Fundus Imaging Based Affordable Eye Care

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Keywords: Glaucoma, Ophthalmoscope, Fundus, Image Processing, Android, OpenCV, CDR Ratio.

Abstract: India is a developing country. It has a very low doctor to patient ratio and hence affordabe healthcare has always been a matter of concern. The high cost of diagnostic devices and unskilled or limited skilled clinicians exacerbate this problem. The treatment of visually impaired patients is a daunting task in India as it requires periodic examination of eyesight. Devices meant for this check up are expensive and often require high degree of expertise to operate. In this paper we propose a low-cost, lightweight, handheld, android phone based fundus imaging device. The application software makes it user-friendly and also can also provide a limited automatic screening capability of some retinal problems. In this paper, we report the use of this device for screening of patients for Glaucoma. The paper presents empirical results using patient data from hospitals. The results indicate that such a device can effectively scale the operations of screening of many eye related problems in under served areas.

1 INTRODUCTION

There are more than 285 million people worldwide suffering from some form of visual impairment. Out of them, 39 million are victims of preventable blindness caused by cataracts (51%), Glaucoma (8%), child blindness (5%), trachoma etc. According to a recent WHO report 90% of these people live in developing countries that lack specialized medical services, sophisticated medical equipment and clinicians (BlindnessCause1; BlindnessCause2). Many of these are cases of preventable blindness like glaucoma. Currently, in India, it is estimated that there are 12 million people suffer from glaucoma and the majority of them are undiagnosed (Thomas). This clearly suggests that many cases of of visual impairment can be mitigated by early stage detection. For this to be possible a periodic but comprehensive examination of the eye is mandated. The diagnostic equipment (Optical Coherence Tomography, Heidelberger Retinal Tomography, Fundus Camera, Slit Lamp etc.) employed for eye examination are bulky, expensive and a trained technician is required to handle them. In under served areas, the large number of patients and time constraints of available opticians or ophthalmologists are significant constraints and there is a need for an innovative solution. To address these problems we have developed a hand held low cost fundus imaging device coupled to the smart phone device that could help in the early detection of the eye

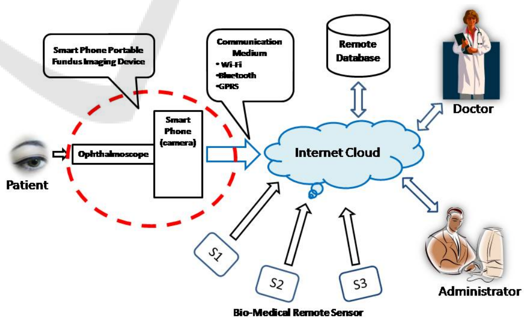

Figure 1: Working of mobile based fundus imaging sensor.

related ailments.

In recent times the smartphone has emerged as a versatile mobile compute platform. The relative ease of using a Smartphone based medical devices for various physiological parameter monitoring can provide cost effective solutions to the problems of portability. A Smartphone can be interfaced with a low cost unit for examining the interior surface of eye, termed as Fundus which is located opposite to the eye lens and includes the retina, optic disc, macula and fovea, and posterior pole. It can be examined using an ophthalmoscope. Image acquisition of the Fundus is the most critical aspect of the design — ophthalmologists use high resolution fundus imaging devices for the same. The proposed Fundus imaging device integrates the phone's inbuilt camera with an ophthalmoscope. A mobile case has been prototyped for coupling the oph-

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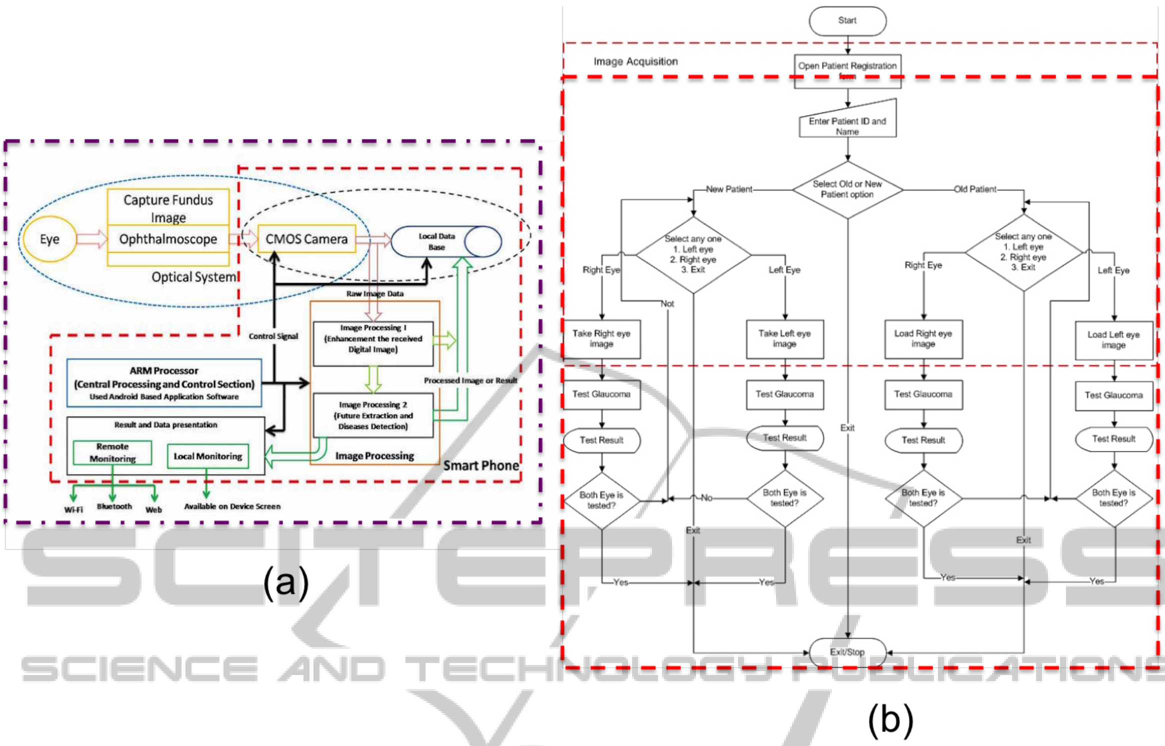

Figure 2: (a)System Architecture and (b) Application software Flow chart.

thalmoscope to the phone. Android based application software enables the capture of fundus Image/Video. The application enhances the quality of the captured image/video and detects the presence of Glaucoma.

The rest of the paper has been organized are follows. We begin with a high level system overview, which briefly discusses the system architecture and its functional sections i.e. image acquisition, storing, processing and diseases determination. Next, we describe the hardware and application software of low cost fundus imaging device. Finally we provide experimental results of using the device along with validation results of hospital trials, to illustrate the portability, scalability and adaptability of the proposed solution.

2 DESIGN OVERVIEW

In this section we outline the design of a Fundus Imaging device subject to constraints of **Cost, Bulkiness, Portability** and **adaptability**. As mentioned earlier, the device is based on the Smartphone. The Device application software enables a semi trained/untrained user to operate the system for detecting certain eye ailments. This has been made possible by embedding the **Optical** (image capturing unit), **Computing** (Microprocessor), **Communication media** (Wi-Fi, Bluetooth, Web etc.) and **Database** functionalities into a single device shown in Figure 2a. As illustrated in the figure, the device consists of different function blocks which are described below:

- **Optical System.**
  This block captures the magnified fundus image with a camera — typically CMOS in nature. The key innovation in the solution is to replace the eye of the ophthalmologist by the smart camera based CMOS sensor to capture the image of the patient's fundus as shown in Figure 4. We use a smart phone of high resolution (> 5MP) Camera for the same purpose. We have also designed and built a custom mobile phone holder Rapid Prototype model to attach the Mobile phone camera to the ophthalmoscope.

- **Image Acquisition and Data Management**
  The Smartphone CMOS camera captures the magnified fundus image formed by ophthalmoscope and saves the image/video in the phone memory or SD Card. The data is organized in a hierarchical method. The image is stored along with meta data like **Patient ID** and **left/right eye** information.

- **Image Processing**
  This functional block does all the image processing related tasks and it is broadly divided into two units, viz., Processing-I and Image Processing-II is shown in Figure 2a. To do the image processing, the device uses Android based application software and the OpenCV library. The first section removes helps to minimize/reduce the noise present in fundus image by applying appropriate median and other filters. After preprocessing tasks, the next block performs the tasks related to detection of ocular ailments (like Glaucoma, Diabetic retinopathy etc).
- **Central Processing and Control Unit**
  An ARM based processor is used for overall control of the device. It uses the smart phone's inbuilt ARM Cortex processor and runs the application software written in Java. The ARM based processor is able to satisfy the computing specifications required for image processing and responsiveness of the application software. The ARM processor that was used for above operations had the following specification:
  - CPU clock: 0.8 GHz to 2 GHz
  - Core: 1-4
  - Instruction Set: ARMv7
- **Result and Data Representation**
  This section is responsible for sharing the fundus data and results with other device or remote user via different communication media either locally or using wireless methods.

The Fundus Imaging system consists of smart phone and an ophthalmoscope. Specifically, a consumer grade (Samsung Galaxy S3/S4) cellular phone is interfaced to a PanOptic's ophthalmoscope. The photo-imaging unit of the phone consists of a flash light as the illumination source to a 8.0 Megapixel (MP) camera at the centre to centre separation of around 10 mm. The ophthalmoscope used provides an easy entry into the eye, together with a wider field of view to better observe eye conditions.The unit captures the fundus image in a JPEG format, which gets stored in the phone. The image is then processed for detection of its optical disk and cup, after which the respective areas are calculated to compute the Cup to Disc Ration (CDR) for setting up the threshold for the affected eyes. The image processing operations as discussed above are built into the Android Application. The setup for capturing the fundus image of a person's eye using the developed system is shown in Figure 3. The system is held very close to the person's eye (for detection of Glaucoma) The real time application on the phone displays the image. Also, it displays the result in a format which can easily be interpreted.

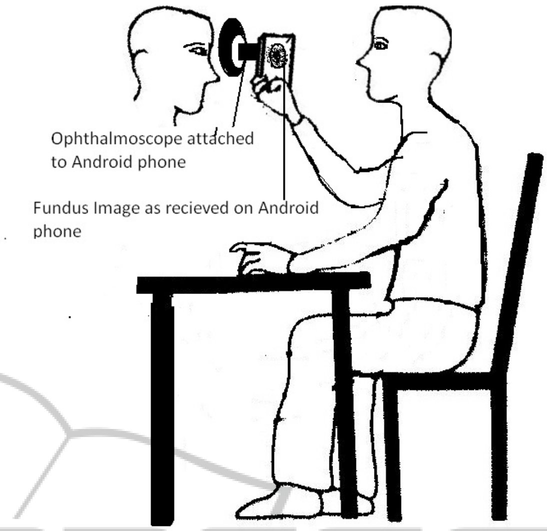

Figure 3: System Setup for taking Fundus Image,In which fundus image is appear on mobile phone screen.

We now describe the image magnifier system which is essentially an ophthalmoscope and then describe the acquisition system which is the smart phone camera.

Optical System The ophthalmoscope is an optical instrument for examining the interior structure of the eye, especially the back part of eye (fundus), which includes the retina, optical disk, optical cup, blood vessel and fovea etc. Ophthalmoscopes are of two kinds, direct and indirect (Timberlake).

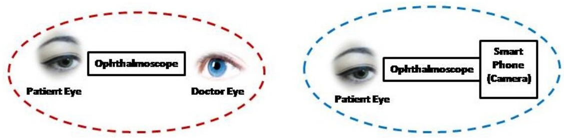

Figure 4: Optical System: Doctor eye is replaced by Camera.

We use PanOptic ophthalmoscope which is very similar to the traditional ophthalmoscope. However, there are number of differences – in particular, the view angle of the PanOptic is 4-5x wider i.e. 25°.

Embedded System. For Image Capturing, Image processing and Result Sharing we need an advanced electronic system that has the capabilities described in the previous section. Modern Smartphones have many of the required compute capabilities in addition to having only communication and data sharing capability. They fulfil the requirements of (a) High resolution CMOS camera (b) Centralized Control System to synchronise and control all processes (c) High computation capability to perform image processing and (d) communication features for sharing result and data with a potential remote user. The proposed solution has been developed on an Android based Samsung Galaxy S-3 smart phone. The Smart phone camera is able to capture fundus image only when if it is properly interfaced with hand held portable ophthalmoscope. In the proposed solution, the physician's eye (Figure 4) is replaced by CMOS Camera. For that we have designed a special type of a phone holder as shown in Figure 5.

Figure 5: (a) RP model of Case and (b) Ophthalmoscope attached with mobile phone holder.

The mobile phone case CAD model is shown in Figure 5, has been designed using SolidWorks software. The material used in Rapid Prototype system for building the case is SLS. Various factors as portability, light weight, aesthetic looks etc. have been considered. The round shape on the top centre has been provided to ensure that the view through the ophthalmoscope can be captured on phone's camera without any obstructions. For a stable fit of the ophthalmoscope with phone, a holder is built at the bottom. Also, to ensure easy charging of the phone, a rectangular shape hole is provided at the bottom and one on the top left for the volume control. The mobile case when integrated with the Ophthalmoscope is shown in Figure 5. The mobile can easily be inserted into the casing.

3 IMAGE ACQUISITION SOFTWARE

In order to display the fundus image and the results, a fundus imaging software has been developed. The application software works on all Android based Smartphones. The application software includes all the image processing operations needed to calculate the degree of Glaucoma in the person's eye. The same has been achieved using OpenCV Library on Android platform and performs two major tasks namely (a) **Image Acquisition** and (b) **Image Processing (Glaucoma Detection)**. For all the tasks, application software switches to different UI screens thus helping guide the user at each stage of the application. This is shown in Figure 2b. As shown in the figure, the Fundus Image Acquisition step is further divided into four stages.

- Filling Patient Information. GUI has two text fields **Patient Name** and **Patient ID**. For each user, patient ID is a must and it must be unique. Patient ID will help in searching and sorting of patient data in future.
- Option to use this device as new and old patient. For both case application will provide separate GUI windows.
- Separate GUI is provided to select left and Right eye one by one for taking the fundus image.
- Image capturing GUI provides image retake and save options. After the capturing operation, the image is visible on thev GUI so that user can accept the image quality or redo the entire operation.

All the above four stages of operation in Android is defined as four different Activities and uses four different Layouts. Image acquisition is done in four stages. All stages are defined as Activities in Android Development environment (ADT). That is described by the AndroidManifest file and briefly described below:

- **BeginActivity: Patient Information Form.** This manages patient related information. User should enter patient name and Patient ID No in the GUI. On the basis of patients ID, the application software will manage all the related data.
- **MidActivity: Select Eye.** MidActivity provides a Menu option to select the eye and patient type for Fundus imaging. By clicking the button/radio button, the user makes the choice. The button's operation is defined in the Activity Layout file.
- **LeftCamActivity/RightCamActivity.** In this activity application will perform Video/Image aquisition task. In this activity, the application captures images/video of left and right eye. To capture Video, application will call native Camera intent. To use intent native Camera again application will perform check for all camera permission. However, in case of old patients, software will automatically search and select the patient fundus image.

The next section describes then Android based application developed for Glaucoma screening.

4 DETECTING GLAUCOMA

Glaucoma is a neurological disorder that causes damage to optical nerves occurs due to Intra ocular pressure (IOP). Glaucoma is evaluated by measuring IOP,visual feild and optical disc shape (Cup to Disc Ratio 'CDR' (Narasimhan; Yuji) and ISNT rule (Harizman)). CDR is one of the main clinical indications of Glaucoma. In case of glaucomatic eye this ratio will high as compared to healthy eye.

In the application, we implement the intensity based segmentation method (Yuji; Wong) to segment out the optical disk and the cup from the green channel of ROI. Using the elliptical area formula android device application software will calculate the area of the optical disk and cup (Narasimham). After that, we use the ellipse area formula to find out the area of segmented region. Finally CDR value is calculated by taking the ratio of Cup Area and Disc Area. On the basis of calculating CDR value one can say about the stage of glaucoma.

We first discuss the method used to identify the ROI. We have used OpenCV library to implement image processing operations for the application whose primary focus to detect the glaucoma in the Fundus image. The working of this Glaucoma detection software is illustrated in the flow chart shown in Figure 6. The Android application performs image processing in two stages. In the first stage, image processing software performs all the tasks related to ROI separation, preprocessing and image quality detection. And in the second stage, the software does Glaucoma detection.

Different algorithms from of Image enhancement (Peli; Paulus) are used to de-noise the captured image as well as perform operations for detection of a particular ocular ailment. This includes the following steps:

1. **ROI Extraction.** The ROI extraction is shown in Figure 6. The application software captured fundus image in RGB mode. The extraction of the optical disk and the cup is done from from the G plane as it provides better contrast compared to the other planes.

   The centre of the disk will be obtained on the basis of maximum intensity region in the G plane/Gray image. The identified maximum intensity point is considered as a reference point to find out ROI. Using that value we separate out ROI of pixel size 300×300 pixels or 500×500 pixels from the original image.

2. **Preprocessing of Extracted ROI.** To differentiate between optical cup and disk, a good quality of images is desirable. Also, even if the image quality is good but edges are not easily differentiable due to the inappropriate intensity levels, image improvement is required. To achieve this, the application performs Histogram Equalization, Normalization and Filtration of blurred image.

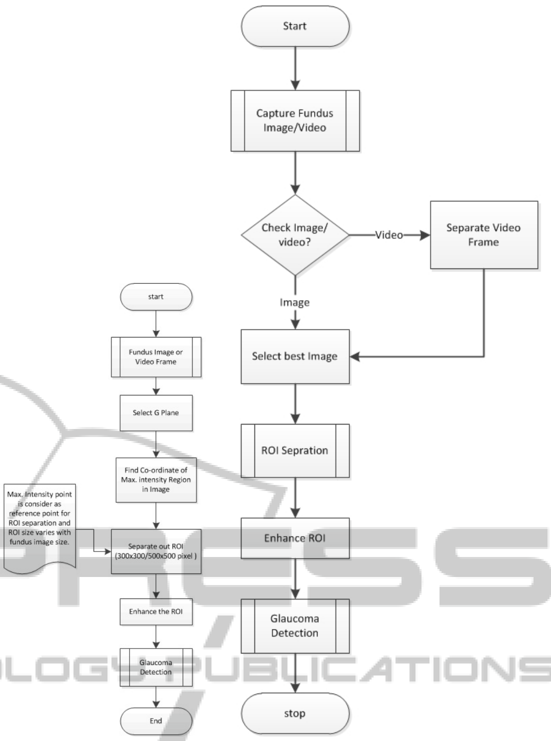

Figure 6: Flow chart for ROI separation and Glaucoma Detection.

3. **Automatic Image Quality Assignment.** Some time users are not able to differentiate the quality of images taken by device. We have used techniques described in (Paulus; Giancardo) to check the image quality.

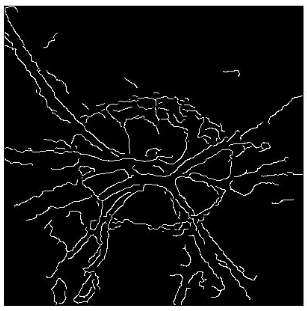

Figure 7: ROI:Blood Vessel.

- **Elliptical Local Vessel Density Measurement.** In OpenCV we use different edge functions to find out edges in ROI. On the basis of density edges in ROI we conclude about the quality of images. Normally if the image is good than available edges density is high.
- **Histogram Based.** The histogram is determined for the Gray Image. The application then uses a method described in (Paulus) to find out the quality of image. Finally the application

software applies both methods to find quality of image.

The application software uses this CDR value to screen out Glaucoma suspects and health person. In the proposed solution, one can also capture fundus video also that will help a clinician to analyse retina in other ways. The entire process is done on an undilated eye. The application performs the following tasks one by one to do the screening:

- **Segmentation of Optical Disk and Optical Cup.** Optical disk detection is carried out in the android application software using the OpenCV library image processing function. Implementation is done in following steps:
  - RGB Fundus image is converted into a Gray image: Used OpenCV library function (Figure 8).
  - Histogram equalization of the image pixel intensity: (Figure 8). After equalization, image intensity value lies between 0-255 and it is helpful in next stage i.e. thresholding.
  - Thresholding and Binarization: In the application software we used 95% of the maximum intensity as a threshold point for Disk segmentation. (Figure 8).

  The optical cup detection is similar to detection of optical disk, the only difference being the selection of the threshold value (here it is 80% of the maximum intensity gray image). The segmented Cup is shown in Figure 9.
- **Cup to Disk Ratio(CDR).** Optical cup size will increase as compared to optical disk and that will reflected through Cup to Disk ratio. For a normal person its value is 0.1-0.3. CDR value plays key role in our proposed solution for Glaucoma screening. But in the case of the eye affected with the disease, the ratio becomes high.
- **Segmented Disk/Cup Area** To find CDR, firstly find out the area of Disk and Cup.Used the binarized optical disc and cup to find out corresponding area using the ellipse method (Narasimhan; Narasimham).

  $$Area = \pi * a * b \quad (1)$$

  Where,
  a = half length of major axis ellipse.
  b = half length of minor axis of ellipse.
  After obtaining the respective areas, the CDR ratio is calculated.

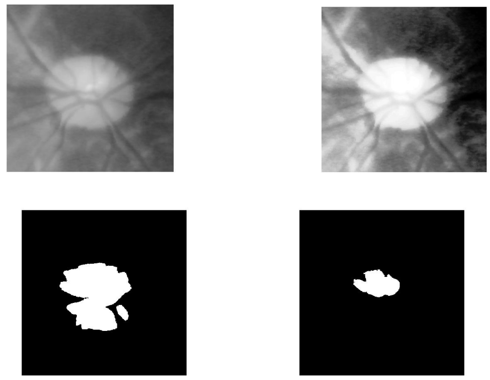

Figure 8: Segmentation: 1. Gray ROI 2. Historarm equalized ROI 3. Segmented optical disc and 4. Segmented optical cup1.

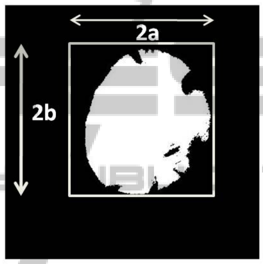

Figure 9: Elliptical Shape of Segmented disk/cup.

5 EXPERIMENTATION AND VALIDATION

This section discusses the experimentation conducted at an Eye Hospital in two stages. In the first stage we took fundus image of 15 patients to find out a threshold CDR for glaucoma detection. In the second stage we haved validate the device with more subjects. For the whole process of experimentation, we have chosen patients randomly and maintain similar test conditions which are enumerated below:

1. Hospital Doctor will first test patient eye for Glaucoma using Tonometry and Ophthalmoscopy
2. Room Light: Dim room light is used for collecting fundus image.
3. Patient Condition:
   (a) Sitting on a chair in rest position
   (b) For Un-dilated eye: Take a fundus image at the same instant.
   (c) For Dilated Eye:Some time patient eye pupil size is not sufficiently large. In that case doctor are not able to see larger view of fundus image. We dilate the eye, so that pupil Diameter will increase and it will take about 20-30 minutes.

(d) Cataract patient: If a patient is suffering from cataract than normal fundus imaging is not able to find clear image of the retina. In that case this device will be better because of image Enhancement capability.

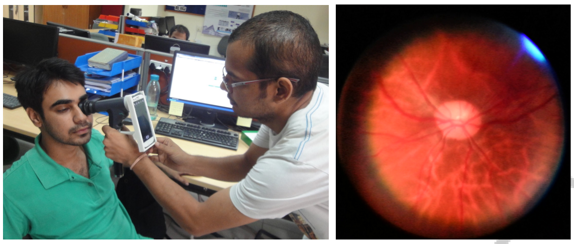

Figure 10: (a) Taking the fundus image colligue in laboratory and (b) Fundus image (Cpature by our device from the hospital).

Repeatability Test

Initially a test was carried out on a healthy participant in laboratory to verify the repeatability of the device. In this case we will check segmented cup and disk on Matlab. Then find its Area and CDR. We got a stable output for the same person repeatedly. Repeatability test data are shown in Table. 1. From Table 1, mean and standard deviation obtained from healthy person is 0.2295 and +/-0.0313 respectively.

Table 1: Repeatability Test: Cup and Disc Area for a healthy person.

S.No.	Cup Area	Disc Area	CDR
1	26829	107980	0.2485
2	23320	107760	0.2165
3	23637	105160	0.2248
4	24014	117780	0.2039
5	28953	118930	0.2434
6	25447	903430	0.2817
7	19195	102310	0.1876

Threshold CDR Value for Glaucoma Screening

After verifying stability of the device, several tests were performed on participants at the Eye Hospital. It was observed that the CDR value obtained for the patients with Glaucoma was always greater than 0.2809.

Whereas, the CDR value obtained for Non Glaucoma patients was always less than 0.2809 (Table 2 and Figure 11). Hence, a threshold of 0.2809 was set for screening Glaucoma patients from Non Glaucoma patients. Also, the mean and standard deviation obtained for Glaucoma and Non Glaucoma patients were 0.4080, +/-0.1020 and 0.2300, 0.0619 respectively.

Table 2: CDR values of glaucomatous and health person.

S.No	Glaucoma patient (CDR)	Non glaucoma patient(CDR)
1	0.4266	0.2564
2	0.2809	0.2802
3	0.3799	0.2006
4	0.4761	0.2672
5	0.5599	0.1166
6	0.3243	0.2591

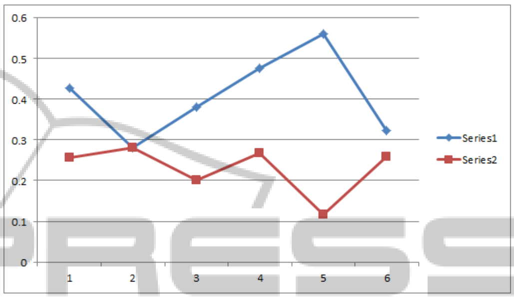

Figure 11: Graph: CDR value Curve.

Device Validation

Second stage of device experimentation, device validation is done in the same eye Hospital with 10 additional subjects. CDR values for these patient is shown in Table 3. CDR value 0.2700 is considered as threshold value for this device . In Table 3 result of patient No 08 is false positive. As for screening device, this is safer side because in the next stage of retinal diagnosis of patient, the problems was identified.

Table 3: Patient diagnosis report using mobile based fundus imaging device, Here threshold value used for diagonosis is 0.2700.

S.No	CDR_LE	CDR_RE	Result_LE	Result_RE
1	0.302		+ve	
2	0.335	0.522	+ve	+ve
3	0.464	0.308	+ve	+ve
4	0.0.043	0.168	-ve	-ve
5	0.369		+ve	
6	0.15	0.195	-ve	-ve
7	0.381	0.261	+ve	-ve
8	0.263	0.429	-ve	False +ve
9	0.205	0.245	-ve	-ve

6 CONCLUSION

The mobile phone based low cost, portable fundus imaging device has been designed and developed to improve accessibility to affordable eyecare. It has been shown that applications can be built to automatically screen eye related ailments. the paper illustrates results for screening patients with glaucoma — the application is being enhanced for detecting other eye ailments notably diabetic retinopathy. Primary experiments and validation also proves its usability, and easy handling capability. It has the capability to support different media of communication to share image/result to remote user. It can be used in primary health care center, OPD and Health care camp where fast screening is necessary.

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REFERENCES

http://www.who.int/blindness/causes/en/index.html

http://www.who.int/mediacentre/factsheets/fs282/en/index.html

Thomas R.,Glaucoma in India: Current status and the road ahead. Indian J Ophthalmol.2011.

http://www.ophthalmologyweb.com/Specialty/ Glaucoma/

Darrell M. West,Improving Health Care through Mobile Medical Devices and Sensors,2013;Center for Technology Innovation at Brookings.

Timberlake G T, Kennedy M D.The Direct Ophthalmoscope:How it Works and How to Use It. 2005.University of Kansas Press.

http://www.aoa.org/

http://www.nei.nih.gov/health/

http://www.android.com/

http://opencv.org/

Peli E., Schwartz B.; Enhancement of fundus photographs taken through cataracts; Ophthalmology. 1987.

Jan Paulus, Jrg Meier, Rdiger Bock, Joachim Hornegger, Georg Michelson;Automated quality assessment of retinal fundus photos;International Journal of Computer Assisted Radiology and Surgery November 2010.

Inoue N., Yanashima K., Magatani K., Kurihara T.; Development of a simple diagnostic method for the glaucoma using ocular Fundus pictures; Conf Proc IEEE Eng Med Biol Soc. 2005.

K. Narasimhan, K. Vijayarekha, K. A. JogiNarayana, P. SivaPrasad ,V. SatishKumar; Glaucoma Detection From Fundus Image Using Opencv; Research Journal of Applied Sciences, Engineering and Technology 2012.

Harizman N1, Oliveira C., Chiang A., Tello C., Marmor M., Ritch R., Liebmann J. M.,The ISNT rule and differentiation of normal from glaucomatous eyes.,Arch Ophthalmol. 2006.

Wong DK1, Liu J., Lim J. H., Jia X., Yin F., Li H., Wong T. Y.,Level-set based automatic cup-to-disc ratio determination using retinal fundus images in ARGALI.,Conf Proc IEEE Eng Med Biol Soc. 2008.

K.Narasimham, K.Vijayarekha; An Efficient Automated System For GLaucoma Detection using Fundus Image; Journal of Theoretical and Applied Information Technology, 2011.

Yuji Hatanaka, Atsushi Noudob, Chisako Muramatsuc, Akira Sawadad, Takeshi Harac, Tetsuya Yamamotod, Hiroshi Fujitac; Vertical cup-to-disc ratio measurement for diagnosis of glaucoma on fundus images; Medical Imaging 2010: Computer-Aided Diagnosis, edited by Nico Karssemeijer, Ronald M. Summers, Proc. of SPIE Vol. 7624, 76243C.

Ahmed Wasif Reza & C. Eswaran & Subhas Hati, Automatic Tracing of Optic Disc and Exudates from Color Fundus Images Using Fixed and Variable Thresholds, Journal of Medical Systems, Feb 2009.

L. Giancardo, F. Meriaudeau, T. Karnowski, E. Chaum, and K. Tobin, New Developments in Biomedical Engineering. InTech, 2010. Quality Assessment of Retinal Fundus Images using Elliptical Local Vessel Density.