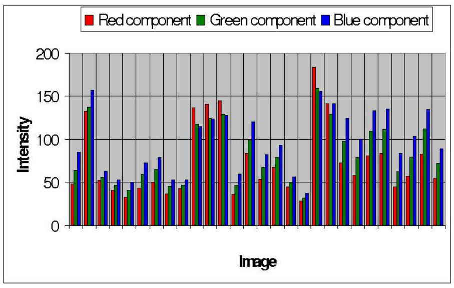
3.2.2 Extracting red-green component

Pupil is the hole or opening that is located in the center of the iris of the eye. The pupil controls the amount of light that enters the eye [8]. Usually, the color of pupil darker than another part of eye anatomy. However, in fact when we use a variety of types and brands of digital cameras, the pupils are not always darker than the surrounding areas. Sometimes darker, sometimes almost the same or sometimes more brightly than the surrounding area. The input image is an RGB color image where each color is is a triplet corresponding to the red, green and blue component [20]. However, some applications in image processing techniques such as edge detection operator, filtering , Hough transform, etc require gray-scale image therefore we extracted pupil image into red, green and blue component.

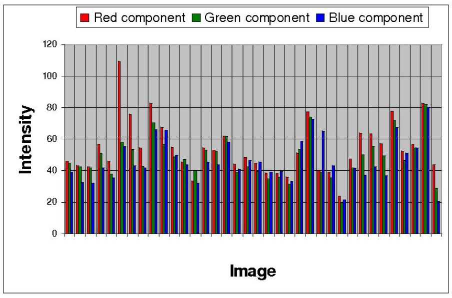
Figure 3.3 shows an example of extracting image into RGB component for some images produced by some kinds of camera. Subfigure 3.3(a) is histogram of red-green-blue component produced by cameras in which we able to separate between flash light and camera. Usually this kinds of camera is used by a professional photographer. For using this kind of camera we need to arrange some tools in this camera; therefore, it is not anyone able to use this kinds of camera. Also, the price of this kinds of camera is little bit expensive.
Subfigure 3.3(b), Subfigure 3.3(c) and Subfigure 3.3(d) are histogram of red-green-blue component produced by compact digital cameras in which we could not separate between flash light and camera. It is a kind of pocket camera with a simple quideline to use it; therefore, anyone able to use this kind of camera easily. Also these kinds of camera is inexpensive. Referring to our goal for developing a cataract screening system by a low cost and easy-to-use equipment, it is suitable for using a pocket digital camera.

By assuming, if we could make a pupil area always darker than surrounding area it means we able to get a clear edge detection of pupil area. In order to make that area darker than surrounding area, we have to make the intensity in the pupil area close to zero; therefore to get intensity equal to zero, the best way is doing subtraction between R-G-B component. We tried some experiments by subtracting each red, green, and blue components as shown in Figures below.

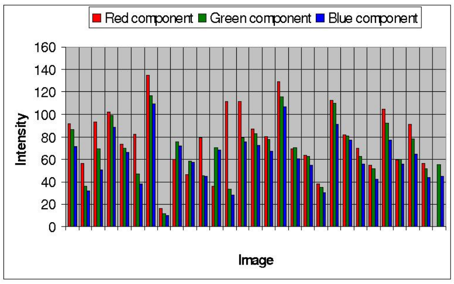
Figure 3.4 shows an example of subtracting red and green component in an image in which a pupil region appears difference with surrounding areas. It appears darker than surrounding area. Also, it is happen in Figure 3.5 which shows an example of subtracting red and blue component in an image. The results is



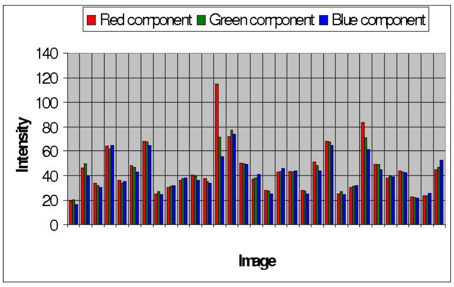
(a) Histogram of red-green-blue component of Nikon D40X



(b) Histogram of red-green-blue component of Nikon coolpix L12



(c) Histogram of red-green-blue component of Canon IXY digital 820IS



(d) Histogram of red-green-blue component of Nikon coolpix S710

Figure 3.3. Histogram of red-green-blue component of some kinds cameras

quite similar with the previous one. Figure 3.6 shows an example of subtracting green and red component in an image in which there is not information about eye area. Figure 3.7 shows an example of subtracting green and blue component in an image in which the result is not clear. Figure 3.8 shows an example of subtracting blue and red component in an image and Figure 3.9 shows an example of subtracting blue and green component in an image. Both images have information about specular reflection area only.

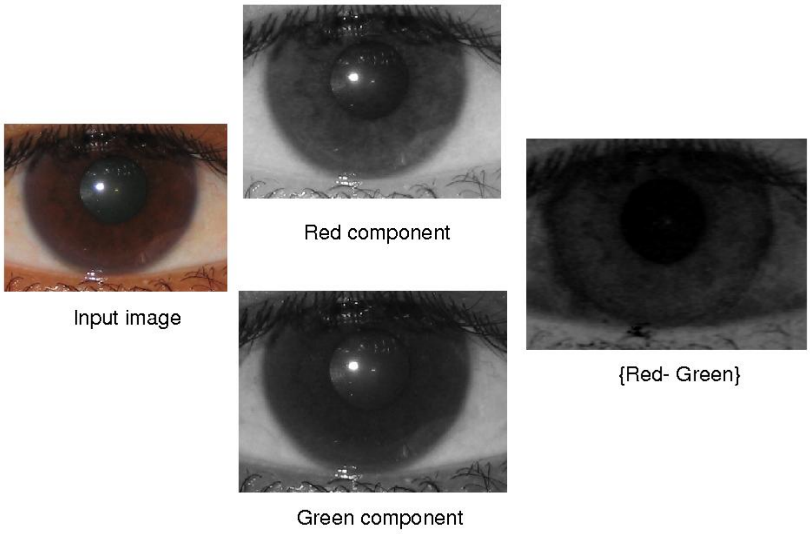


Figure 3.4. Example of subtracting red-green component in an image

Referring to the results as shown in Figures 3.4 to Figure 3.9, We got an appropriate result when we subtract red component by green component;therefore, we determine to use this algorithm.

3.2.3 Implementing median filter

Median filter is a spatial filter that replaces the center value in the window with the median of all the pixel values in the window [20]. An example of median filtering of a single 3×3 window of values is shown in Figure 3.10.

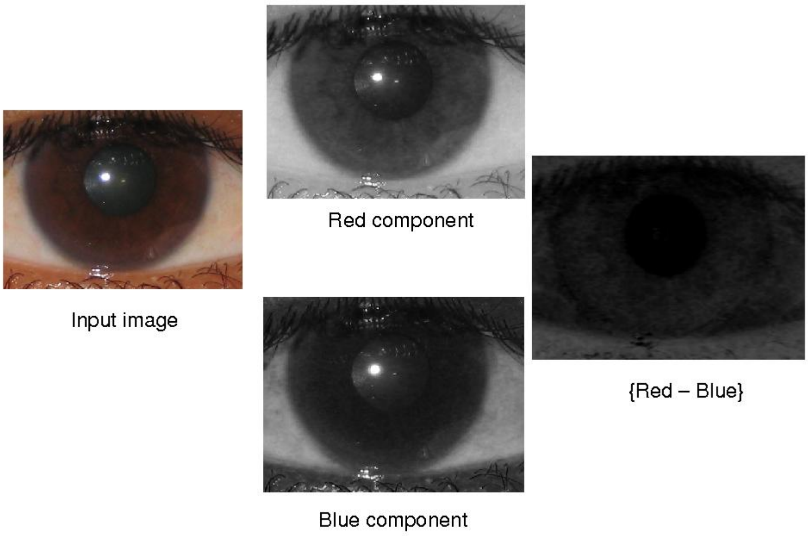


Figure 3.5. Example of subtracting red-blue component in an image

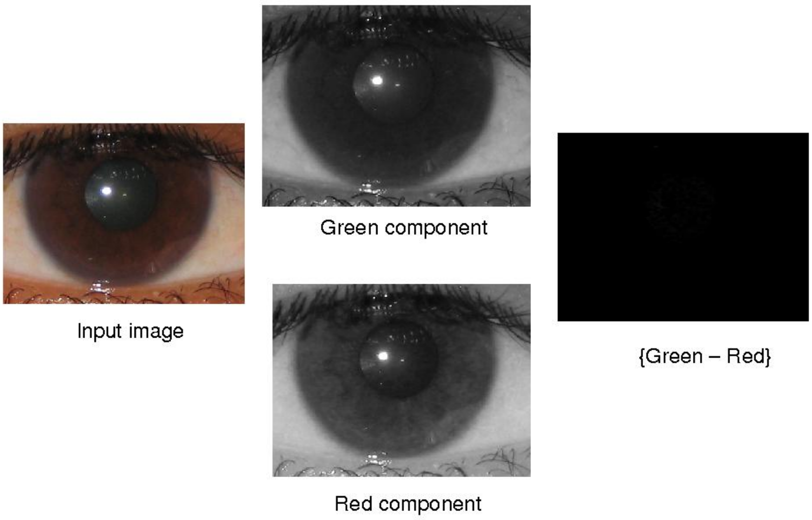


Figure 3.6. Example of subtracting green-red component in an image

Time processing when applying median filter to pupil localization algorithm depends on the size of median filter itself. A large size of a median filter faster than a small size. Figure 3.11 shows an effect of median filter size to time processing in our algorithm. The function of median filter is used to remove salt and pepper noise in the input image. In our algorithm, implementing median filter is

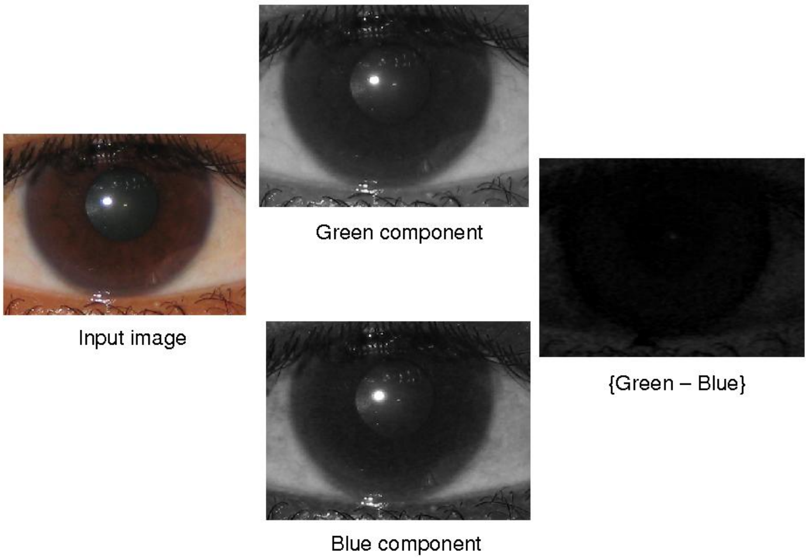


Figure 3.7. Example of subtracting green-blue component in an image

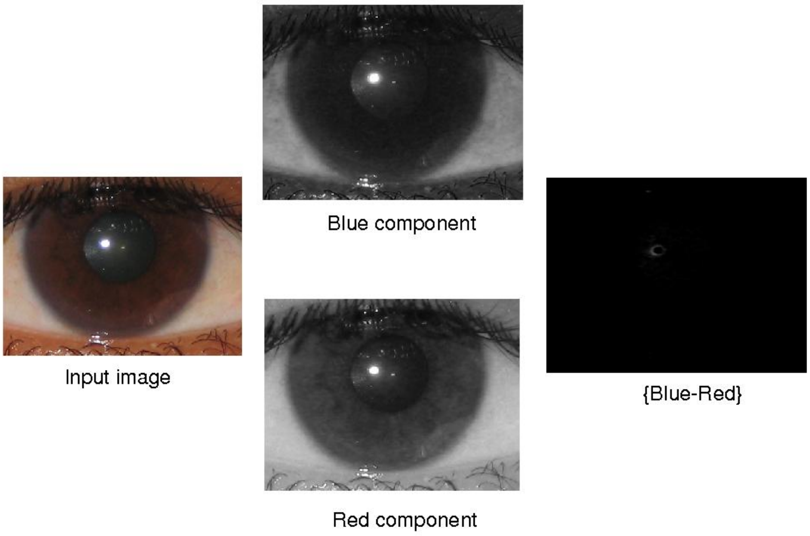


Figure 3.8. Example of subtracting blue - red component in an image

used to remove undesired area except the pupil area only. However, sometimes a large size of median filter will remove many areas including the pupil area, therefore, although a large size of median filter has a fasten time processing but it does not mean have a good accuracy to remove undesired noise. Figure 3.12

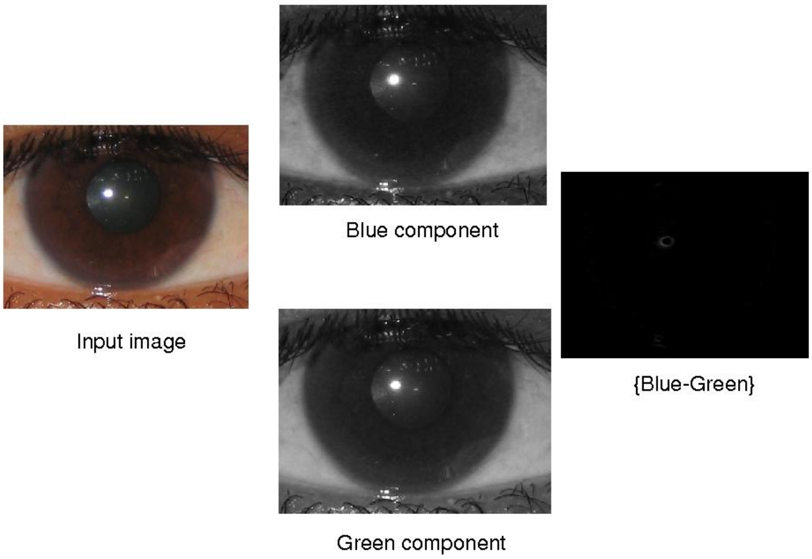


Figure 3.9. Example of subtracting blue - green component in an image

Original image

$$\begin{bmatrix} 6 & 2 & 0 \\ 3 & 97 & 4 \\ 19 & 3 & 10 \end{bmatrix}$$

In order : 0,2,3,3,4,6,10,19,97

Median filtered

$$\begin{bmatrix} * & * & * \\ * & 4 & * \\ * & * & * \end{bmatrix}$$

Figure 3.10. An example of median filtering

shows a result when applying median filter into an image by variations size of median filter.

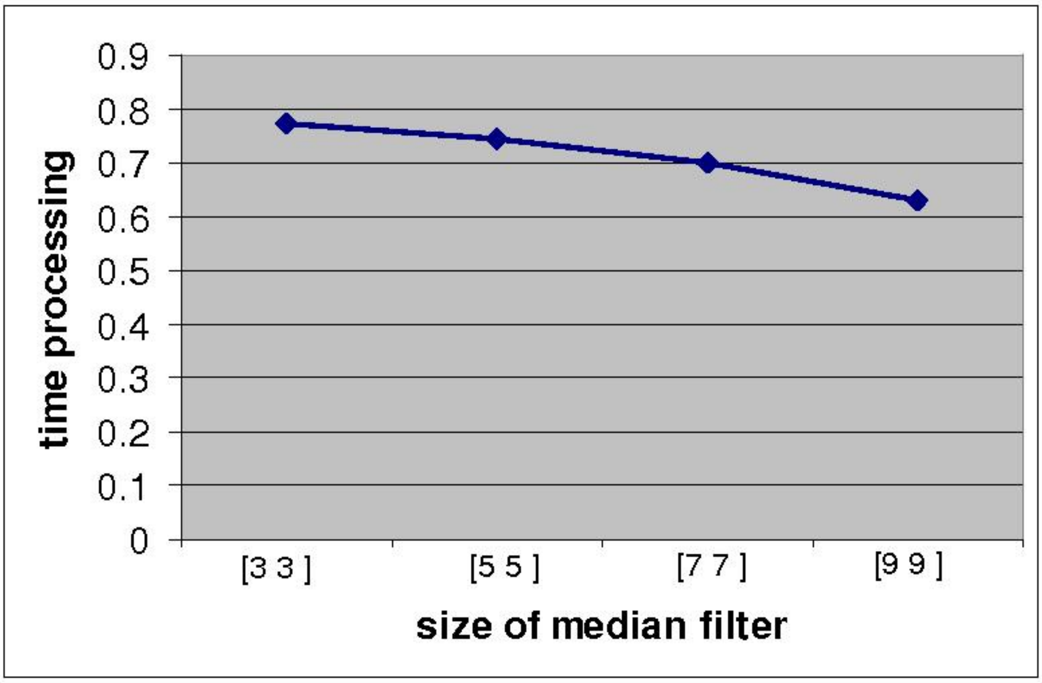


Figure 3.11. Graph of time processing

3.2.4 Edge detection

Edge detection is an algorithms which aim at identifying points in a digital image at which the image brightness changes sharply or more formally has discontinuities. The quality of images produced by portable digital camera is average and sometimes have a worst quality while the canny edge detector algorithm is known to many as the optimal edge detector [2]. Therefore we implement canny edge detection to get an edge point for detecting pupil area. Figure 3.13 shows a result of canny edge detection with varying values of σ. Symbol σ expressing a standard deviation of gaussian filter and control the degree of smoothing.

It appears in Figure 3.13 when $\sigma = 1$ edge detection has a discontinue line in a pupil area with a lot of noise, while when $\sigma = 2, \sigma = 3, \sigma = 4$ the edge detection has a full area of a pupil with some noise variations. To evaluate accuracy of each σ to the whole images, we train all values of σ into images.

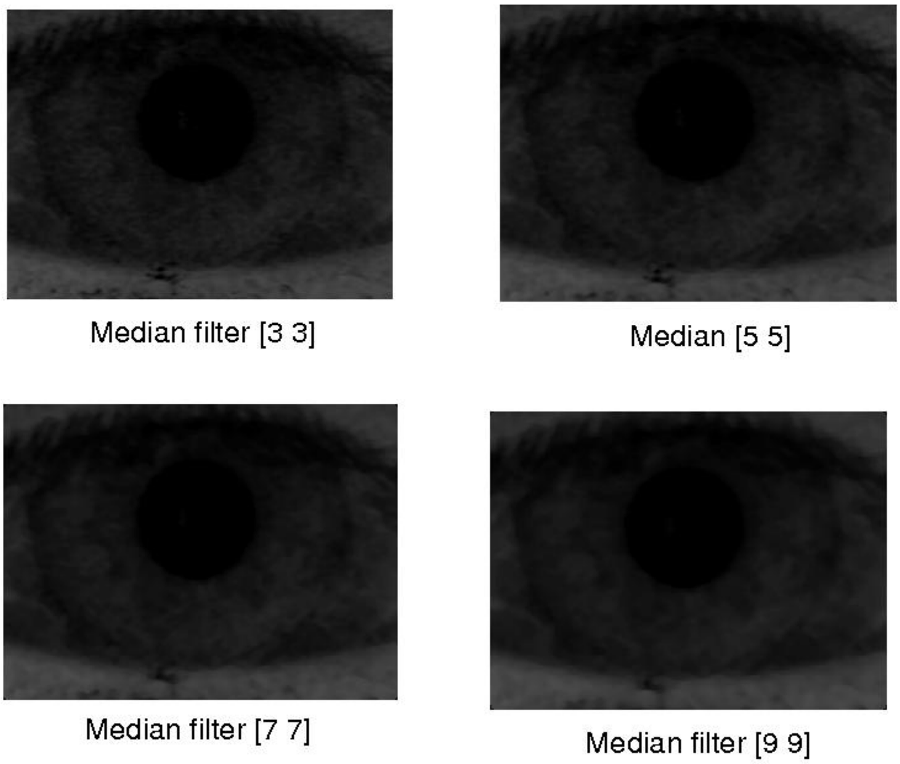


Figure 3.12. Size variations of applying median filter

3.2.5 Reducing noise

As discussed in Subsection 3.2.3 and Subsection 3.2.4, although the function of median filter if it is implemented in an image is reducing noise, however we still get undesired area in canny edge detection result. We assume that a smaller radius of pupil in our algorithm is 25 pixel. The reason is we took photographs in the same condition of distance between object and camera about 30-60 cm as shown in Chapter 2 Figure 7.6. Then we calculate a perimeter of circle by $K = 2.\pi.r$. Where r is a radius of pupil (assumed 25) and π is $3,1416$. We remove edge line that has number of element $< K$. Figure 3.14 shows an image result after reducing noise. It appears that some noise has been remove, although we still get some undesirable area.

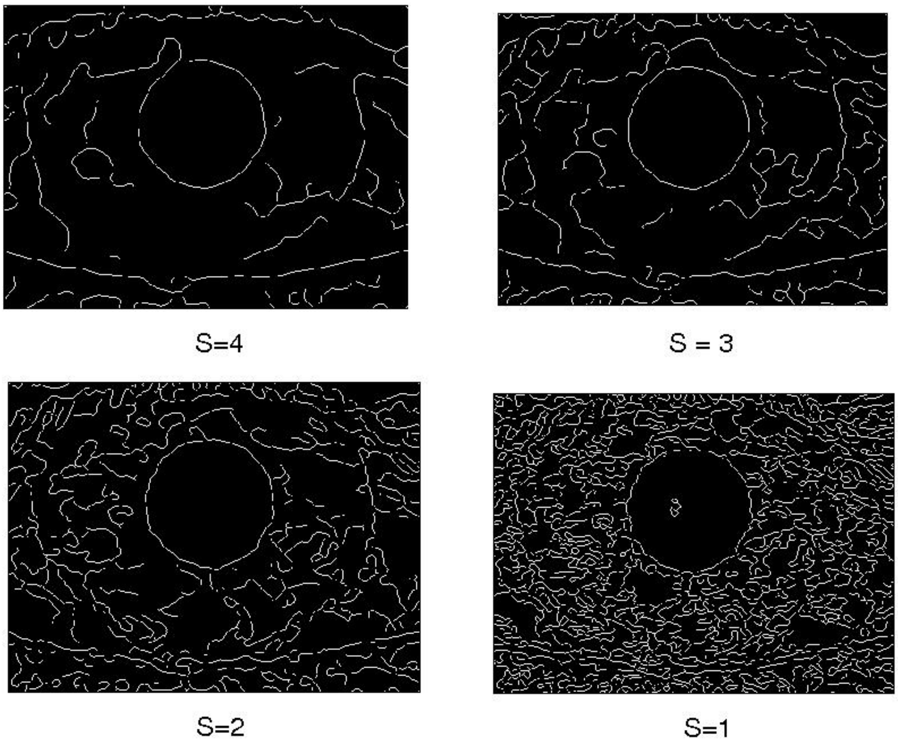


Figure 3.13. Canny edge detection result

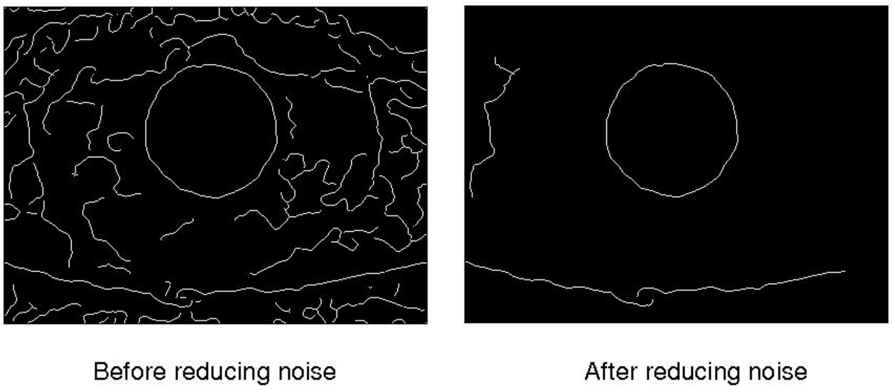


Figure 3.14. Reducing noise

3.2.6 Hough transform

Hough transform is a technique which can be used to isolate features of a particular shape within an image. Hough transform is most commonly used for the detection of regular curves such as lines, circles, ellipses, etc [2]. The main advantages of Hough transform are the robustness to discontinuous pixels and noise in real world images therefore it can identify positions of arbitrary shape. By assuming pupil is a circle we can identify a center and radius of the pupil, therefore we can localize pupil. Figure 3.15 shows a result of pupil localization.

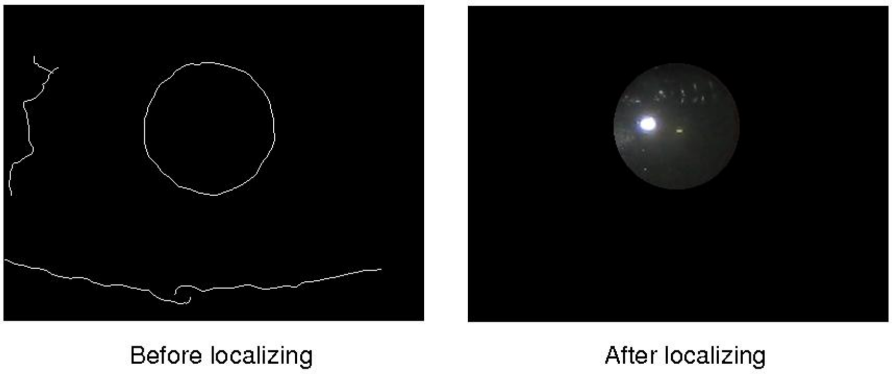


Figure 3.15. Localizing pupil

3.3. Experimental results

We tested our algorithm into 777 images taken by an amateur photographer using a portable digital camera and illumination is uncontrolled. The result of algorithm to localize pupil is shown in Figure 3.16.

It appears that our algorithm has a highest accuracy about 89% when the size of median filter is 3×3 with the value of $\sigma = 3$, although time processing is slower than others [Subsection 3.2.3]. It is caused by a condition when we apply a median filter with size 3×3, we still get the whole area of pupil although there are some noises available. However, when we apply a median filter with higher size, we success to reduce a lot of noises but it also remove some desired area. By

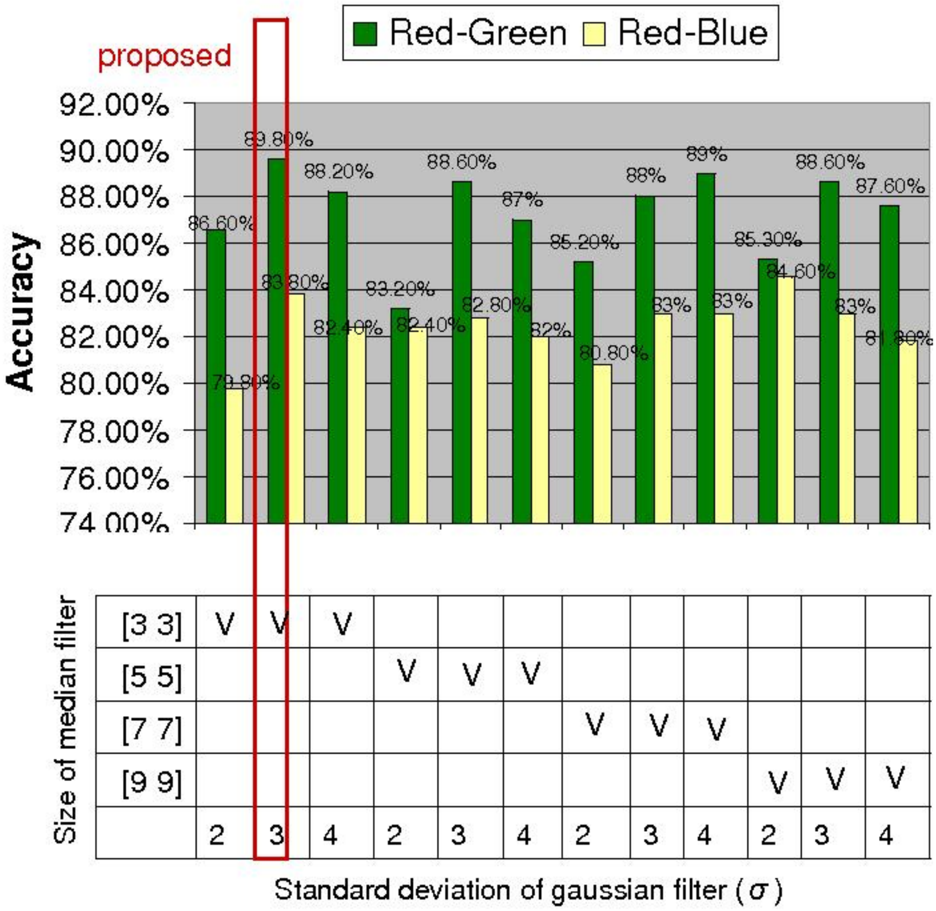


Figure 3.16. Performance evaluation

applying a smaller size of median filter and a circular Hough transform we able to get a good accuracy for localizing pupil.

Failure in the pupil localization caused a reason as follows: during taking photograph of patients, users have to ask the patient to open his eyes as wide as possible to avoid noise caused by eyelashes and eyelid. However, in fact it is difficult to do that, although in this way we can prevent noise caused by the eyelid, but it is difficult to eliminate noise caused by eyelashes. This is because most of Indonesian people had long eyelashes, so even if he opened his eyes as wide as possible but eyelashes still cover the pupil. Figure 3.17 shows an examples of the input image, where the inappropriate input image will cause the failure of the pupil localization.

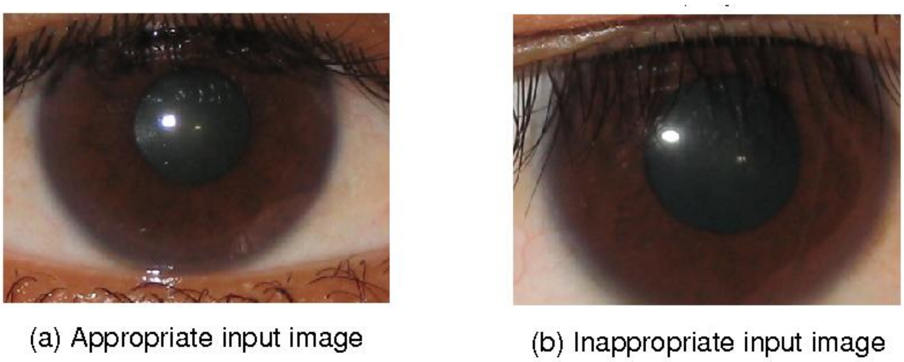


Figure 3.17. Example of input image

In the real condition, we can not ignore this factor because in fact to make this system work we will always be faced with the same cases. Regarding this case, in further research we should consider the existence of eyelashes for localizing pupil, so the performance of algorithm can be improved.

Chapter 4

Specular Reflection Analysis

4.1. Definition of reflection

Specular reflection is viewpoint dependent. According to Snell's law, light striking a specular surface will be reflected at an angle which mirrors the incident light angle, which makes the viewing angle very important. Specular reflection forms tight, bright highlights, making the surface appear glossy. In reality, Diffusion and Specular reflection are generated by exactly the same process of light scattering. Diffusion is dominant from a surface which has so much small-scale roughness in the surface with respect to wavelength, that light is reflected in many different directions from each tiny bit of the surface with tiny changes in surface angle.

On the other hand, specular reflection dominates on a surface which is smooth, with respect to wavelength. This implies that the scattered rays from each point of the surface are directed almost in the same direction rather than being diffusely scattered. It is just a matter of the scale of the detail. If the surface roughness is much smaller than the wavelength of the incident light it appears flat and acts as a mirror [31]. This is readily apparent on shiny surfaces. For an ideal reflector, such as a mirror, the angle of incidence equals the angle of specular reflection [66] as shown in Figure 4.1.

Our method adopted the specular reflection process occurs, however the surface used here is the eye lens as described in detail in the next section and described in Figure 4.2.

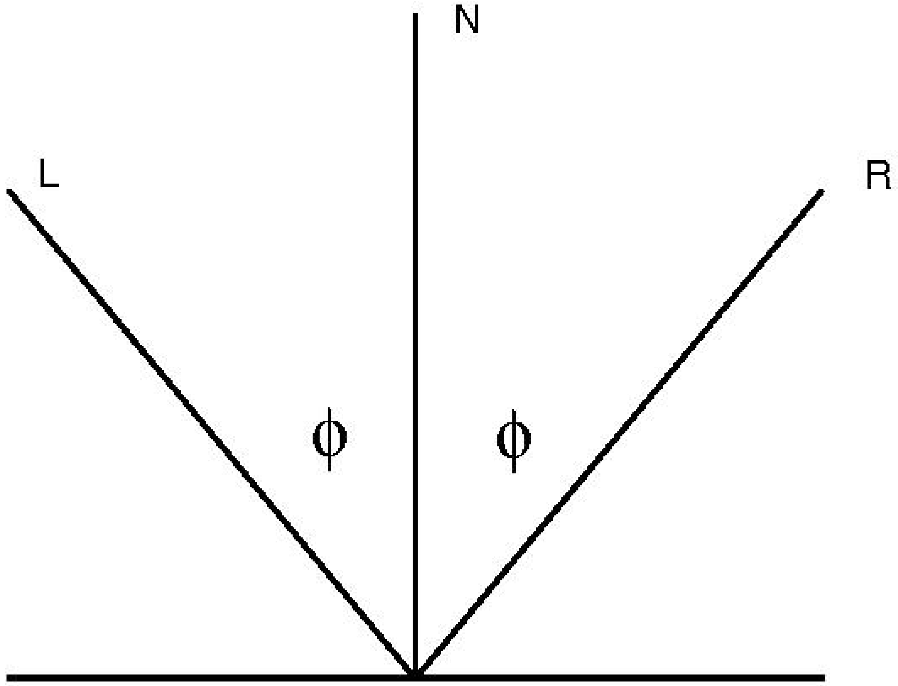


Figure 4.1. Example of ideal reflection

4.2. Specular reflection for detecting cataract

We develop our algorithm refer to the working principles of the ophthalmoscope and slit lamp. An ophthalmoscope is an instrument that enables an ophthalmologist to examine inside of a person eye. The instrument has an angled mirror, various lenses, and a light source. A slit lamp is an instrument that enables a doctor to examine the entire eye under high magnification and that allows measurement of depth. The slit lamp focuses a bright light into the eye [9]. Both tools are similar for diagnosing cataract in that they utilize a light to examine the opacities inside the lens.

Figure 4.2 describes the principle work of the specular reflection method [82],[81]. Light hits the frontal surface of the lens and makes a reflection called the frontside reflection. However, actually light also hits the rear side of the lens. For a non-serious condition, there is not a whitish color inside the lens therefore it will be reflected again, which is called backside reflection. For a serious

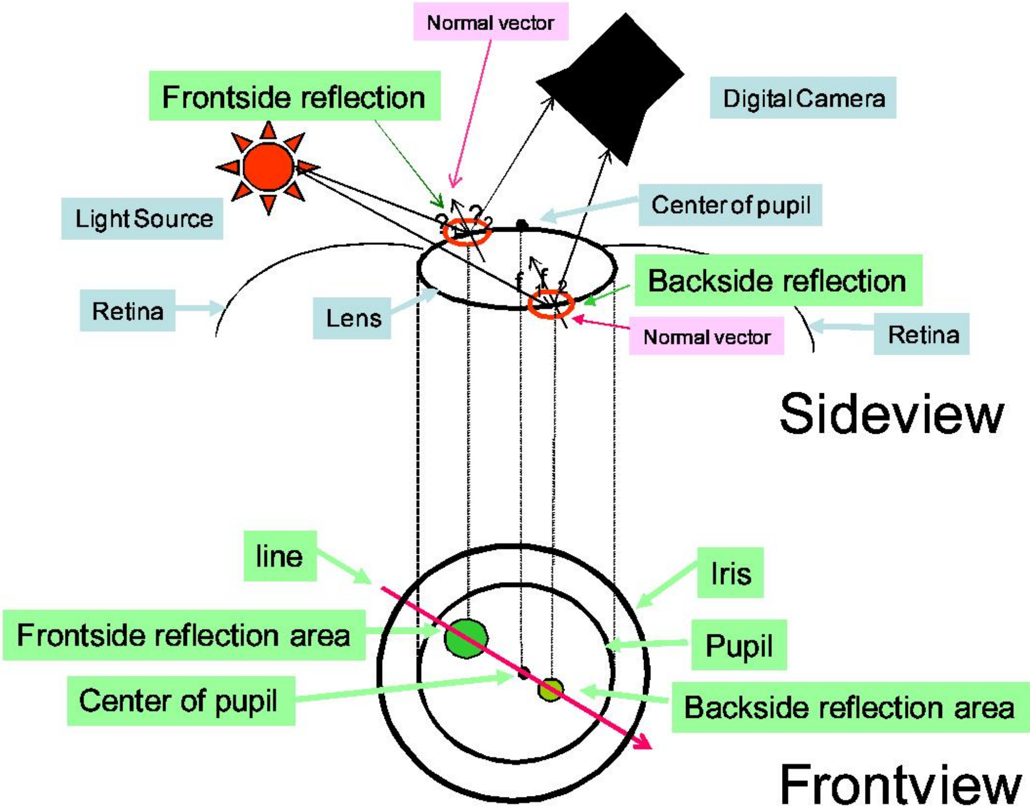
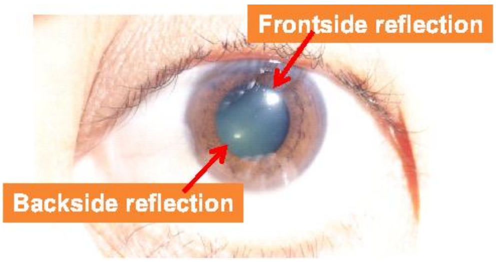


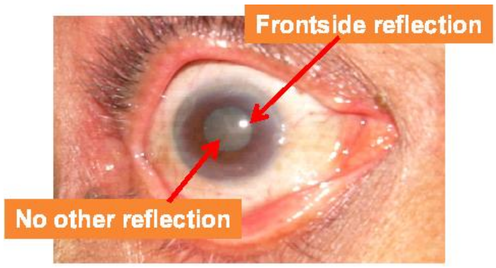
Figure 4.2. Model of reflection characteristic in eye

condition in particular, because there is a lot of clouding in the lens, light will not be reflected again. The different characteristics are shown in Figure 4.3. Referring to reflection theorem, the direction of the normal vector always goes to the center of the pupil; therefore, when we look at the image appearance we can find the relationship of the location between the two reflections and the center of the pupil; they are on a single line. Using relationship between both reflections, we conducted a search to find the backside reflection as depicted in Figure 4.4. Also by using coordinate of center and radius of the frontside reflection, we then searched for backside reflection by searching for areas of higher intensity beside the frontside reflection compared with their immediately surrounding areas in a line that expressed by Equation 4.1.

$$A = (d + r) - \delta \tag{4.1}$$



(a) non serious condition



(b) serious condition

Figure 4.3. Example of reflection appearance

where A is length of backside reflection searching, d is distance between center of pupil and the center of frontside reflection, r is radius of pupil and δ is radius of backside reflection.

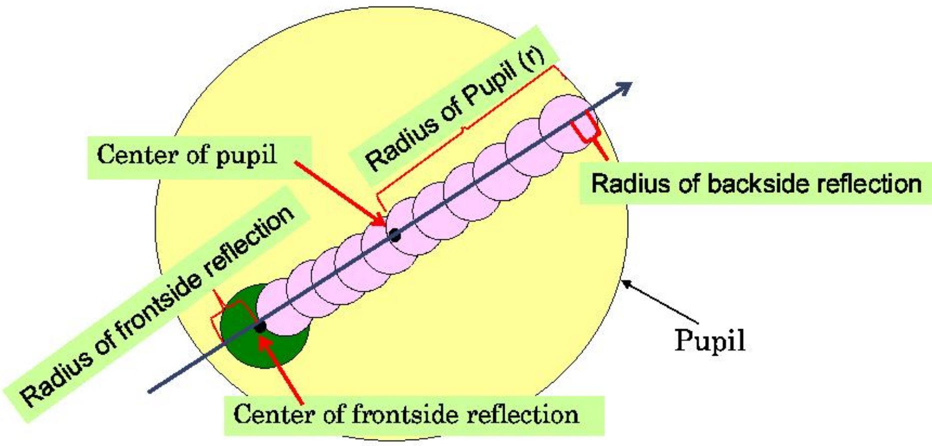


Figure 4.4. Searching backside reflection area data

Referring to the result of intensity tracking as shown in Figure 4.4, we implement a differential function in a discrete system to develop an automatic screening between serious and non-serious condition based on intensity tracking result that is expressed by Equation 4.2.

$$D = I(S) - I(S-1) \tag{4.2}$$

where I is intensity and S is a distance between center of the frontside reflection and the next circle that will be investigated. During intensity searching, if $D(S) > 0$ means there is an increasing intensity value. Otherwise, if $D(S) < 0$ means there is a decreasing intensity value. A non-serious condition will always have a great increasing intensity that indicates existence of a backside reflection [82],[81]. However it does not mean that a serious condition did not have increasing intensity during intensity tracking. According there are some variations numbers of intensity searching, we did normalization for number of increasing value by Equation 4.3.

$$P_n = \frac{T}{n} \tag{4.3}$$

where T is number of points that have increasing intensity value and n is number of points along intensity tracking line.

4.3. Algorithm for detecting frontside reflection

4.3.1 Overview of algorithm

Algorithm for detecting frontside reflection is shown in Figure 4.5. The first step in specular reflection analysis is detecting frontside reflection. We use the result of pupil localization in Chapter 3 as an input image. Second, we convert an input image to binary image based on a threshold that will discuss in the next section. Then we apply Sobel edge detector for boundary detection and apply Hough transform to localize frontside reflection.

4.3.2 Converting to binary image

The simplest type of image which is used widely in a variety of industrial and medical applications is binary, i.e. a black-and-white or silhouette image. Binary image processing has several advantages : First, Easy to acquire: simple digital cameras can be used together with very simple frame stores, or low-cost

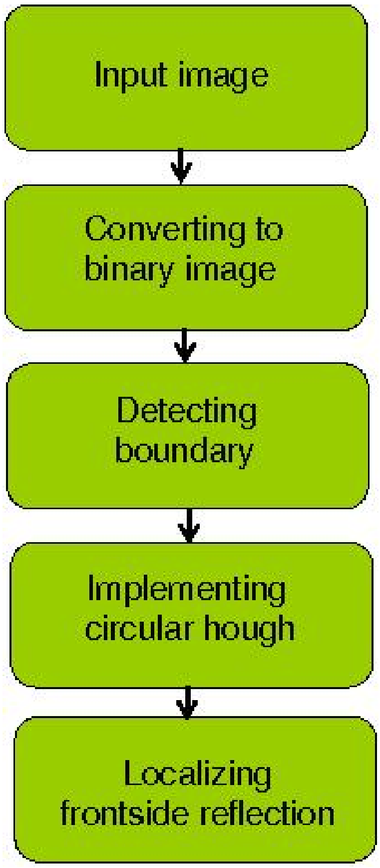


Figure 4.5. Flow chart of detecting frontside reflection

scanners, or thresholding may be applied to grey-level images. Second, Low storage: no more than 1 bit/pixel, often this can be reduced as such images are very amenable to compression (e.g. run-length coding), and third, Simple processing: the algorithms are in most cases much simpler than those applied to gray-level images [37]. In the simplest case, an image may consist of a single object or several separated objects of relatively high intensity, viewed against a background of relatively low intensity. This allows figure/ground separation by thresholding. In order to create the two-valued binary image a simple threshold may be applied so that all the pixels in the image plane are classified into object and background pixels. A binary image function can then be constructed such that pixels above the threshold are foreground ("1") and below the threshold are background ("0"). In this thesis we express a threshold by symbol Th. Referring to our experiment result as shown in Figure 4.6, it appears that frontside reflection always have an intensity value more than 200 although we took image in uncontrolled illumination condition and without considering another aspects. Therefore in our research we assume that Th is 200. This value will be used for converting to binary image. In different environmental setup, it is possible to change value of Th. An example of converting an input image to binary image shown in Figure 4.7.

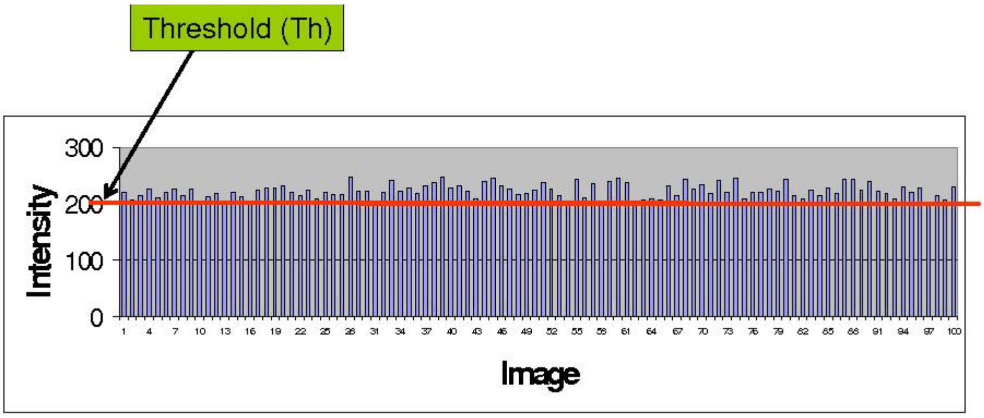


Figure 4.6. Intensity of frontside reflection area

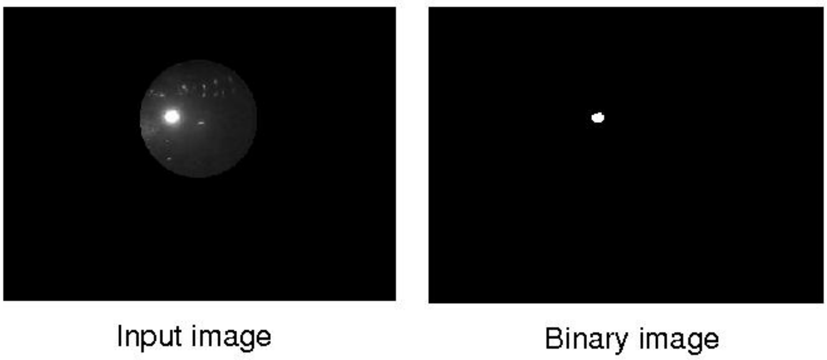


Figure 4.7. Example of converting to binary image

4.3.3 Detecting boundary

Edge detection is a terminology in image processing and computer vision, particularly in the areas of feature detection and feature extraction, referring to algorithms which aim at identifying points in a digital image at which the image brightness changes sharply or more formally has discontinuities. The Sobel operator is used in image processing, particularly within edge detection algorithms. Technically, it is a discrete differentiation operator, computing an approximation of the gradient of the image intensity function. At each point in the image, the result of the Sobel operator is either the corresponding gradient vector or the norm of this vector. The Sobel operator is based on convolving the image with a small, separable, and integer valued filter in horizontal and vertical direction and is therefore relatively inexpensive in terms of computations. On the other hand, the gradient approximation which it produces is relatively crude, in particular for high frequency variations in the image [43] [96]. In our algorithm, we apply Sobel edge detection on a binary image for detecting boundary of specular reflection as shown in Figure 4.8.

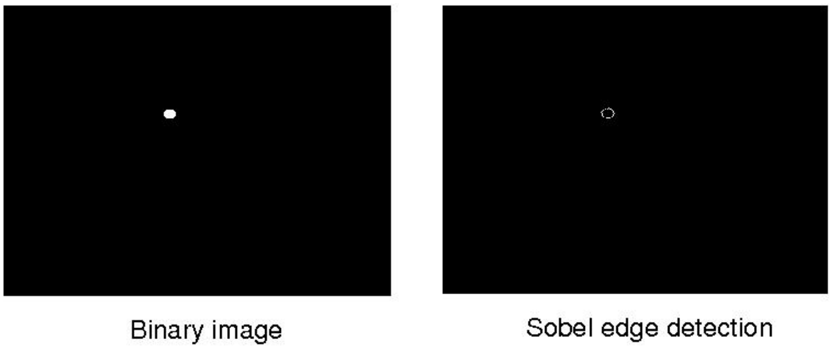


Figure 4.8. Example of applying Sobel edge detection

4.3.4 Implementing circular Hough transform

The Hough Transform is performed to recognize circular patterns based on parameters such as circle radius range, gradient threshold and presence of concentric circles. The Hough Transform will in as an input a range of radii. It will then generate circles of varying radii which cover the entire range. These circles are convolved with the image and the goodness of match is recorded in an accumulation array [100]. In our algorithm we assume that frontside reflection is a circle. By implementing a circular Hough transform on the result of boundary detection, we got coordinate of center and radius of the frontside reflection. Figure 4.9 shows an example of localizing frontside reflection.

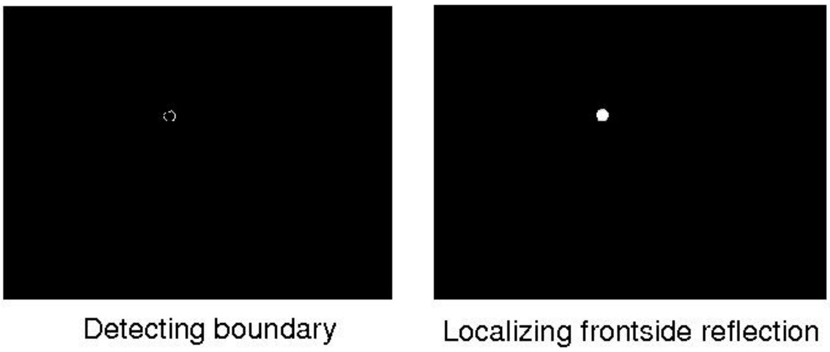


Figure 4.9. Example of localizing frontside reflection

4.4. Algorithm of searching for backside reflection

This is the core method for extracting specular reflection feature because it will present backside reflection availability inside the pupil. Basically, we search for intensity along the direction line starting from the center of the frontside reflection pixel by pixel [82],[81]. During intensity tracking, we measure average intensity in a circular area around a focused pixel. The size of circle radius is determined by the following study. In fact, the size of backside reflection always smaller than the radius size of frontside reflection, although the difference is not known exactly. In our experiments, we have many assumptions about the radius size of backside reflection.

First we assume that it has the same size as radius of the frontside reflection, after that we reduce size step by step as shown in Figure 4.10. We implement

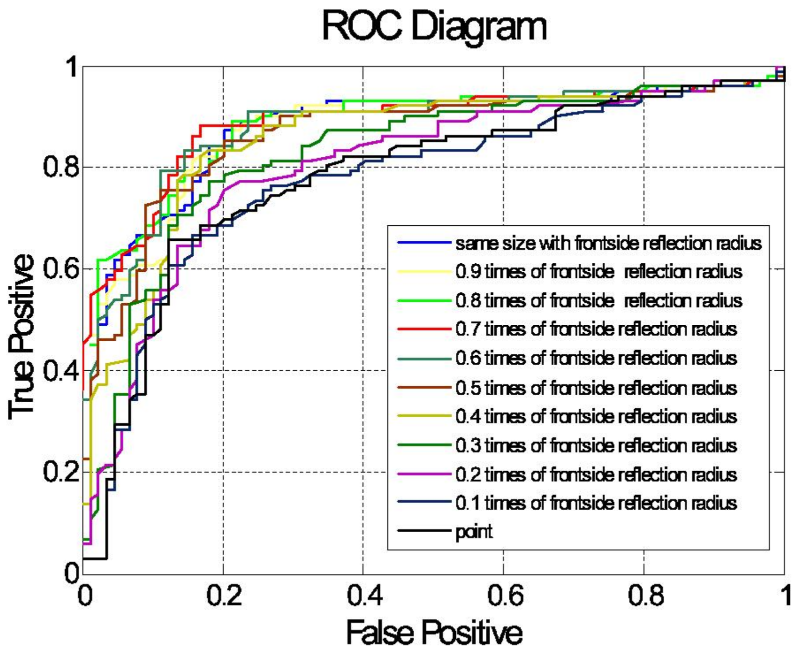


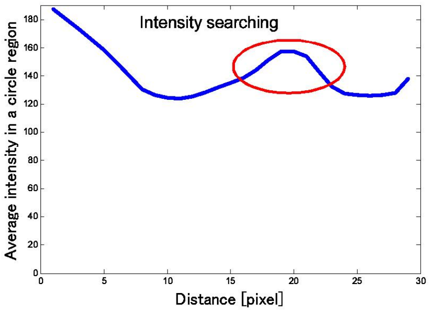
Figure 4.10. Preliminary study of radius size of backside reflection

each radius size of backside reflection into cataract diagnosing system based on specular reflection appearance only [82],[81]. We compare the diagnosing performance for each backside reflection radius size and we got the best result when radius size of the backside reflection was assumed to be 0.7 times of the frontside reflection's radius.

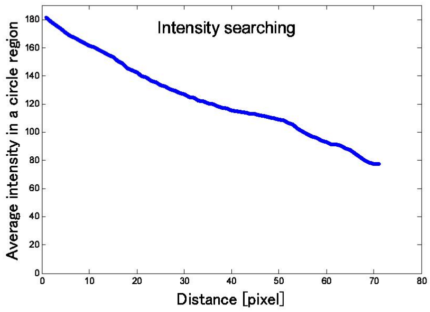
The main characteristic of serious and non-serious conditions depends on the presence of backside reflection in an image. It is shown by increasing intensity in an area during intensity searching. Figure 4.11 shows an example of intensity tracking result for serious and non-serious conditions. It appears that for a non-serious condition, there is an increasing intensity in indicating backside reflection availability. While for a serious condition, in searching backside reflection area data, intensity tends to decrease. By implementing Equation 4.3, we determined a threshold value T_p and classify both conditions refer by following statements :

1. Serious conditions if the value of $P_n < T_p$

2. Non-serious conditions if the value of $P_n > T_p$



(a) Non serious condition



(b) Serious condition

Figure 4.11. Characteristic of intensity tracking result for both conditions

4.5. Preliminary result

In order to examine performance of specular reflection method for screening cataract, we take photographs for both cataract and normal patients in Indonesia and Japan. However, we did not consider yet about a procedure for getting a good input image, because we did not find yet an appropriate method for classifying between serious and non-serious condition. First, we assume that serious conditions indicated by a high intensity inside the pupil; however, sometimes we face problems about illumination conditions. Taking photographs using digital cameras without illumination control will cause a different results for each condition. To solve this problem, we analyze information about specular reflection availability inside the pupil. By comparing performance of specular reflection analysis and color information analysis, the result shows that specular reflection analysis method has a good performance than color information as described in Figure 4.12.

Although specular reflection analysis method has a good performance compared with color information method as shown in Figure 4.12, however we face a problem when a whitish color in a serious condition located in the line direction of backside reflection searching as shown in Figure 4.13. Our system will assume

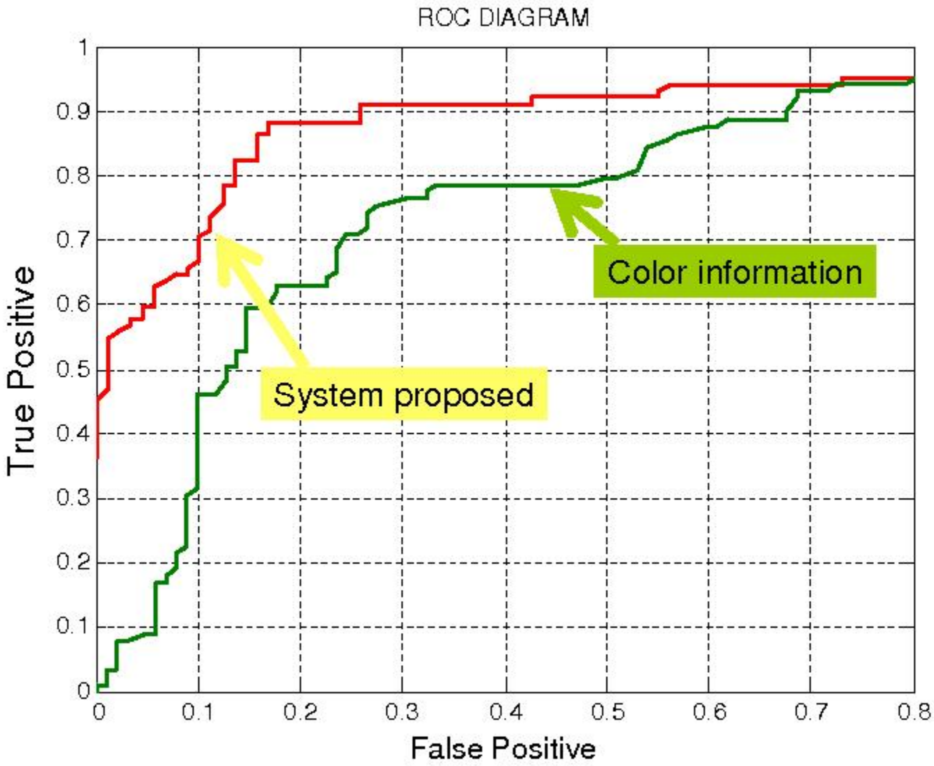


Figure 4.12. ROC diagram for comparing specular reflection method and color information method

that a whitish color is a backside reflection therefore the value of P_n will increase as in a non-serious condition.

When we apply the specular reflection analysis method on the existing data, we get the performance as shown in Figure 4.14. It is appears that the value of TPR is about 81%, which means that our system could detect about 81% patients with serious condition among all patients who have serious condition. While the value of FPR is about 45% . To overcome this problem, we have to consider another features to improve our method to screen cataract, and we prefer to use texture analysis for supporting our method. The discussion about texture analysis will discuss in Chapter 5.

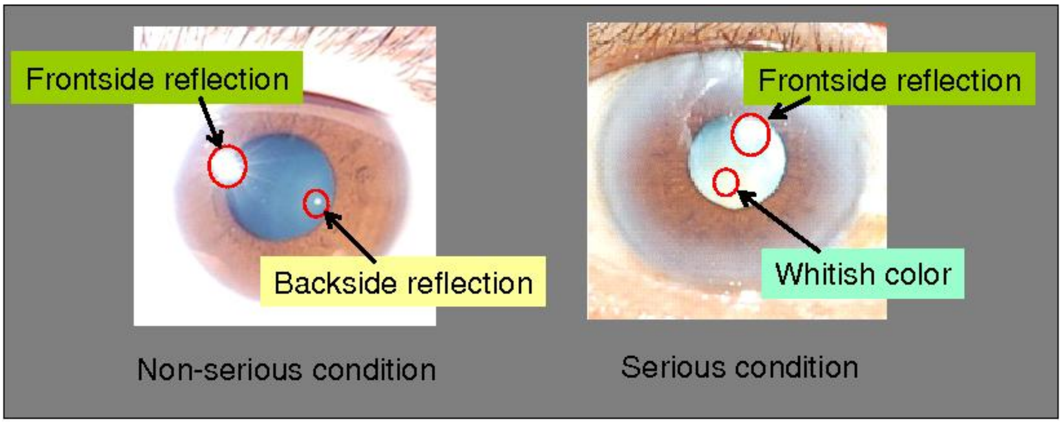


Figure 4.13. Example of misdiagnosis using information about specular reflection only

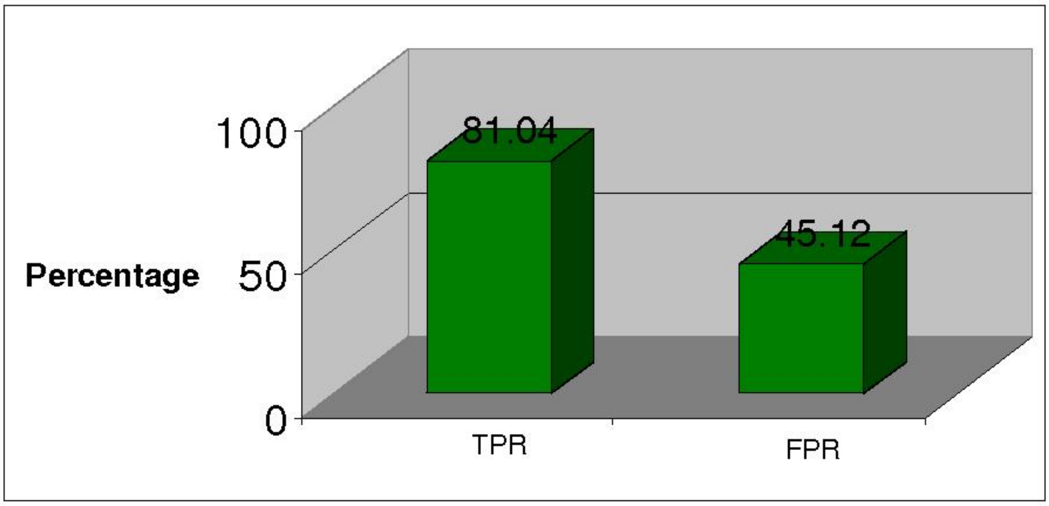


Figure 4.14. Performance of specular reflection analysis method

Chapter 5

Texture Analysis

Although specular reflection analysis method has a good performance to distinguish between serious and non-serious conditions, however sometimes we face problems distinguishing between specular reflection and whitish color if it is located in the same line as discussed in Section 4.5. This is critical problem for the screening result, therefore we consider texture analysis for handling such problems by extracting uniformity and average intensity inside the pupil.

5.1. Definition of texture

Texture analysis refers to a class of mathematical procedures and models that characterize the spatial variations within imagery as a means of extracting information. Texture is an areal construct that defines local spatial organization of spatially varying spectral values that is repeated in a region of larger spatial scale. Thus, the perception of texture is a function of spatial and radiometric scales[80]. An important approach to region description is to quantify its texture content. Although there is not formal definition of texture exists, intuitively this descriptor provides measures of properties such as smoothness, coarseness and regularity. The three principles approaches used in image processing to describe the texture of a region are statistical, structural and spectral. Statistical approaches yield characterizations of textures as smooth, coarse, grainy, and so on. Structural techniques deal with the arrangement of image primitives, such as the description of texture based on properties of the fourier spectrum and are used primarily to detect global periodicity in an image by identifying high energy, narrow peaks in the spectrum [20]. This research discuss some texture approaches for texture analysis by computing local features at each point in the image, and deriving a set of statistic from the distributions of the local features [63]. Statistical approaches yield characterization of textures as fine, coarse etc. Thus one measure of texture based on the primitive size, which could be the average area of these primitives of relatively constant gray level. In this research we consider about uniformity and average intensity features, however as discussed in Chapter 2, Section 2.1 **it should be noted here** that these conditions are not stable because it depends on the illumination conditions, while our system does not consider the existence of a controlled illumination conditions. .

5.2. Algorithm of uniformity texture for detecting cataract

Uniformity is a value to determine an image texture belongs to smooth or coarse. This can be calculated by the uniformity value expressed in Equation 5.1.

$$U = \sum_{i=0}^{L-1} \left(\frac{H(i)}{N} \right)^2 \tag{5.1}$$

where U is value of uniformity, H is frequency of intensity levels in a region, and N is number of pixel in an image, Let $i = 0, 1, 2, \cdots, L-1$, be the corresponding histogram, where L is the value of possible intensity. Uniformity will be maximum when all gray levels are equal. For example, in a 3×3 region and belongs to a smooth texture as shown in Figure 5.1 , the uniformity is shown in calculation below:

$U = \left(\frac{9}{9}\right)^2 = 1$

Another example, in a 3×3 region and belongs to a coarse texture as shown in Figure 5.2 , the uniformity is shown in calculation below:

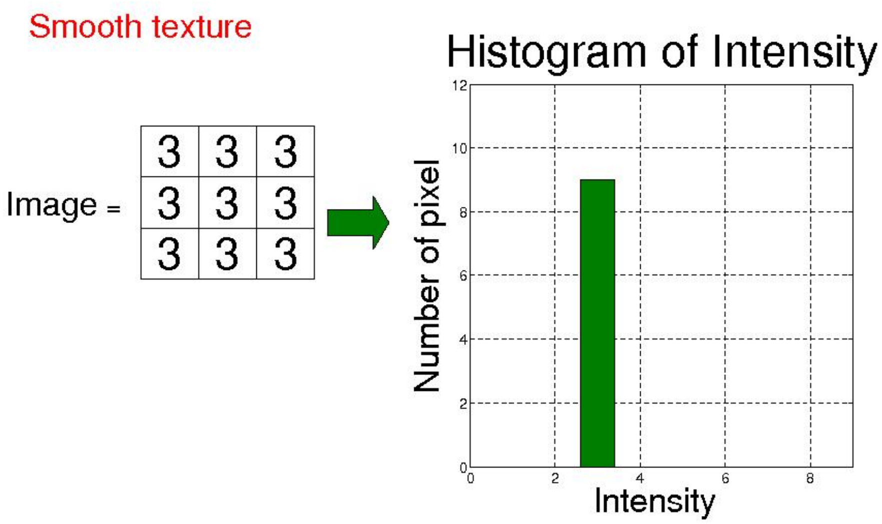


Figure 5.1. Example of smooth texture

$$U = \left(\frac{1}{9}\right)^2 + \left(\frac{1}{9}\right)^2 + \left(\frac{1}{9}\right)^2 + \left(\frac{1}{9}\right)^2 + \left(\frac{1}{9}\right)^2 + \left(\frac{1}{9}\right)^2 + \left(\frac{1}{9}\right)^2 + \left(\frac{1}{9}\right)^2 + \left(\frac{1}{9}\right)^2 = 0.111$$

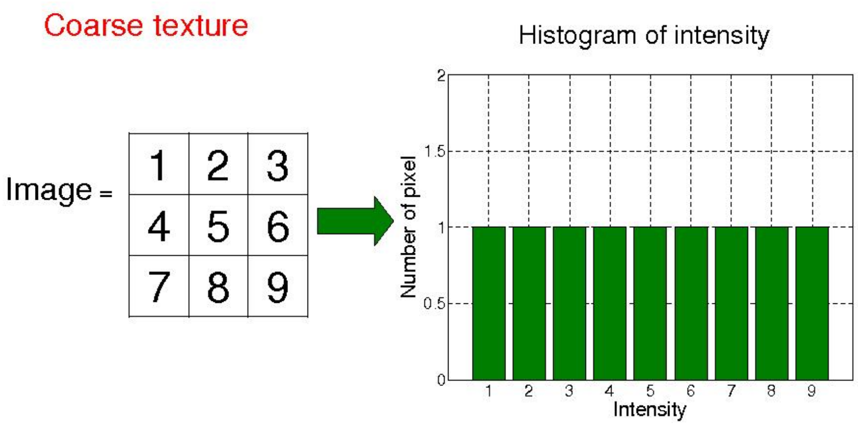
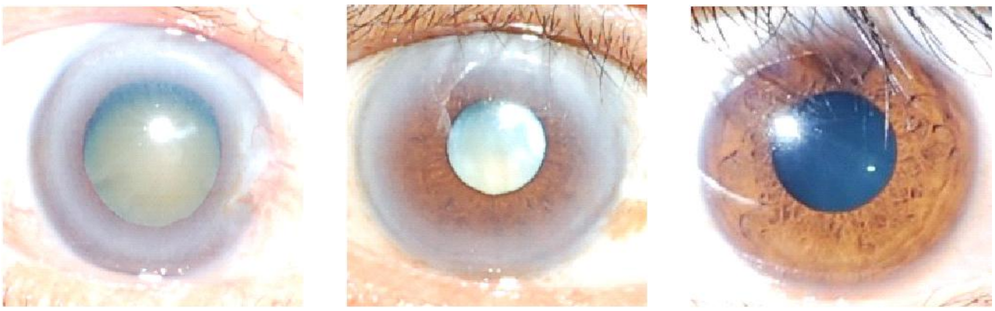


Figure 5.2. Example of a coarse texture

Whitish color inside the lens have two kinds distributions. **First**, whitish color spread smoothly inside the pupil. In early stage, this kind of cataract has a thin layer of whitish color and covers the whole lens surface gradually until the whitish color layer becomes thick. **Second**, whitish color spread uneven inside



(a) Serious (b) Serious (c) Non serious

Figure 5.3. Example of texture appearance

the lens. It will appears a coarse texture inside the pupil. Almost all non serious conditions have smooth texture with high value of uniformity. A variation of uniformity texture appearance inside the pupil shown in Figure 5.3

Figure 5.3(a) shows an image of eye in serious condition with a high value of uniformity caused by the whitish color is spreading smoothly inside the pupil. In the early stage, this kind of cataract has a thin layer of whitish color and covers the whole lens surface gradually until the whitish color layer becomes thick. Figure 5.3(b) shows an image of an eye with a coarse texture because the whitish color is spreading unevenly inside the pupil. Figure 5.3(c) shows an image of an eye in non-serious condition. Almost all non-serious conditions have a smooth texture with a high value of uniformity.

5.3. Algorithm of average intensity for detecting cataract

The equation to measure an average intensity expressed in Equation 5.2, where m is mean (average) of intensity, I is possible intensity, and N is number of pixel in an image . It will be very simple intuition that cataract eyes have brighter intensities than normal eyes.

$$m = \sum_{i=0}^{L-1} \left(\frac{I(i)}{N} \right) \tag{5.2}$$

For example, in a 3×3 region as shown in Figure 5.4 , the average intensity is shown in calculation below :

$m = \left(\frac{3+3+2+1+2+5+7+1+4}{9} \right) = 3.1111$

$$\text{Image} = \begin{array}{|c|c|c|} \hline 3 & 3 & 2 \\ \hline 1 & 2 & 5 \\ \hline 7 & 1 & 4 \\ \hline \end{array}$$

Figure 5.4. An example of average intensity

The whitish color inside a pupil has a corresponding with increasing intensity. Figure 5.5 shows an eye normal image and a cataract eye image. It appears that a cataract eye image has a higher intensity than a normal eye image. By assuming that a serious condition have a higher intensity than a non-serious condition, we distinguish both conditions.

5.4. Preliminary result

To test the performance of the combination of specular reflection and uniformity, we applied the calculation of P_n values and uniformity values on limited data and get results as shown in Figure 5.6. Figure 5.6 shows combination between values of P_n and uniformity U which are clearly separate between serious and

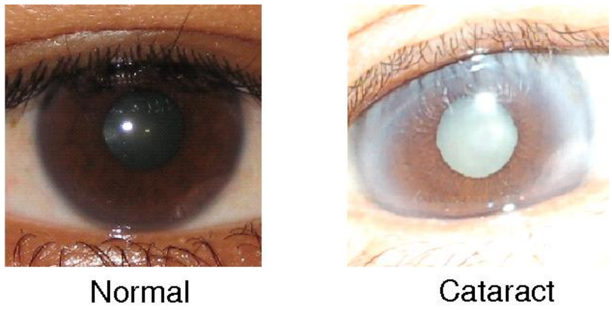


Figure 5.5. Intensity difference between normal and cataract

non-serious conditions. P_n is presented as a x-axis entitled backside reflection availability and U is presented as a y-axis entitled uniformity.

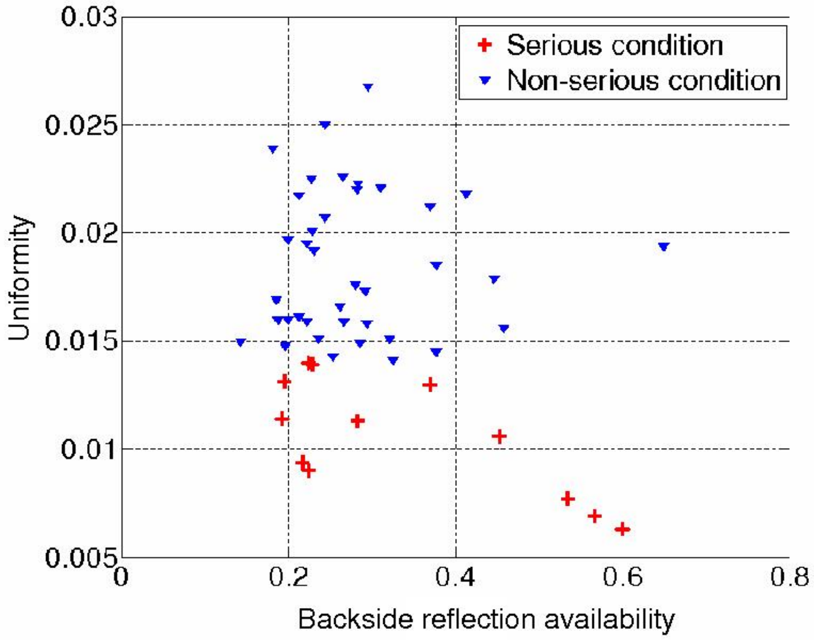


Figure 5.6. Example data of two parameters

Finally, in order to improve the performance of our system, we did a calculation on a combination of P_n values, uniformity and average intensity on limited data. Figure 5.7 shows examples data of three parameters between two classes serious and non serious condition that have values as discussed above including ; specular reflection appearance presented as a x-axis entitled backside reflection availability, the uniformity presented as a y-axis entitled uniformity, and average intensity presented as a z-axis entitled average intensity. The Figure shows that between serious and non-serious condition are separating clearly.

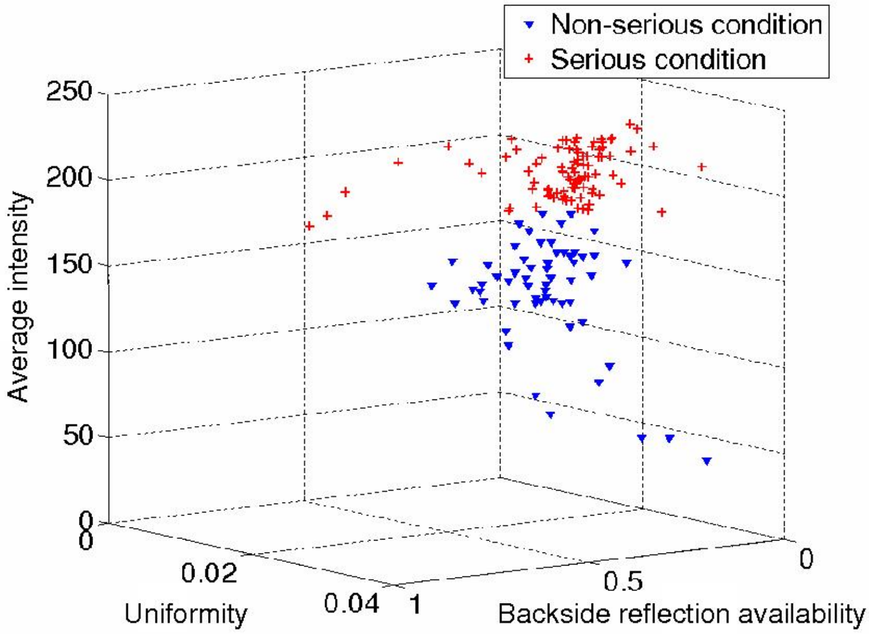


Figure 5.7. Example data of three parameters

Chapter 6

Classification for Screening

6.1. Support vector machine

6.1.1 Definitions

Support Vector Machine (SVM) are learning system that use a hypothesis space of linear function in a high dimenstional space, trained with a learning algorithm from optimisation theory that implements a learning bias derived from statistical learning theory. This learning strategy introduced by Vapnik and co-workers is a principled and very powerful method in the few years since its introduction has already outperfomed most other systems in a wide variety of applications [21].

Some examples of applications and extension support vector machines summarize by Burges [49] as follows. For the pattern recognition case, SVMs has been used for isolated handwritten digit recognition [23] [17] [14] [15], object recognition [93], speaker identification [62], face detection in image [64], and text categorization [90]. For the regression estimation case, SVMs have been compared on benchmark time series prediction test [54], the Boston housing problem [45].In most of these cases, SVM generalization performance (i.e. error rates on test sets) either matches or significantly better than that of competing methods. The use of SVMs for density estimation [52] and ANOVA decomposition [60] has also been studied. Regarding extensions, the basic SVMs contain no prior knowledge of the problem (for example, a large class of SVMs for the image recognition problem would give the same permutation), an act of vandalism that would leave the best performing neural networks severely handicapped and much work has been done on incorporating prior knowledge into SVMs [16] [12] [13]. Although SVMs have good generalization performance, they can abysmally slow in test phase, a problem addressed in [22] [65]. Recent work has generalized the basic ideas [6] [3], shown connections to regularization theory [4] [36] [94] and shown how SVM ideas can be incorporated in a wide range of other algorithms [4].

Based on the explanation above, SVM is useful when used in the classification process as a few examples of the above applications, threfore our research using SVM to distinguish serious and non-serious conditions.

The problem which drove the initial development of SVMs occurs in several guises, the bias variance tradeoff [77],overfitting [26], but the basic idea is the same. Roughly speaking, for a given learning task with a given finite amount of training data, the best generalization performance will be achieved if the right balance is struck between the accuracy attained on the particular training set and the "capacity" of the machine, that is, the ability of the machine to learn any training set without error.

SVMs use an implicit mapping Φ of the input data into high-dimensional feature space defined by kernel function, i.e. a function returning the inner product $< \Phi(x), \Phi(x') >$ between the images of two data points x, x' in the feature space. The learning then takes place in the feature space, and the data points only appear inside dot products with other points. More precisely, if a projection $\Phi : X \to H$ is used, the dot product $< \Phi(x), \Phi(x') >$ can be represented by a kernel function k indicated in Equation 6.1 which is computationally simpler than explicitly projecting x and x' into the feature space H.

$$k(x, x') =< \Phi(x), \Phi(x') > \tag{6.1}$$

Training a SVM for classification, regression or novelty detection involves a quadratic optimization problem. Using a standard quadratic problem solver for training an SVM would involve solving a big QP problem even a moderate sized data set, including the computation of an $m \times m$ matrix in memory (m number of training points).

6.1.2 Classification

In classification, support vector machine separate the different classes of data by a hyperplane as indicated in Equation 6.2

$$< w, \Phi(x) > +b = 0 \tag{6.2}$$

corresponding to the decision function in Equation 6.3

$$f(x) = sign(< w, \Phi(x) > +b) \tag{6.3}$$

It can be shown that the optimal, in terms of classification performance, hyperplane is the one with the maximal margin of separation between two classes. It can be constructed by solving a constrained quadratic optimization problem whose solution w has an expansion $w = \Sigma_i \alpha_i \Phi(x_i)$ in terms of a subset of training pattern that lie on the margin. These training patterns called support vector, carry all relevant information about the classification problem.

Given a training set of instance-label pairs $(x_i, y_i), i = 1, \ldots, l$ where $x_i \varepsilon R^n$ and $y \varepsilon 1, -1^l$, the support vector machine require the solution of the following optimization problem as show in equation 6.4

$$\min_{w,b,\epsilon} \frac{1}{2} w^T w + C \sum_{i=1}^{l} \epsilon_i subjecttoy_i(w^T \Phi(x_i) + b) \geq 1 - \epsilon_i, \epsilon_i \geq 0 \tag{6.4}$$

Here training vectors x_i are mapped into a higher dimensional space by the function Φ. Then SVM finds a linear separating hyperplane with the maximal margin in this higher dimensional space. $C > 0$ is the penalty parameter of the error term. Furthermore, $K(x_i, x_j) \equiv \Phi(x_i)^T \Phi(x_j)$ is called the kernel function.

6.1.3 Kernel function

The kernel function return the inner product between two points in a suitable feature space, thus defining a notion of similarity, with little computational cost even in very high-dimensional space. Kernels commonly used with kernel methods and SVMs in particular include the following:

1. The linear kernel implementing the simplest of all kernel function

$$k(x, x') =< x, x' > \tag{6.5}$$

2.The Gaussian Radial Basis Function(RBF) kernel

$$k(x, x') = \exp(-\sigma\|x - x'\|^2) \tag{6.6}$$

3.The polinomial kernel

$$k(x, x') = (scale. < x, x' > +offset)^{degree} \tag{6.7}$$

4. The hyperbolic tangent kernel

$$k(x, x') = tanh(scale. < x, x' > +offset) \tag{6.8}$$

5. The Laplace Radial Basis Function (RBF) kernel

$$k(x, x') = \exp(-\sigma\|x - x'\|) \tag{6.9}$$

6. The ANOVA radial basis kernel

$$k(x, x') = (\sum_{k=1}^{n} \exp(-\sigma(x^k - x'^k)^2)^d \tag{6.10}$$

7. The linier splines kernel in one dimension

$$k(x, x') = 1 + xx' \min(x, x') - \frac{x + x'}{2}(\min(x, x')^2 + \frac{\min(x, x')^3}{3}) \tag{6.11}$$

and for the multidimensional case $k(x, x') = \Pi_{k=1}^{n} k(x^k, x'^k)$.

The Gaussian and Laplace RBF are general-purpose kernel used when there is no prior knowledge about data. The linear kernel is useful when dealing with large sparse data vectors as is usually the case in text categorization. The polynomial kernel is popular in image processing and the sigmoid kernel is mainly used as a proxy for neural networks. The splines and ANOVA RBF kernels typically perform well in regression problems.

In our system, we use the existing SVM developed by Canu [18]. In this tool, He used a gaussian kernel function. The system just classify two conditions only, serious and non-serious condition.

6.2. Experimental results

6.2.1 Data collection

We acquire data with some considerations below:

1. Distance

We emphasize our assumption that a close distance between camera and object will give a larger size of pupil. The image is acquired by a compact digital camera placed at distance about $30 - 60$ cm from patient as shown in Figure 7.6(a) while Figure 6.1 shows a relationship between distance and pupil size.

2. Angle

As discussed in Chapter 3 and Chapter 4 we assume that both of pupil and fronstide reflection are circle as described in Figure 6.2; therefore, we able to compute distance between center of pupil and frontside reflection using Euclidian formulation $D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$.

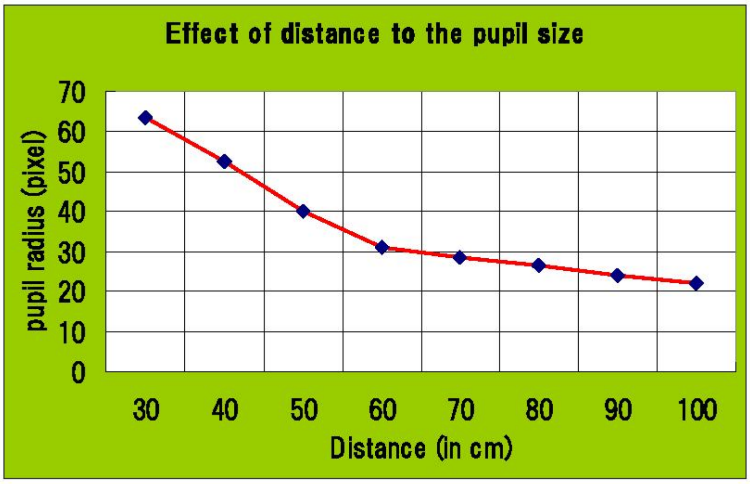


Figure 6.1. Effect of Distance to Pupil Size

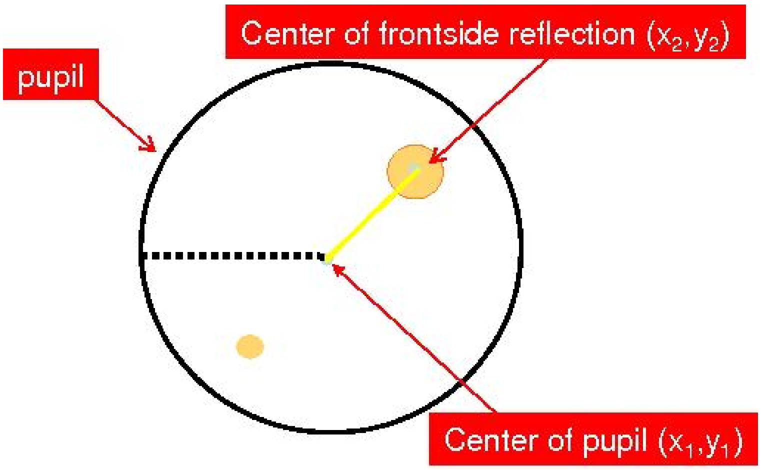


Figure 6.2. Euclidian distance between center of pupil and center of fronstside reflection

However, the eye images have many variations of pupil size, therefore, we make a normalization by dividing distance result D and radius of pupil r using Equation 6.12.

$$D_N = \frac{D}{r} \tag{6.12}$$

During experiment we found that position of backside reflection depends to the position of frontside reflection. For example, if position of frontside reflection very close with center of pupil it will affect that backside reflection will be very close with frontside reflecton and sometimes will be overlap,therefore, D_N is important factor in our system especially during taking photographs. Figure 6.3 described relationship between backside reflection and frontside reflection. Also, based on our experiment we classify the position of specular reflection inside pupil refer to angle consideration as shown in Table 6.1.

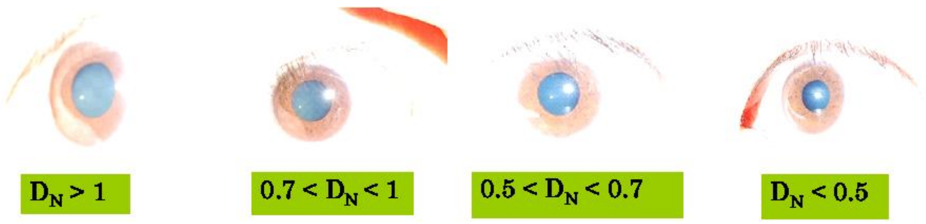


Figure 6.3. Image examples for each D_N classification

We tried many positions between camera and light source to object. **The first** position is flash light attached in camera and it move smoothly from angle 10^o to 170^o. **The second** position is camera takes in the fix position at angle 90_o in frontside of patient and flash light move smoothly from angle 10^o to 170^o . **The third** position is flash light take in the fix position at angle 90^o and camera move smoothly from angle 10^o to 170^o. The first and second position gave us result which is match with classification in Table 6.1. While the third position always give us values of $D_N < 0.5$. It means that this position inappropriate with our system. Figure 6.4, Figure 6.5, and Figure 6.6 described the sketch and results of experiments.

Referring to the final goal of our research for using a simple and low cost equipment for acquiring data; therefore, we choose to use a camera with light source attached to camera.

Table 6.1. 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 with our system because we could not get a specular reflection inside a pupil.
$0.7 < D_N < 1$	Some part of frontside reflection in outside of pupil. This condition is not so appropriate for our system because we could not get a whole shape of frontside reflection inside a pupil.
$0.5 < D_N < 0.7$	It is appropriate condition of our system. We could get a whole shape of frontside reflection inside pupil;also this condition has enough distance between frontside reflection and backside reflection. It is appropriate condition of our system. 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 frontside reflection inside a pupil but the position between frontside reflection and backside reflection is very near. It is inappropriate with our system because sometimes between frontside reflection and backside reflection will be overlap.

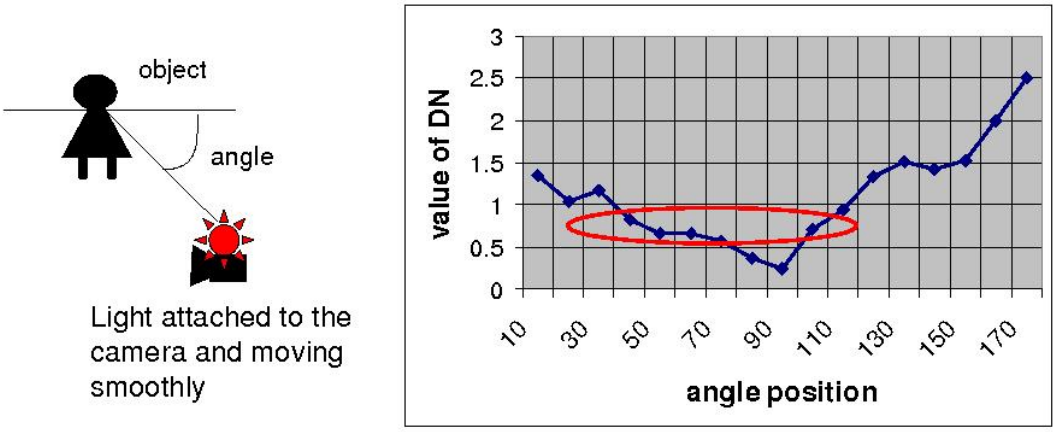


Figure 6.4. The distance characteristic between center of pupil and center of frontside reflection with light attached to camera

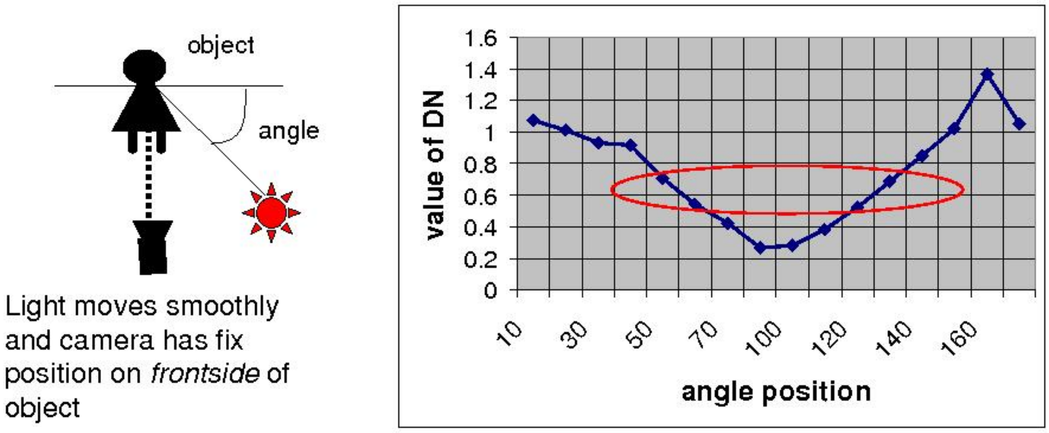


Figure 6.5. The distance characteristic between center of pupil and center of frontside reflection with camera has fix position in front of object and light source move smoothly based on angle position

3. Conditions of environment

In order to get an effect of environment while taking photographs, we did some experiments in different conditions. **The first** condition is taking a photograph inside a room, **Second** is in semi-outdoor room and **Third** condition is in outdoor as described in Figure 6.7. An example of image result for each condition is described in Figure 6.8

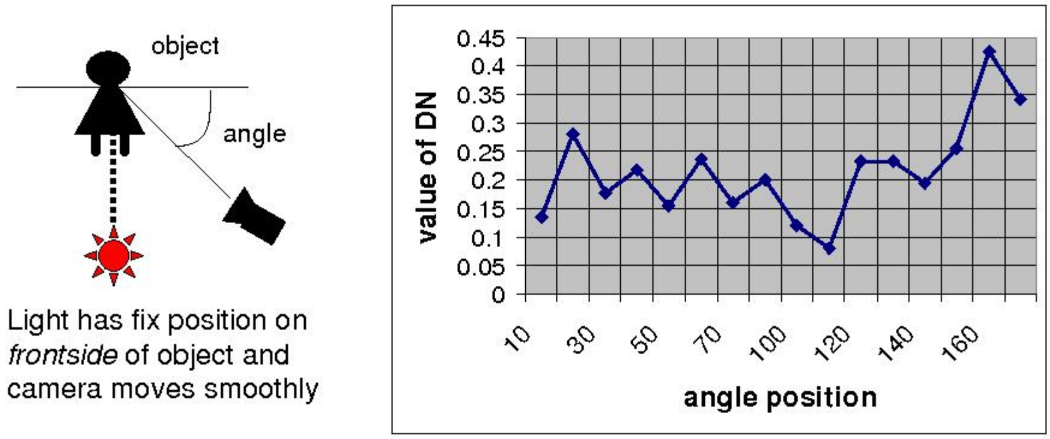


Figure 6.6. The distance characteristic between center of pupil and center of frontside reflection with light source has fix position in front of object and camera move smoothly based on angle position

Figure 6.7. Conditions of environment while taking a photograph

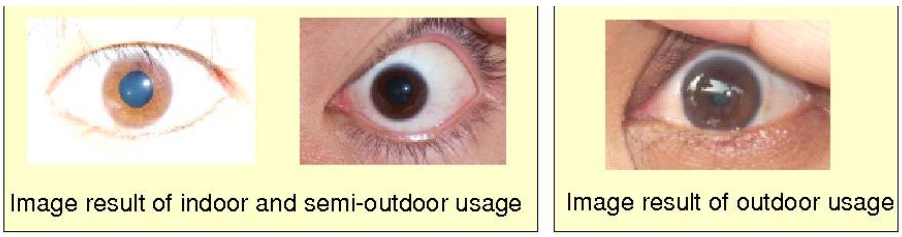


Figure 6.8. Example of image result for each condition

Referring to Figure 6.8 it appears that image result in indoor and semi-outdoor conditions have a clear appearance of specular reflection while image result in outdoor condition has too many noise; therefore, specular reflection is not have a clear appearance. Also, when we implement algorithm for detecting pupil as discussed in Chapter 3, we got a results that images were taken in outdoor condition have a worse performance than images were taken in indoor and semi-outdoor condition as shown in Figure 6.9. Therefore, for further implementation,we always take photographs in indoor or semi-outdoor conditions.

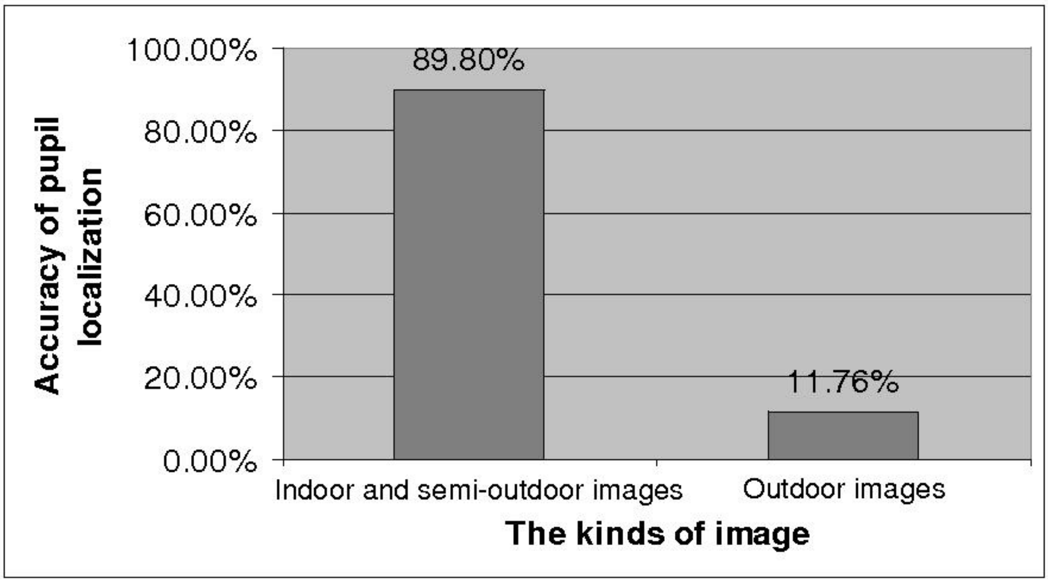


Figure 6.9. Effect of environment condition on the accuracy of pupil detecting

6.2.2 Performance

We tested our system on 777 images taken in Indonesia and Japan, also with different considerations as discussed in Chapter 2. However, because our algorithm extract all information inside the pupil only; therefore, first we have to localize pupil. The performance of algorithm to detect pupil is about 89% as discussed in Chapter 3; so we tested our algorithm for cataract screening on about 698 images data only. Referring to diagnosis by an eye doctor, there were 188 images of serious conditions and 510 of non-serious conditions.

To build the system, we used Matlab R2007B with image processing toolbox. Also, for building a classifier to classify between serious and non-serious condition, we use SVM toolbox developed by Canu [18]. In order to make a classification for cataract screening we need two kinds of data: training data and testing data. Training data used to train the system to recognize the characteristics of a serious condition and non-serious condition so the system can determine the threshold for distinguishing between two conditions automatically. While testing data used to evaluate system performance refer to the characteristics obtained in the training data.

We use TPR and FPR parameters to express the performance of our system as has been discussed in Section 1.2. Criterion values for getting TPR and FPR parameters is described in Figure 6.10. The value of TPR can be obtained by $TPR = \frac{TP}{(TP+FN)}$, while the value of FPR can be obtained by $FPR = \frac{FP}{(FP+TN)}$.

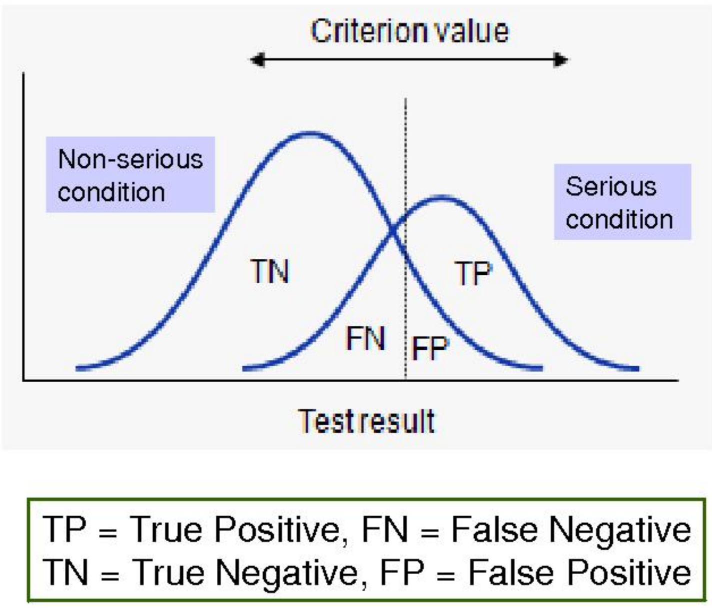


Figure 6.10. Parameter for measuring performance

Also, as discussed in Section 2.2, We use a variety of types and brands of digital cameras for data acquisition. Types and brands of digital cameras used are Nikon Coolpix L12, Nikon Coolpix S710, Nikon D40X, Canon IXY Digital 820IS. Figure 6.11 shows the performance of systems based on the types and brands of camera system. for example, when we examine the performance of systems based on the digital camera with brand Nikon coolpix L12, then the images produced by other cameras are used as training data, while the images produces by Nikon coolpix L12 used as testing data, and so on.

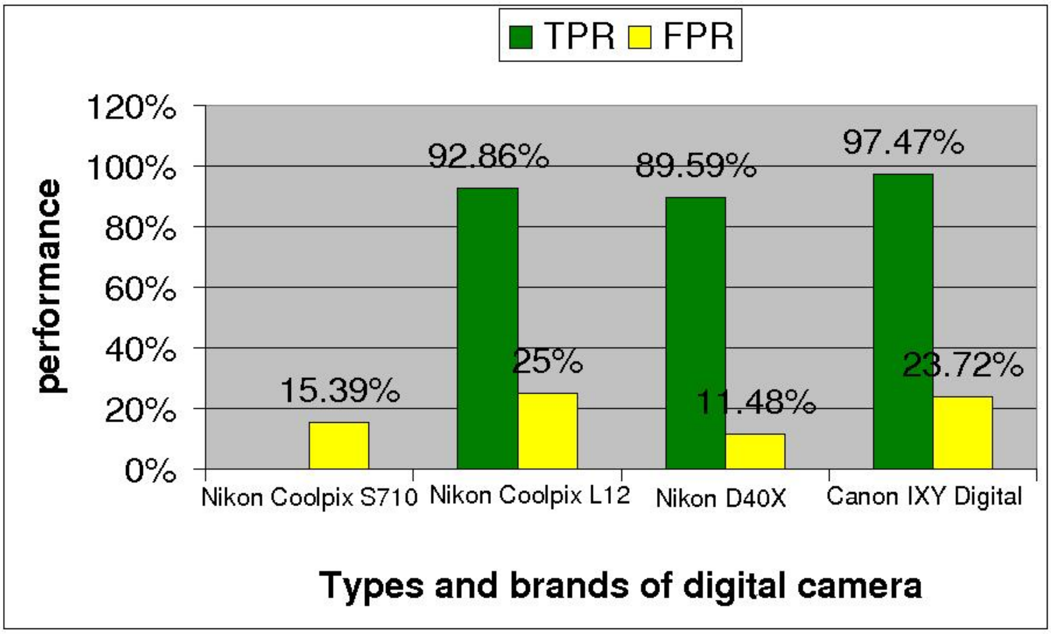


Figure 6.11. System performance based on types and brands of digital camera

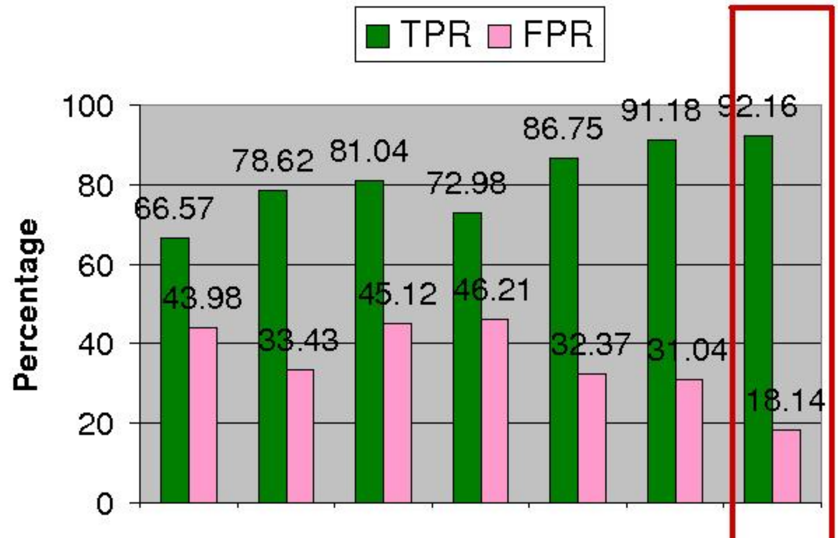
Referring to Figure 6.11, when we evaluate system performance based on Nikon coolpix S710, in this graph there is not TPR value, it is because the use of nikon coolpix S710 only for data acquisition in patients with non-serious conditions only, so we do not get the TPR value. Although it can be said that the performance for each camera is almost evenly, but it seemed that the canon IXY has the highest value of TPR, while the nikon d40x has the lowest value of FPR. However to compare the performance each digital camera, objects used to be the same. According to the Figure 6.11 although we get the performance of each camera, but each camera used different patients as has been discussed in Chapter2, so that we can not conclude that one camera is the best camera than others.

To evaluate the overall system performance, we use cross validation techniques in which we did evaluation several times until all data were evaluated.. So that all images produced by various kinds of cameras are grouped into two groups. The first group is the images that show the serious conditions, while the second group is the images that show the non-serious conditions. We did some testing times by taking 90% of data as training data and 10% of data as testing data. Data changed each time, until finally all data used as training data and testing data. Figure 6.12 shows a summary of performance our algorithm. The result shows that current method has a good performance than other method.

Referring to Figure 6.12, **First** we analyze each characteristic of information appears in a pupil for cataract detecting including average intensity. uniformity and specular reflection. When we analyze average intensity inside a pupil, the results shows that this method has TPR about 66% , while when analyze uniformity inside a pupil the value of TPR about 78%. However, when we analyze specular reflection appearance inside a pupil, the value of TPR about 81%. This is the highest value of each characteristic appears inside a pupil. The main reason is specular reflection does not depends on the illumination condition and this is appropriate with our research goal for using a low-cost and easy-to-use equipment for data acquisition.

In order to improve our system, we combine two types of characteristic appearance inside the pupil. The first combination is average intensity combine with uniformity. This combination give TPR about 72%. This the lowest value of combination between two types of characteristic appearance inside the pupil. The second combination is average intensity with specular reflection. This combination give TPR about 86%. The last combination is specular reflection and uniformity. This combination give a value of TPR about 91%. This is the highest value of TPR because the characteristic of whitish color and backside reflection is quite different. In non-serious conditions, almost the uniformity is higher than serious conditions because whitish color spread in some part of pupil region, while in non-serious conditions, there are not a whitish color.
However, this combination still have a value of FPR about 31%; therefore, we need to improve our method by reducing the value of FPR. We consider about

average intensity. We assume that serious conditions have a higher intensity in a pupil region than non-serious condition. The result shows that this combination give a value of TPR about 92% and a value of FPR about 18%.



Average instensity	V			V	V		V
Texture uniformity		V		V		V	V
Specular reflection			V		V	V	V

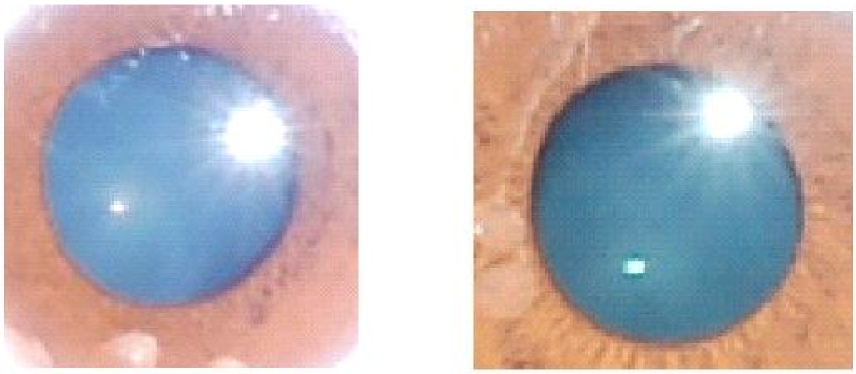
proposed

Figure 6.12. Performance comparison of each method

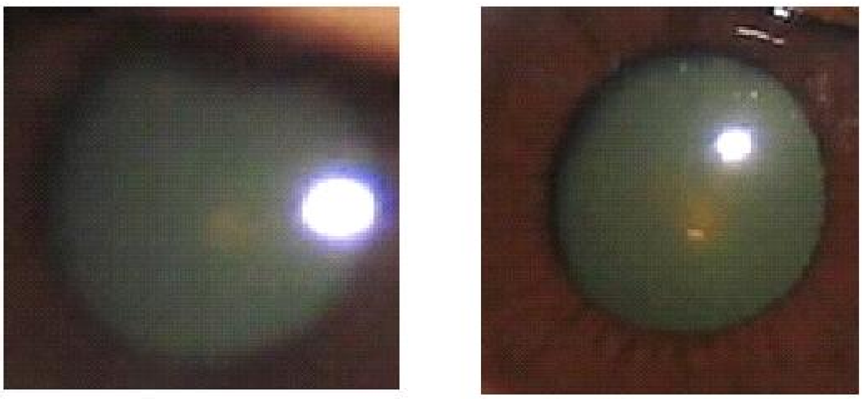
Figure 6.13 shows examples of images that a failure diagnosis by our system. In Figure 6.13a, a non-serious condition diagnosed as a serious condition. This is caused by several reasons. The first is backside reflection size too small and sometimes very weak intensity. While in Chapter 4, we are definite that the size of backside reflection is 0.7 times the size of frontside reflection, so we should reconsider the size of the backside reflection. In addition, in Chapter 4 we assume that the specular reflection has the shape of a circle. In fact there are some that are not circular, or as shown in Figure 6.13a, although the main form fronstide reflection is a circle, but it is more correct to say that the shape of the frontside reflection is a luminous star which can affect the value of uniformity. Therefore we should be considered on the power light of the flashlight to the shape of specular reflection.

In Figure 6.13b, serious condition diagnosed as non-serious condition. This is due to opacities located in alignment with the frontside reflection causes a high value of P_n, while others opacities spread evenly across the surface of the pupil, therefore the value of uniformity became high, then there is a failure of analysis. To overcome these problems, we must consider the relationship between frontside reflection and backside reflection, about the two reflections have the same shape or not, or the tendency of the backside reflection shape. Thus the system will distinguish between opacities and the backside reflection, although they are located in the one line with a frontside reflection.

Although this result is not the same as the definition of a perfect system where the TPR is 100% and the FPR was 0%, however it is promising for further development. By doing such considerations mentioned above, it is expected that a perfect system can be achieved by getting TPR 100% and FPR 0%.



(a) Non-serious condition diagnosed as serious condition



(b) Serious condition diagnosed as non-serious condition

Figure 6.13. Failure examples

Chapter 7

Design Considerations on Practical Screening System

7.1. Limited health facilities in developing countries

Cataract diagnosing in developing countries such as Bangladesh, Indonesia, Nepal, Mali and Thailand present both challenges and opportunities. Challenges in diagnosing cataract are presented by limited of health facilities including numbers of ophthalmologists, distribution of ophthalmologists are not equal, and also geographic conditions. Opportunities include the highest numbers of people with cataract in developing countries and some programs from World health Organization (WHO) that focusing on the fight against avoidable blindness in developing countries because there are at least 28 millions blind in the world, more than 75% of whom live in developing countries as described in Figure 7.1 [70].

As discussed in Chapter 1, according the World Health Organization report [70] the most important causes of loss vision are shown in Figure 7.2. It is seen in the graph that the biggest cause of blindness is cataract. In its most common form, cataract develops with age, usually in 6th or 7th decade of life. In tropical areas where most developing countries are situated, visual loss from cataract may, however, be of earlier onset and more severe. There are not known preventive

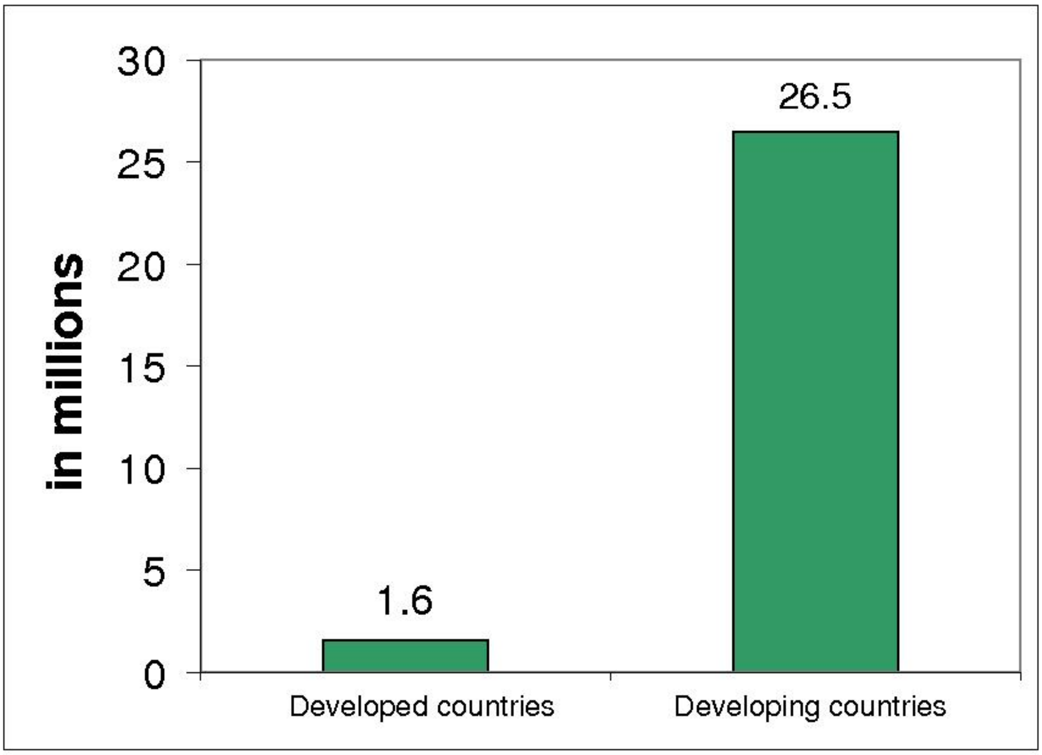


Figure 7.1. The distribution of blindness world wide

measures against cataract, the only treatment for cataract is surgery only.

However, regarding the limitations of ophthalmologists in developing countries in which they are not focus on cataract only, therefore it is crucial to implement a simple and robust cataract screening system. It is expected a simple and robust cataract screening system able to assist ophthalmologists for diagnosing cataract; therefore, in further they optimize for doing surgery only.

7.2. Design of compact but effective cataract screening system under limited health facilities

Although the design concept of our system is discussed in Chapter 2, but in the real implementation we made modifications as shown in Figure 7.3. This is caused

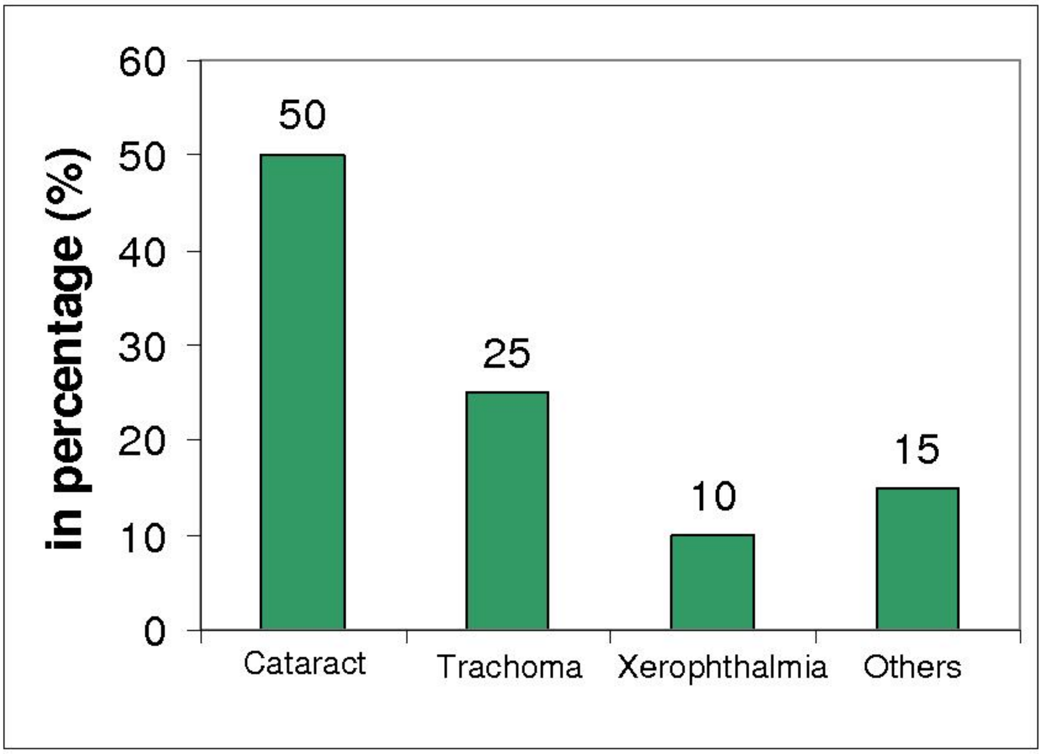


Figure 7.2. The causes of blindness in the world

by the following reasons, in the research phase all the data obtained in conditions in accordance with our system. For example, data taken in Indonesia, conducted in the eye clinic. While the main purpose of the use of this system is the system can be used by anyone and anywhere, so in a real implementation would have the possibility of the input image is not appropriate to our system. To avoid misclassification, we define what is meant by the appropriate input image with our system as will be discussed in the next section.

First user simply takes a patients photograph of an eye. Figure 7.4 shows typical examples of an input image in which our system will able to observe it. If an input image is appropriate then system will localize pupil for getting information about cataract inside pupil region as has been discuss in Chapter 3, else means something is missing during taking photograph of patient eye. This condition may cause a misclassification on screening. By extracting specular reflection and texture appearance inside the pupil, system will analyze the condition of the patient eyes and classified them into two conditions are serious and non-serious conditions.

As already discussed in the paragraph above, that our system is expected to be used by all people in all places, so that the equipment will be used in our system must also be simple as shown in Figure 7.5. Brief description about the function of each equipment is described in the following paragraph.

1. Chin rest

This is an equipment for patient to lean forward and place his or her in the chin rest and forehead against the bar [55]. We use a simple chin rest created manually by using a board that is placed on something that could make it stand upright. The main goal is to put the patient's chin so that patients feel comfortable during taking a photograph. On the other hand, by using a chin rest so will allow a user to get the right eye image during taking a photograph because the patient does not move his head movement that will result in the patient's eye movement. **We should be emphasized here** that this tool is not absolutely necessary in our system, if users can take photograph that make an appropriate input image and the patient feel comfortable, not moving their head so that the position of the eyes in a state of permanent, then the use of these tools are not needed.

2. Tripod

Tripods are used for both still and motion photography to prevent camera movement [5]. The main purpose of using a tripod in our system is to make it easier to get good quality photo because the camera will be in a fixed position and not moving so the possibility of blur can be prevented. Another reason is to get more accurate angular position between the camera and the patient because they will affect the existence of specular reflection inside a pupil as be described in Section 7.3. **It should be noted here** that as well as the use of chin rest, the use of a tripod in our system is not an absolute thing. If users can get an appropriate input image without using a tripod so this equipment is not required in our system.

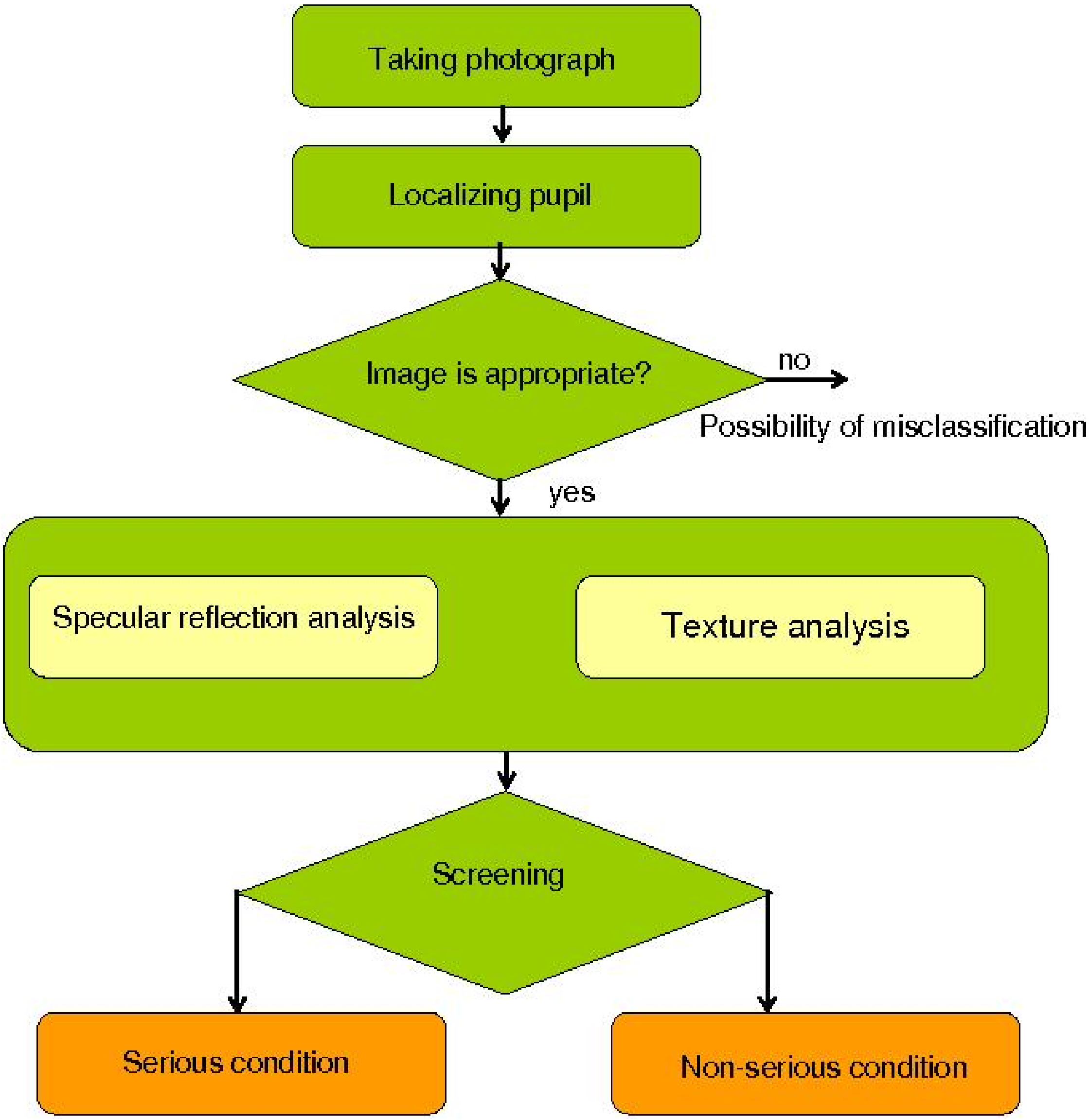


Figure 7.3. Flowchart of proposed screening method for real implementation

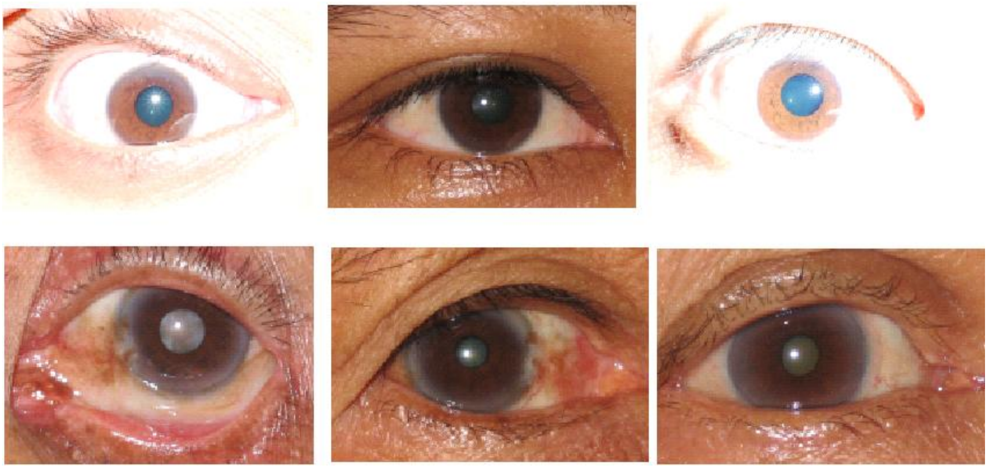


Figure 7.4. Typical examples of appropriate input image for diagnosis

3. Digital camera
This is the most important equipment in our system because all the input images be taken from a digital camera. In our system, we use all types of digital cameras from various brands available such as Canon and Nikon. We do not consider about the performance of cameras such as the number of pixels, zooming capabilities, and other facilities. Most important for our system is the camera has flash facility as a light source to get specular reflections, has a macro facility to get a good enough quality when taking photographs for the pupil of the eye area.

4. Scale
Equipment to provide guidance angle camera placement. We use a kind of plastic mats that have been marked as shown in Figure 7.5 to measure the angle between the patient and the camera.

5. Personal computer
The main function is an interface for analyzing of input images that have been obtained in the data acquisition session. Our method written in the form of graphical user interface (GUI) so that user easily use it just by pressing the command buttons available. Users do not need to analyze the complicated result because our methods give results about the patient's condition which he included

Figure 7.5. Equipment used in our sytem

in serious or non-serious condition.

7.3. Adequate photographs and their acquisition

As discussed in Chapter 1, for doing data acquisition we use a portable digital camera. However, by using digital cameras, our system will find two main problems. **The first problem** is how to develop a robust cataract screening system, because the input images generated by different digital camera is image quality is not sufficient and illumination is not controlled. **The second problem** is how to develop a simple and easy guideline to use our system, because everyone who do not have a special knowledge have to use this system.

In order to solve the first problem about developing a robust cataract screening techniques, we propose image processing techniques which use specular reflection as the core method for cataract screening and also considering texture information as the supporting method to improve system performance. Detail discussion about this part discussed in Chapter 4 and Chapter 5. While for solving the second problem about developing a simple and easy guideline to use this system, we derive practical guideline from simulation and actual condition and will discuss in this Chapter.

As has been discussed in the previous chapters, the core of our method is specular reflection analysis. In this method we will analyze the presence of specular reflection inside a pupil. In short, as shown in Figure 4.3, the non-serious

condition has two specular reflection inside a pupil, while for serious condition there is only one specular reflection inside a pupil; therefore, the image requirements in our system are:
1. There is two reflections inside a pupil
2. Both reflections have enough distance

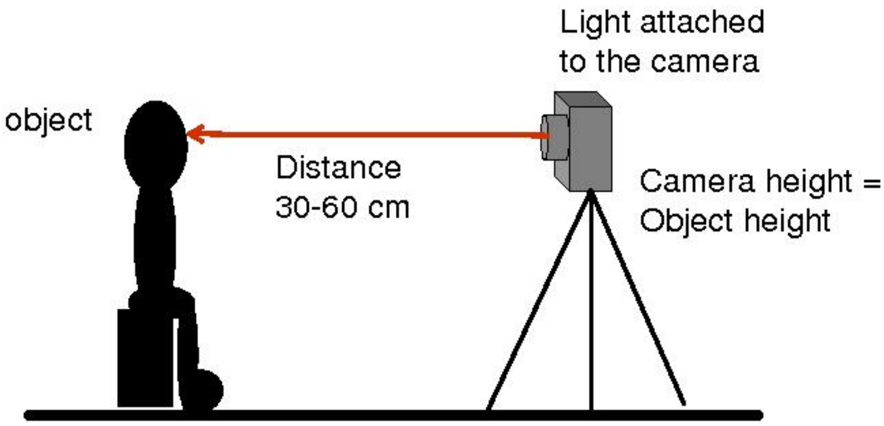
As shown in Figure 7.3, if input image is not appropriate with our system, we will face problems. **First**, patient really has a serious condition. **Second**, the other reflection is missing because of bad condition for taking photograph. Regarding these problems, we have to make sure that we put camera and patient in an appropriate position. The purposes are:
1. Getting an optimal position of angle between camera and lens
2. Getting an optimal pupil size to get an appropriate distance between two reflections

In order to get the input images in accordance with our system, we determine two important factors associated with the appropriateness of images, **First** is distance and angle because we can control both variables during the process of data retrieval, **Second** is pupil size because we have to get an appropriate size of pupil for diagnosis, however we can not control this variable during the process of data retrieval. The discussion about this factors are following:

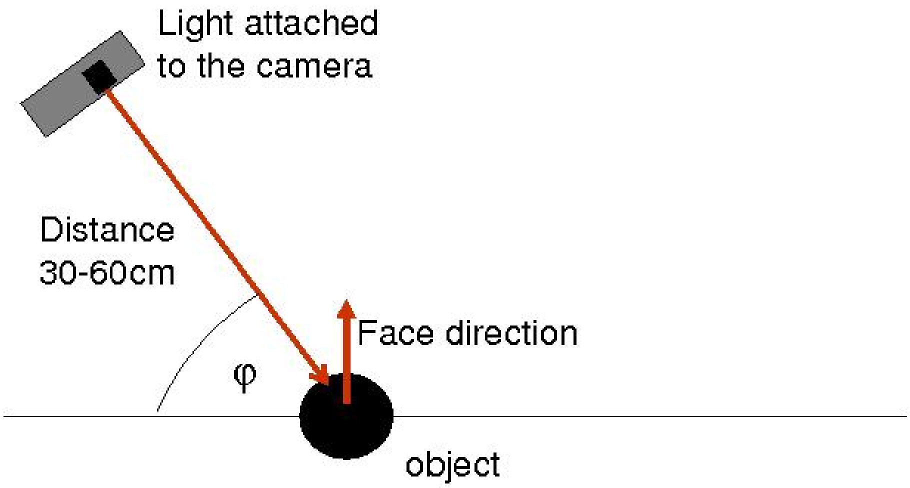
1. Distance

Although almost all digital cameras have a zoom facility to get the object enlargement, but because in this research we are also associated with the analysis of the presence of reflection in the pupil, we consider the factor of distance between the camera and the object to be photographed. Camera configuration settings shown in Figure 7.6.

By assuming we do not use a zoom facility in the camera, then if we look an object by a close distance, we will get a big size of our object but it does not mean that we will get clear information about our object. Otherwise, if we look an object by a far distance we will get small size of our object, but it does not mean that we will not get clean information of our object.



(a) Side view of camera configuration



(b) view from above of camera configuration

Figure 7.6. Camera configuration

Table 7.1. The effect of distance while taking a photograph

Distance	**RoP**	**RoF**	**AvoF**	**BR availability**
30 cm	**52**	**15**	**152**	**Detected (clear)**
40 cm	**37**	**13**	**149**	**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

Referring to this condition, we did experiments to get the best distance during taking photograph. Table 7.1 shows the effects of distance between camera and object observed. According the result shown in Table 7.1, the distance will affect to the size and intensity of the object. In table 7.1 the size of pupil radius and frontside reflection radius will decrease following the increasing distance from object. It is also occuring in the average intensity of the frontside reflection. The important thing in this consideration is detecting backside reflection availability.

We take an image from distance between 30 cm to 100 cm because it is very hard to take image that content enough information about pupil by distance less than 30 cm. Also we have to pay attention for taking eye area desired in the center of camera focus, because in the next step we will assume that all input images have eye area in the center of image so we can make fix cropping in this area. We also have to ask the patient to open his eyes as wide as possible to avoid noise caused by eyelid and eyelashes.
According to the Table 7.1, the bold types indicate the best position of distance to detect the backside reflection during tracking intensity. Refer to Table 7.1 **RoP** is radius of pupil, **RoF** is radius of frontside reflection, **AvoF** is average intensity of frontside reflection and **BR** is backside reflection availability.

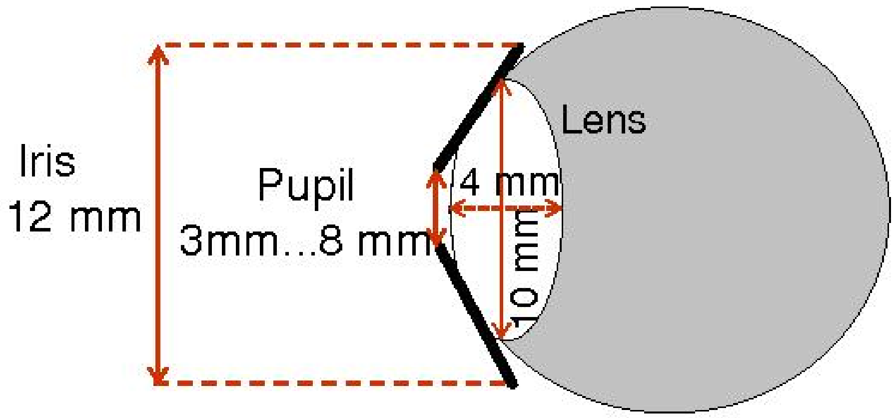


Figure 7.7. Typical shape and size of eye

2. Angle

The variable angle is used for placement of the digital camera to the object. This effect on the presence of specular reflection inside the pupil. To get a clear description of the influence of camera angle with the object, in this case is the eye lens, then we will use a simulation such as its description below.

First, we need to describe the shape and size of the eye lens to be used in our simulations. The eye lens has an ellipsoid, biconvex shape. It is typically circa 10 mm in diameter and has an axial length of about 4 mm . An iris is a circle shape inside the eye with diameter of about 12 mm [92]. Figure 7.7 describes typically shape and size of the lens, pupil and iris in our design.

In this part, there are three conditions. **First** is a condition where the reflection does not occur inside the lens. **Second** is a condition where only a frontside reflection occurs and can be observed inside the lens. **Third** is an appropriate condition where a frontside reflection and backside reflection occur and can be observed in an image plane. Figure 7.8 to Figure 7.10 show each condition, respectively.

Referring to Figure 7.8, Figure 7.9 and Figure 7.10, we can make a simple conclusion based on intuitive consideration that the camera will be in a bad po-

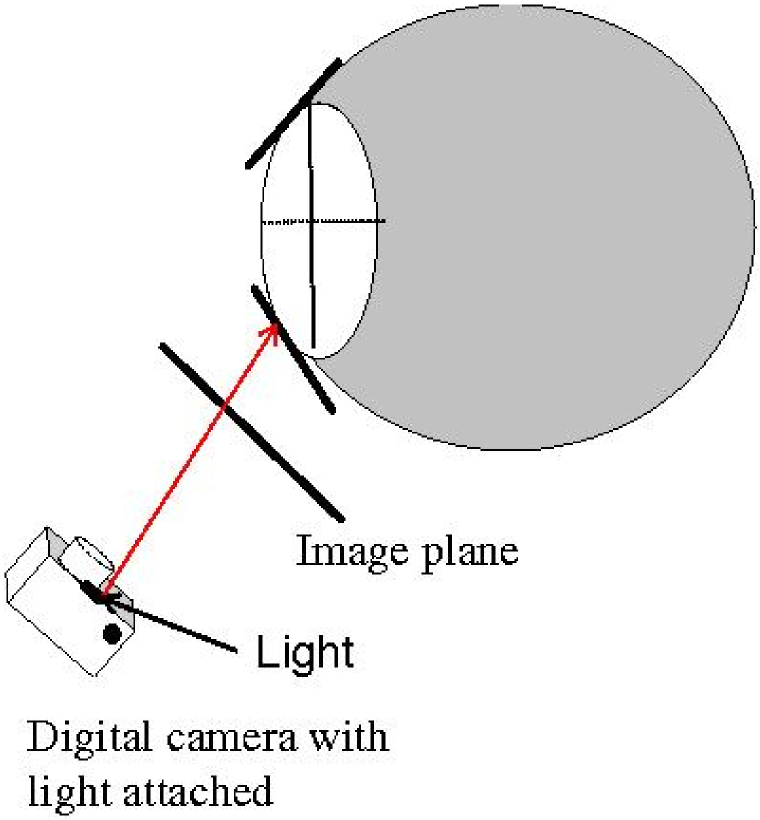


Figure 7.8. Bad condition in which no reflection occurs

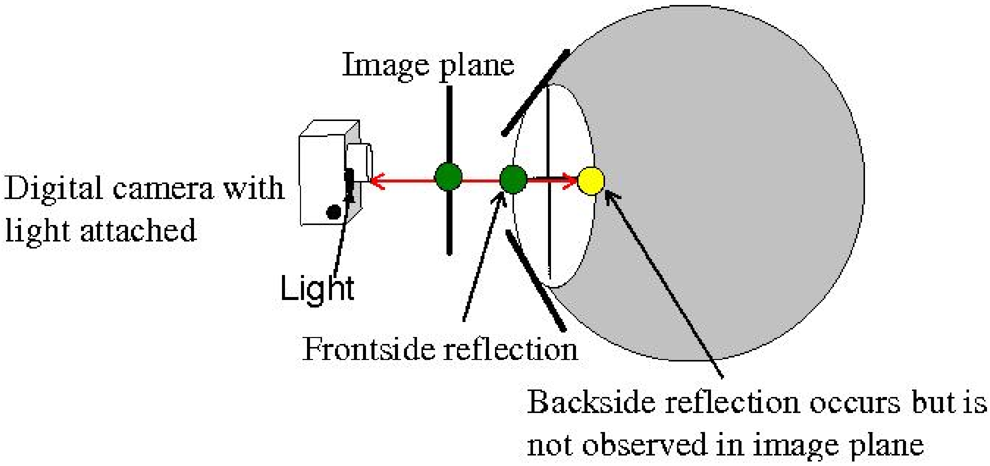


Figure 7.9. Bad condition in which only frontside reflection occurs and is observed in an image plane

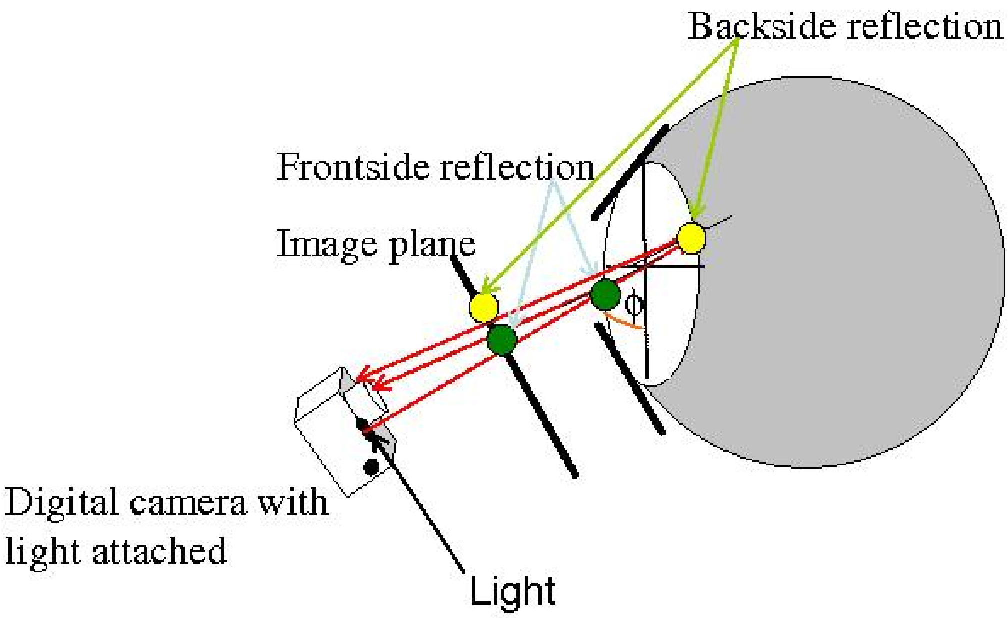


Figure 7.10. Appropriate condition in which both reflections occur and are observed in an image plane

sition when the camera is placed at: **first** in the right front of eye lens as shown in Figure 7.9, **second**, angle (ϕ) is too small or too large as shown in Figure 7.8. In order to get an appropriate position as shown in Figure 7.10, there are some criteria as the following:
i. Putting camera to the suggested position.
ii. Taking photo.
iii. Measuring the size of pupil in the image.
iv. Determining whether the image is appropriate or no.

As already discussed in the paragraph above that we can not control the pupil size; therefore in this section we emphasize our discussion about putting camera and determining appropriate image.

First we must make a clear definition of the size that will be used in the discussion here. In our discussion, we express a pupil size by a ratio between pupil and iris as described in Figure 7.11. It is indicated by symbol P_r and expressing

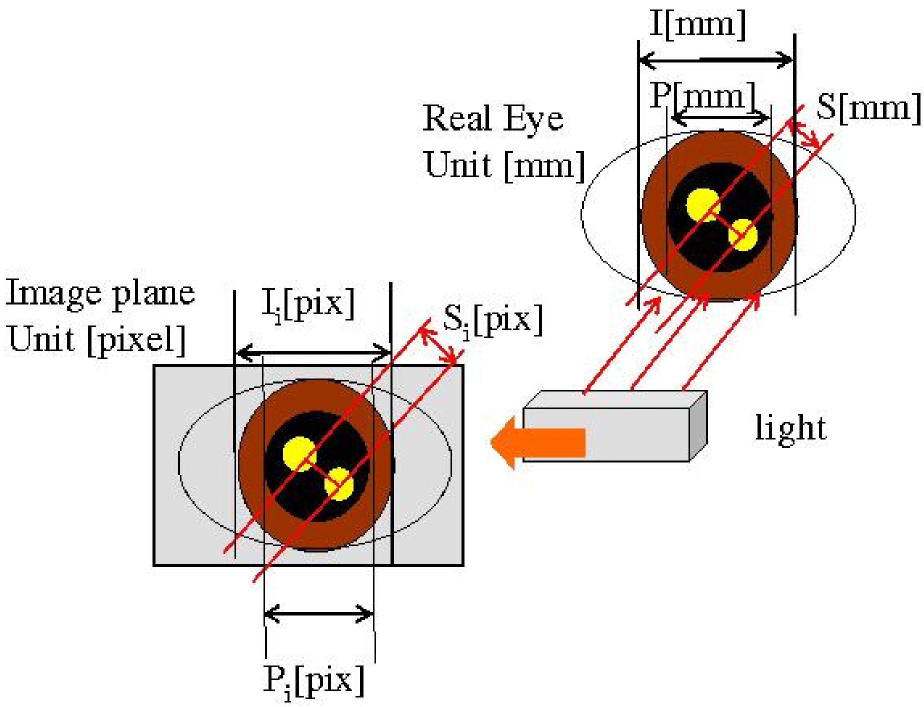


Figure 7.11. Definitions of pupil's size and distance between two reflections

by Equation 7.1 in which P_i and I_i is a pupil and iris size in an image plane.

$$p_r = \frac{P_i}{I_i} \tag{7.1}$$

While, for expressing distance between two reflections we use a symbol S_r as shown in Figure 7.11. It is ratio of distance between two reflections and iris size and expressing by Equation 7.2. S_i indicate distance of fronstide and backside reflections while I_i indicate diameter of iris in an image plane.

$$S_r = \frac{S_i}{I_i}. \tag{7.2}$$

Referring to our experiments, our algorithm able to observe availability of two reflections with minimum ratio S_r about 0.125. This value gave an enough distance between two reflections. This number may change if our algorithm implemented in a different environmental setup. In our experiment, it is an important

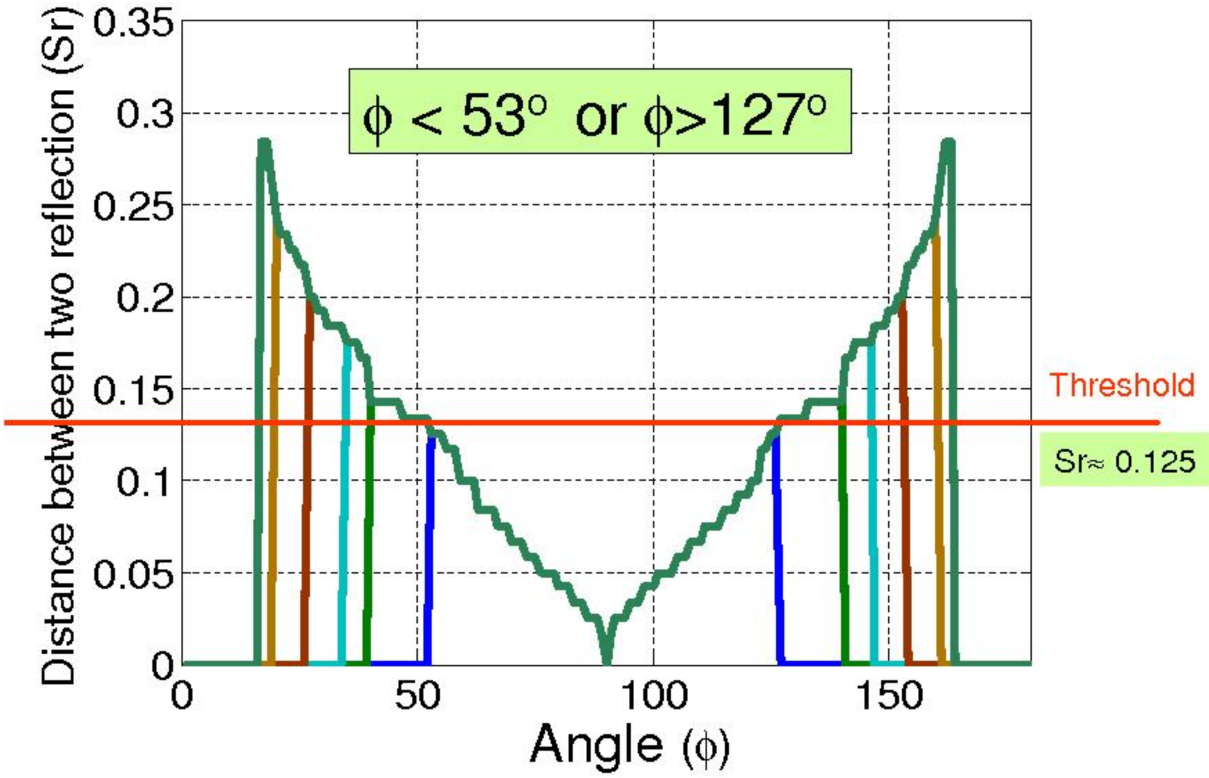


Figure 7.12. Relationship between angle and the values of Sr

value for investigating availability of the two reflections, so to find out where the position of angle between the camera and eye lens to get the threshold value of S_r then we made a simulation about the impact of angle to the values of S_r as shown in Figure 7.12.

Referring to Figure 7.12, it is appears that a predefined threshold was obtained when the camera is at an angle below 53^o or above 127^o. Only it should be emphasized here, that we can not control the amount of distance between two reflections. On the other hand, the size of the pupil can become a standard of distance between two reflections. Referring to Figure 7.7, which in our simulations showed that the pupil size always change depends on the circumstances, so it is difficult for us to control it. To overcome this problem, we analyze the

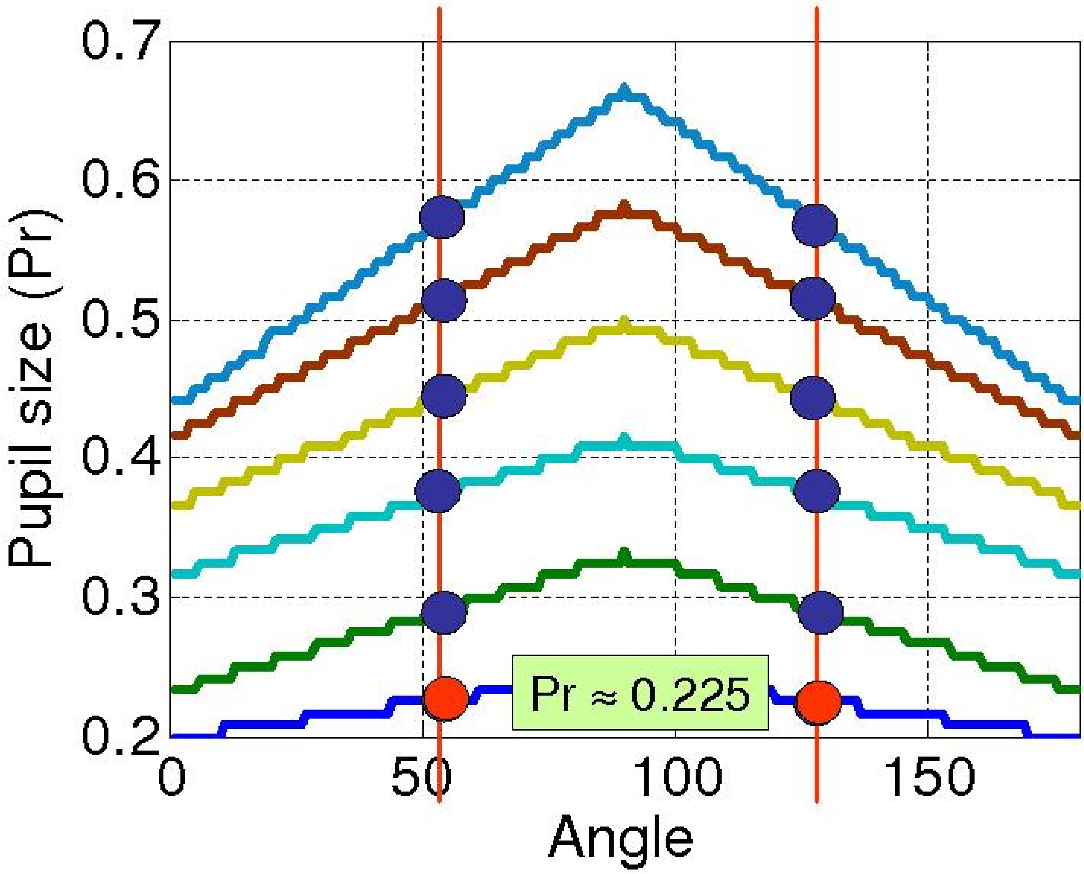


Figure 7.13. Relationship between angle and pupil size

relationship between the pupil size and angle as shown in Figure 7.13.

Referring to Figure 7.13, it is appears when the camera is at angle of 53^o or 127^o there are various pupil sizes. However, because we will create a guideline that can be applied generally, so we decided to choose the smallest pupil size when the camera is at angle 53^o or 127^o, that is when the pupil size P_r equal to 0.225. Then we can conclude our guideline that to obtain an appropriate input image with our system, so the camera should be placed at angle of 53^o or 127^o and the minimum value of pupil size P_r is 0.225. If the pupil size P_r is less than 0.225 it means something is missing and system might be make a misclassification of diagnosing.

In a real implementation, in order to avoid misclassification condition as shown in Figure 7.3 user can perform some of the following actions. User can ask a patient to enter a dark room or closed his eyes before photographed. Entering a dark room is an alternative to enlarging pupil size. In this experiment, we take a photograph of a patient before entering a dark room. After that, we ask the patient to enter a dark room for about 5 to 10 minutes and take a photograph again. Before entering a dark room the pupil size is about 4.1 mm while after entering a dark room the pupil size is becomes about 4.4 mm.

In addition to avoid misclassification condition as shown in Figure 7.3 the user can take photograph of patient more than one time for each patient. Therefore, when in the first image incompatible with our system, the system can switch to the next photo. If up to the last image remains found conditions that do not appropriate with our system, the system will assume that the patient is in abnormal condition that requires further examination by ophthalmologist, therefore in this case the patient is considered in serious condition.

In order to confirm our design in real conditions, we did a practical data acquisition using equipments as described in Figure 2.5. In a real implementation, it is difficult to get a position between lens and camera as described in Figure 7.10; therefore, we measure a position between camera and points located at $\frac{1}{4}$ length of the chin rest as described in Figure 7.14 and Figure 7.15. An equation for calculating the angle between camera (point A) and object (point D) is described as follows.

Referring to Figure 7.15, we calculate an angle φ as follows. First, we calculate the length of b and c using a laser distance meter. In our own setup $a = a_1 + a_2$, and the length of a is fixed at 0.17 meters; therefore, $a_1 = \frac{3}{4}a$ and $a_2 = \frac{1}{4}a$. The length of d is calculated by the Stewart rule [27] as described in Equation 7.3.

$$d = \sqrt{\frac{a_2.b^2 + a_1.c^2 - a_2.a_1.a}{a}} \tag{7.3}$$

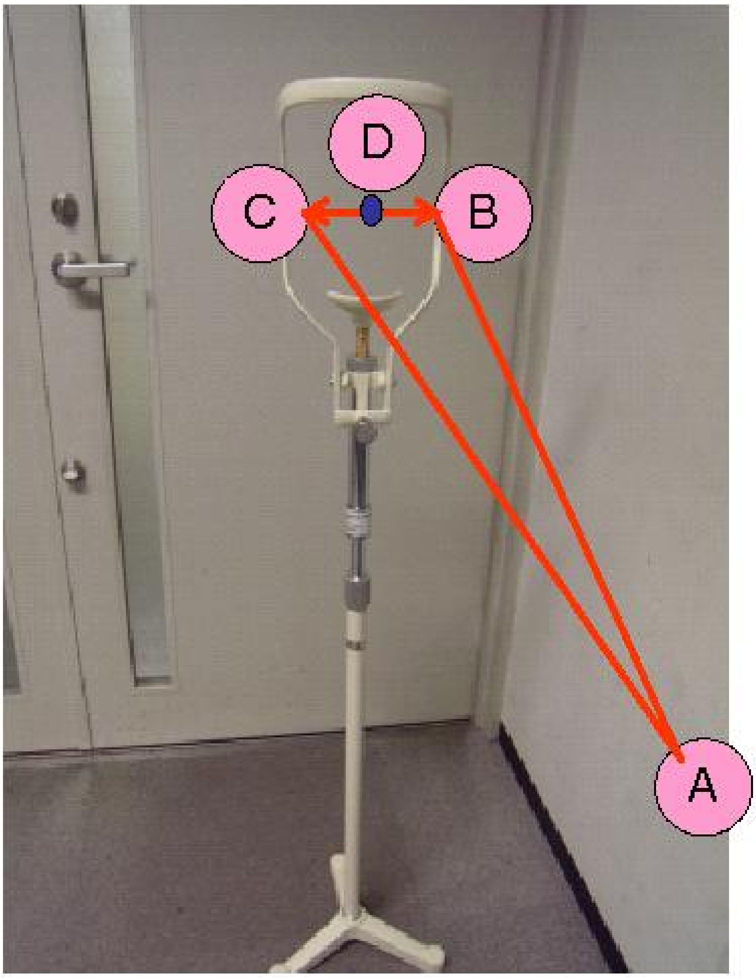


Figure 7.14. Measuring points

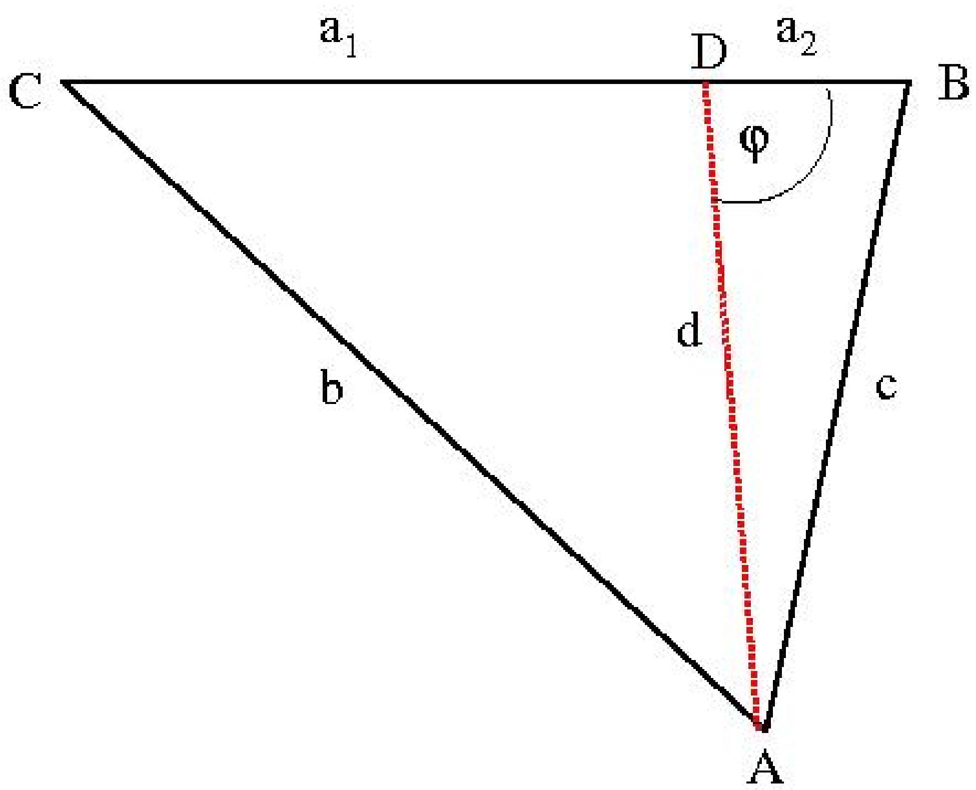


Figure 7.15. Model of calculation

By comparing Trigonometrys rule [19] in Equation 7.4 and Herons formula [97] in Equation 7.5, we able to calculate angle φ as described in Equation 7.6.

$$S = \frac{1}{2}.a_2.d.sin\varphi \tag{7.4}$$

$$S = \frac{1}{4}\sqrt{(c+d-a_2)(c-d+a_2)(-c+d+a_2)(c+d+a_2)} \tag{7.5}$$

$$sin\varphi = \sqrt{\frac{(c+d-a_2)(c-d+a_2)(-c+d+a_2)(c+d+a_2)}{2.a_2.d}} \tag{7.6}$$

In general, practical data acquisition results shows an appropriate condition with our design in which the largest pupil size has the lowest distance between two reflections. Also, the results show that the relationship between pupil size and distance in our design and practical is quite similar. We tested our design on some data and got a typical characteristic as shown in Figure 7.16.

Also, We obtained the relationship between the angle in our design and real implementation as shown in Figure 7.17 and Table 7.2 where φ is an angle in real implementation and ϕ is an angle in our design.

$$\varphi = \phi + 10 \tag{7.7}$$

Referring to Figure 7.17, it appears that angle value in a real implementation always higher about 8 to 11 degrees than an angles value in our design. This is caused by the difference in target of angles measurement. In our design, we measure the angle between camera and lens accurately, while in a practical, the angle is between the camera and point as described above. Although an interval of increasing angles value in a real implementation is not fixing in one value, however the difference is not too much. To get an equation for converting an angle in our design to a real implementation, we calculate the average interval of increasing angle, which is 10. Using this value, we express a conversion equation as shown in Equation 7.7.

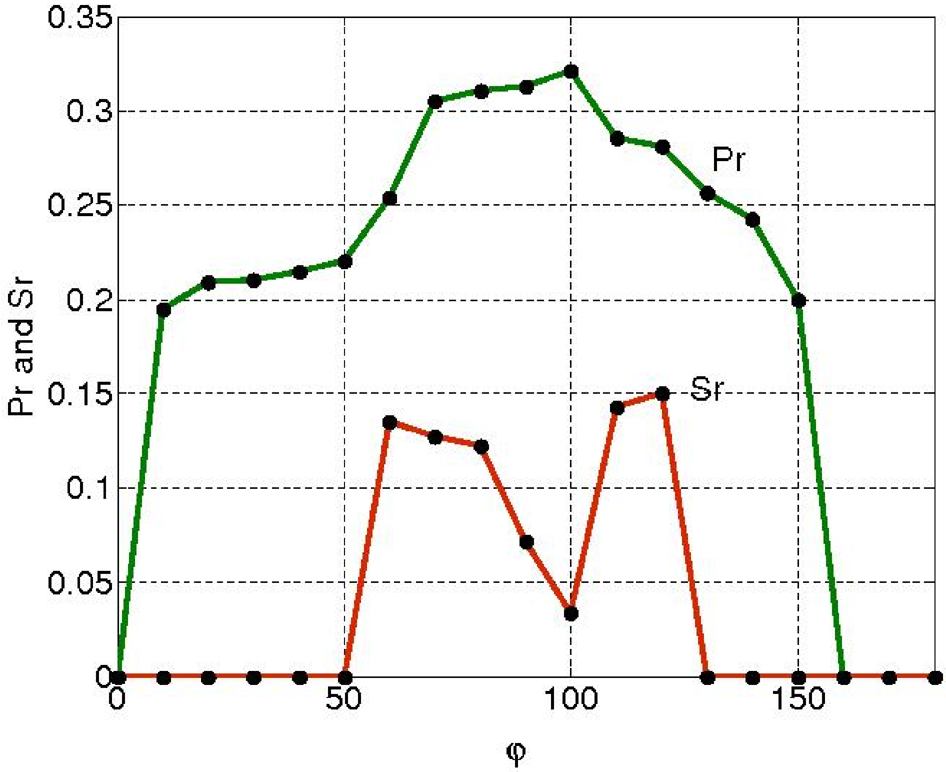


Figure 7.16. Relationship between angles and the value of P_r and S_r in practical data acquisition

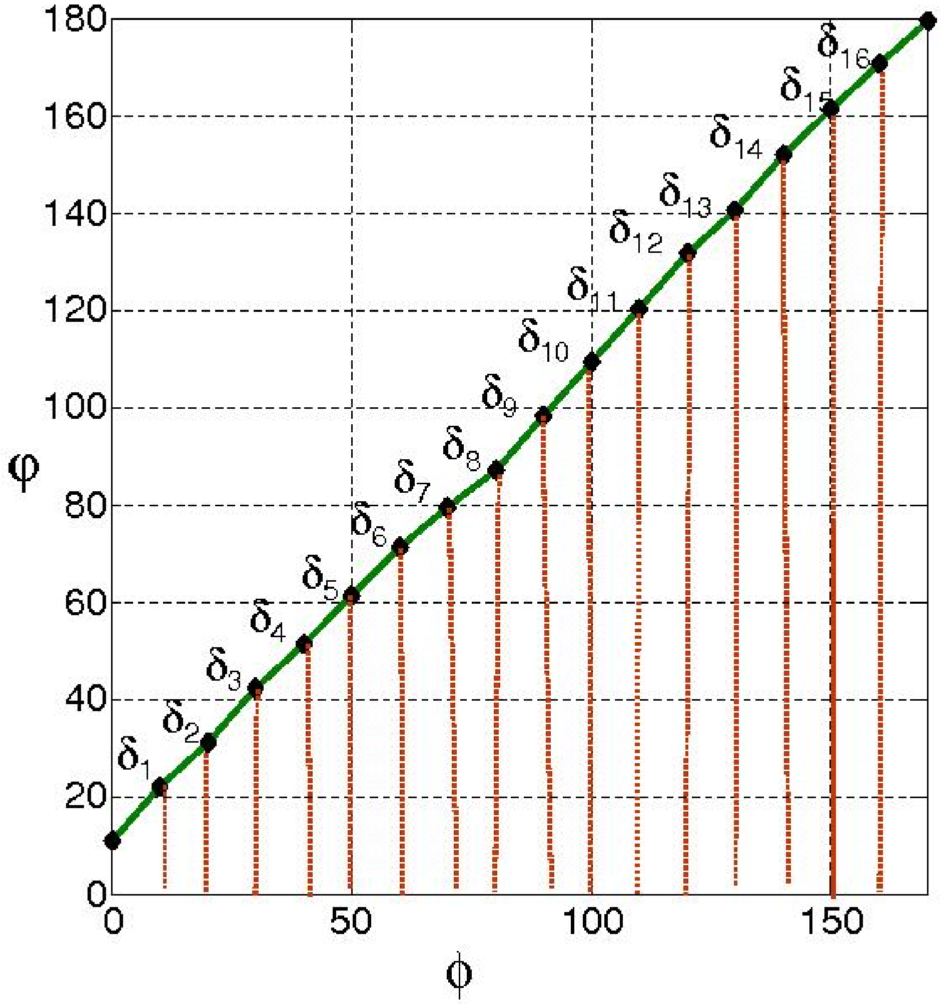


Figure 7.17. Relationship between value of angle in design (ϕ) and practical (φ) data acquisition

Table 7.2. The difference angle between design and real implementation

Angle in simulation (ϕ)	**Angle in real (φ)**	$\triangle$
10	21.22	11.22
20	29	9
30	41.14	11.14
40	49.09	9.09
50	59.93	9.93
60	69.98	9.98
70	78.29	8.29
80	87.71	7.71
90	101.01	11.01
100	111.2	11.2
110	120.74	10.74
120	131.6	11.6
130	138.58	8.58
140	149.21	9.21
150	159.3	9.3
160	168.98	8.98
170	179.03	9.03

Chapter 8

Conclusion

8.1. Summary of result

Cataracts are a kind of eye disease; that is a clouding in the lens of the eye that affects vision [78]. The World Health Report published in 2001 estimated that there were 20 million people who are bilaterally blind people (i.e., eyesight less than 3/60 in the better eye) whose blindness was caused by age-related cataracts. That number will have increased to 40 million by the year 2020 [40]. Increasing age is associated with an increasing prevalence of cataracts, but in most developing countries, cataracts often occur earlier in life. One of the developing countries that has the highest number of people with cataracts is Indonesia. There are about 6 million people in Indonesia who suffer from cataracts, but Indonesia only has about 750 ophthalmologists for a population of more than 200 million people (one for every 350.000 people). In addition, ophthalmologists are not evenly distributed [35]. To avoid blindness, we need to detect cataracts early. Today, ophthalmologists use a slit lamp to obtain clear information about the inside of the eye lens for detecting eye diseases like cataracts and glaucoma, for example. Performing early detection for avoiding blindness using a slit lamp may not be a problem in developed countries like Japan, the USA, and the UK, for example. However, it is a problem for some developing countries like Indonesia, Nepal, and Vietnam, for example. Based on conditions in developing countries like Indonesia which has a limited number of both ophthalmologists and health facilities, we propose a simple method for cataract screening. The main equipment is a compact digital camera that 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 less expensive than a slit lamp camera.

The goal of our research is developing a simple and robust screening system for cataract with compact digital camera. User simply taking a patients photograph and system will automatically analyze image by extracting information inside a pupil including specular reflection analysis and texture appearance analysis for distinguishing between serious and non-serious condition. In a specular analysis method, we investigated an availability of backside reflection. It is a kind of specular reflection that occurred in the rear side of lens. For a non-serious condition there is a backside reflection appears in a pupil, while for a serious condition, there is not a backside reflection appears in a pupil. In texture appearance analysis method, we were extracting information about uniformity and average intensity. Assuming that a non-serious condition does not have a whitish color inside the lens and the surface of pupil is smooth therefore a non-serious condition has a higher uniformity than a serious condition. In another side, a serious condition has a lot of whitish color inside the lens therefore a serious condition has a higher average intensity than a non- serious condition.

Our algorithm is a simple and robust for cataract screening because we able to distinguish between serious and non-serious condition based a threshold value of backside reflection availability inside the pupil although it was implemented in a few images data [82] .Also, when we implement our algorithm in more images data, we got a better performance than using a straightforward algorithm like color information method [81] We improve our algorithm by adding an uniformity feature inside the pupil for analyzing cataract, and we got a significant performance for distinguishing serious and non serious condition, although we still get some problems during classification [83] [84] and finally, we solved the problems for screening cataract by extracting all information appear inside the pupil including specular reflection appearance and statistical texture appearance that consists from uniformity and average intensity [86]. Also, we already have a guideline for getting an appropriate input image, therefore, our algorithm analyze an appropriate input image only in order for getting a robust classification of serious and non-serious condition [85]. However , current research have some limitations:

1. Algorithm of pupil detection is not perfect yet, this is indicated by the performance of the algorithm that only just 89.8%, while the method in our system depend on the success of pupil localization algorithm, so that in further research we have to improve the performance of pupil localization algorithm.

2. Although current research has a good performance, indicated by percentage value of TPR is about 92% and percentage value of FPR is about 18%, however to get a robust screening method, we have to improve our methods performance to get value of TPR equal to 100% and value of FPR equal to 0%.

3. Although in Chapter 7 we have explained our design concept in real implementation, but we have not tested yet the system in actual implementation such as in a rural area in which there is not ophthalmologists or health facilities, that it needs to be done testing our system on an actual implementation to get the real problems that arise of the on-site testing.

8.2. Open Issues and future works

As discuss above, Indonesia has limitations both eye doctors and health facilities. For example, in Central Java region with area about 32.544, 12 km (35 cities) and population about 32.380.279 people there is one eye clinic only [88]. Although in each city there is some Health Community Center, however there is not an eye doctor therefore people have to go to eye clinic for getting diagnosis about cataract. Health Community Center is a functional organization which is conducting a simple health services that are comprehensive, integrated, equitable, acceptable and affordable by the community. According to the fact, our future work as follows:

8.2.1 Improving the robustness of total screening system

In order to develop a compact cataract screening system, we consider to improve all parts of algorithm, from taking a photograph to make a decision for classifying between serious and non-serious condition by following techniques:

Algorithm of pupil detection

The main problem in current research is detecting pupil, while for making a complete system this part is very important. In Chapter 3 we already discussed about the causes of failure in our algorithm, so that in further research we will consider the existence of eyelashes as a source of failure in our pupil localization algorithm as already discussed in Chapter 3.

Improving performance of algorithm for classifying serious and non-serious condition

Current research considers three features: specular reflection, uniformity and average intensity for distinguishing between serious and non-serious condition, but in reality, our system has not got yet a perfect performance. Therefore for getting the ideal value of TPR and FPR we will consider the following features; **First** reconsider about the size of the backside reflection. **Second** consider on the power light of the flashlight to the shape of specular reflection and **Third** we must consider the relationship between frontside reflection and backside reflection, about the two reflections have the same shape or not, or the tendency of the backside reflection shape. All of the considerations already discussed in Chapter 6.

8.2.2 Collaboration with eye clinic in practical implementation

In order to achieve robust system, we need to collect more data in a real condition. We already have permission from Head of Kamandaka eye clinic in Central Java Indonesia for collecting data of patients both serious and non-serious condition. Also we had an informal contact with a head of Health Community Center for developing a pilot project to implement our system. In this step, we will install all hardware and software requirements for cataract screening system in a Health Community Center in Indonesia in which I had a contact. Staffs in Health Community Center will operate our system and give a report about performance our system anytime. Problems that arise from our system on-site testing will be a valuable input to improve our system. In order to improve our system, we will have a discussion and supervising both engineering and medical view from Nara Institute and Science and Technology and Shiga Medical University, while for continuing our project in Indonesia, we already had a contact with staffs in electrical engineering department, Jenderal Soedirman University. They will be a management in charge for developing a compact cataract screening system.

Expected results of this works describes as follows. Our system has a robust performance for cataract screening. By developing a pilot project to implement our system into a health community center, they will have a database of cataract eye patients without going to eye hospital/eye clinic. In an emergency case in which patients have to get a surgery as soon as possible, they send patients to eye hospital/eye clinic for getting surgery. Also we can consider to apply our system to the telemedicine system. For example, Indonesia currently being developed in several pilot projects in telemedicine systems as developed by Soegidjarko [79]. For telemedicine environments, it is crucial to implement a compact screening system for several diseases common there.

If the system is successfully implemented in Indonesia, therefore it is expected to be a reference for implementation in other developing countries that have the same problems with Indonesia in terms of the limited health facilities.

Achievements

Journal

- Retno Supriyanti, Hitoshi Habe, Masatsugu Kidode and Satoru Nagata: Cataract Screening by Specular Reflection and Texture Analysis, Communications of SIWN (Systemic and Informatics World Network), Vol. 6, pp. 59-64, 2009.

International Conference

- Retno Supriyanti, Hitoshi Habe, Masatsugu Kidode and Satoru Nagata,A Simple and Robust Method to Screen Cataract using Specular Reflection Appearance, SPIE Medical Imaging Conference, February, 2008. (Honorable Mention Poster Award)

- Retno Supriyanti, Hitoshi Habe, Masatsugu Kidode and Satoru Nagata, Extracting Appearance Information inside the Pupil for Cataract Screening, IAPR Conference on Machine Vision Application, May, 2009. (Oral presentation)

- Retno Supriyanti, Hitoshi Habe, Masatsugu Kidode and Satoru Nagata, Compact Cataract Screening System: Design and Practical Data Acquisition, International Conference on Instrumentation, Communication, Information Technology and Biomedical Engineering (ICICI-BME), November, 2009. (Oral presentation)

Domestic Conference

- Retno Supriyanti, Hitoshi Habe, Masatsugu Kidode and Satoru Nagata, Cataract Screening using Reflection on Eye Lens, Symposium of Sensing via Image Information (SSII), June, 2008.

Prize

- Honorable Mention Poster Award, SPIE Medical Imaging Conference, San Diego, California, February 2008.

Patent

- Japan Patent, Number 2008-035367. after that supporting by JSPS project, this patent was submitted to International patent with number PCT / JP2009/52572

List of Figures

List of Tables

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Appendix

Manual instructions for taking photograph

- In order for placing camera and chin rest easily, please use a plastic mat and marked on the angle size using a protractor as shown in Figure 8.1.
- Put the chin rest on the plastic mat marked. Chin rest placed at the center of corner markers as shown in Figure 8.2.
- Put the tripod on the plastic mat marked. Position of the center of tripod is at an angle of about 60^o for left eye and about 120^o for right eye, while the distance between the center of tripod and chin rest is about $30cm$ as shown in Figure 8.3
- Put digital camera on the tripod as shown in Figure 8.4
- Ask the patient to put his/her chin on the chin rest as shown in Figure 8.5. The eyes straight ahead.
- Set the camera in macro function and also must use a flash light facility. Also set the eye will be photographed at the center of focus as shown in Figure 8.6
- Ready to take photograph as shown in Figure 8.7

Figure 8.1. Plastic mat marked

Figure 8.2. Chin rest placement

Figure 8.3. Tripod placement

Figure 8.4. Camera placement

Figure 8.5. Patient position

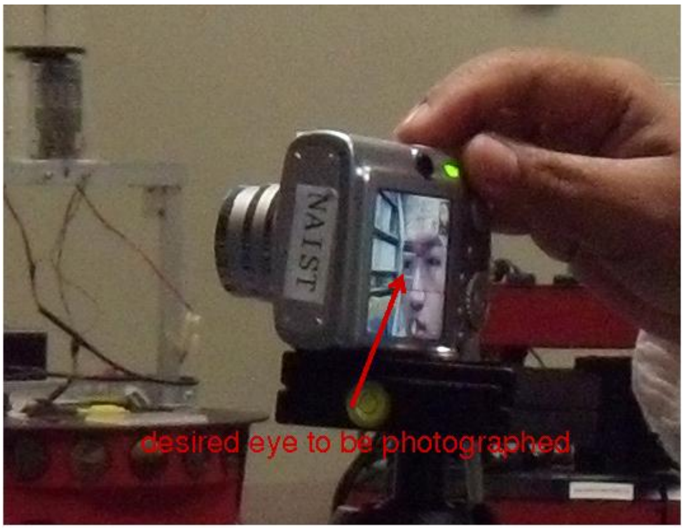

Figure 8.6. Camera set up

Figure 8.7. Position of taking photograph