# Smartphone Based Fundus Camera for the Diagnosis of Retinal Diseases

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# Smartphone based fundus camera for the diagnosis of retinal diseases

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ABSTRACT

Fundus photography is necessary to monitor the progression of retinal diseases like diabetic retinopathy, age-macular degeneration (AMD) and glaucoma. Traditionally, fundus photography is done by a specialized fundus camera which costs tens to hundreds of thousand dollars and weighs around fifteen kilograms. In this paper, we develop a smartphone based fundus camera for the early detection of the retinal diseases for the people in destitute areas who do not have access to the costly fundus camera and ophthalmologists. A major challenge in the smartphone based fundus photography system without involving an ophthalmologist is to ensure that the captured fundus image content is sufficient for detecting retinal diseases. To obtain a perfect fundus image, it is essential that the photo is shot exactly at the time when the camera is perfectly positioned and focused. To address this issue, our system captures a video and then selects a small set of fundus images from the video that have the required features for detecting retinal diseases. The manual selection of the best fundus images from the video is again a cumbersome process and requires an ophthalmologist. We propose an automation technique to identify the best fundus images from the video with low processing overhead. We evaluate the effectiveness and efficiency of our automation technique using in real settings. Similar to the original fundus camera, our system dilates the pupil before capturing the video. However, in this paper, we also investigate the challenges for smartphone based fundus photography without dilating the pupil of the eye and show the future research directions.

## 1. Introduction

According to a study published by World Health Organization (2018), approximately 1.3 billion people live with some form of vision impairment and 80% of all vision impairment globally is considered avoidable. Retinal diseases such as age-related macular degeneration, glaucoma, diabetic retinopathy, and trachoma are among the leading causes of blindness and vision impairment, which can be avoided to a great extent by an early detection of these diseases. A fundus image of the eye (back of the retina), which is captured by the fundus camera, is used to diagnose and detect retinal diseases. Typically, fundus cameras are very costly, heavy, and immobile. They can cost up to hundreds of thousands of dollars and weigh around 15 kg. Hence, many medical clinics in destitute areas do not have access to these devices, forming a tough barrier to the early detection of ophthalmic diseases. Recent advancement in technology have enabled smartphones to become an alternative to many of these expensive medical devices.

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In this paper, we aim to build a smartphone based fundus photography system that have the following characteristics: cheap, ubiquitous, readily available, able to capture high quality fundus images, and does not require an ophthalmologist to be present during the image capture procedure. A major challenge in the smartphone based fundus photography system without involving an ophthalmologist is to ensure that the captured fundus image content is sufficient for detecting retinal diseases. To obtain a perfect fundus image, it is essential that the photo is shot exactly at the time when the camera is perfectly positioned and focused. To address this issue, our system captures a video, selects a small set of fundus images from the video that have the required features for detecting retinal diseases, and send them to a remote ophthalmologist for detecting retinal diseases. Figure 1 shows an overview of our system.

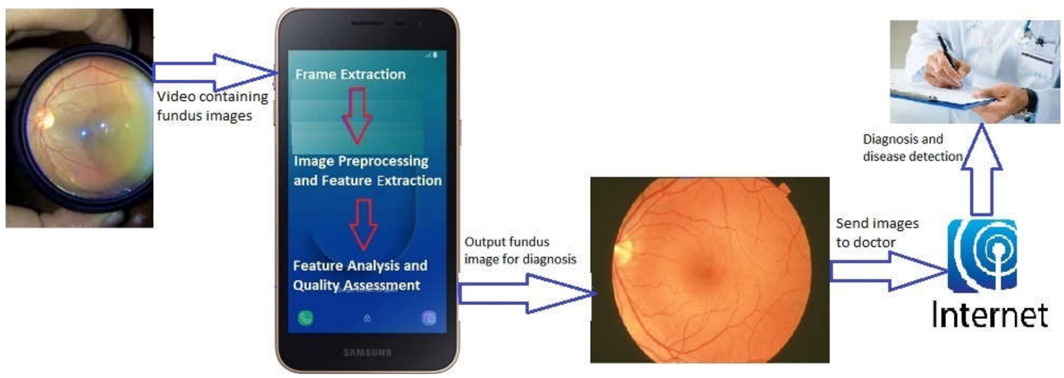



**Fig. 1.** System Overview

Recently, researchers have attempted to develop a number of techniques (e.g., Giardini et al. (2014); Haddock et al. (2013); Lin et al. (2014); Lord et al. (2010); Myung et al. (2014); Raju & Raju (2015); Russo et al. (2015); Shen & Mukai (2017)) to use smartphones as fundus cameras. However, none of these solutions is complete and ready to deploy in real settings. Furthermore, the solutions involve an ophthalmologist either during the image capture procedure or for the manual selection of the best fundus images from the video. The manual selection of the best fundus images from the video is also a complex procedure and takes time from the ophthalmologist. In this paper, we develop an automation technique to extract a small set of best fundus images from the video. An additional advantage of our technique is that it allows a user to send a small set of fundus images instead of a large video to a remote ophthalmologist using the low speed Internet, which is a common scenario in the destitute areas.

Our algorithm to find best fundus images from the video incurs low processing overhead and thus suitable to run in the energy constraint smartphone environment. The key idea of our efficient automation technique is to first extract the inner part of the ophthalmic lens, then extract features and utilize them to rank accordingly.

Both the original fundus camera and the smartphone based fundus camera are designed for mydriatic photography that requires to dilate the pupil to make it open wider using an eye drop before capturing the fundus image. Only the work done by Shen & Mukai (2017) that considers non-mydriatic fundus photography uses a raspberry-pi computer and captures fundus images in the dark. In reality, it would be nearly impossible for a non-expert to focus inside the retina in the dark environment while capturing the image. In this paper, we investigate whether it is possible to perform non-mydriatic fundus photography using a smartphone instead of a raspberry-pi. Similar to our smartphone based mydriatic fundus photography, we use video mode instead of still photo capturing mode so that a non-expert can capture fundus images easily.

The contribution of this paper are summarized as follows:

- We develop an easy, ubiquitous and cheap smartphone based fundus photography system. Our solution allows the detection of retinal diseases for the people in destitute areas.
- We propose an automation technique to identify a small set of fundus images from the video. Our technique incurs low processing overhead, which is an essential requirement for the smartphone environment, and ensures that the identified fundus images have the required features for identifying the retinal diseases.
- We investigate the challenges in building a smartphone based fundus camera that does not need to dilate the pupil of an eye. We discuss the future research directions to overcome the challenges.

The remainder of this paper is organized as follows. We discuss the basic concepts and terminologies in Section 2. We review the existing works related to our research problem in Section 3. We present our smartphone based fundus camera in Section 4. We discuss the challenges and future research directions for non-mydriatic fundus photography in Section 5. Finally, we conclude the paper in Section 6.

## 2. Background

We discuss some terms, which appear frequently in this paper, in short details here.

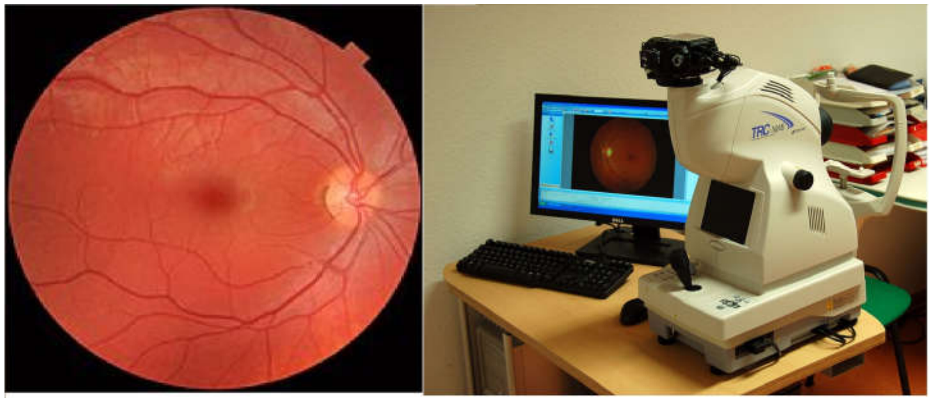


**Fig. 2.** The fundus of a human eye( Commons (2016))(left image) and a typical fundus camera( Commons (2015)) (right image)

### *2.1. Fundus*

The word "fundus" means part of a hollow organ. Fundus of an eye refers to the part of the eyeball opposite the pupil. It includes the retina, optic disk, fovea, macula and the posterior pole of the eye.

Left image of Figure 2 shows fundus images of eye. The macula is in the center and the optic disk is located towards right. The vessels can also be seen.

### *2.2. Ophthalmoscopy*

Ophthalmoscopy, also known as funduscopy, is a test by which a health professional observes the fundus of an eye using an ophthalmoscope or a funduscope device. The human eye has a hole located in the center of the retinal known as pupil. In ophthalmoscopy, the light enters through pupil and strikes the retina. The wider the pupil is, more light can pass through the pupil. Therefore, opening the pupil wider is a simple but effective way to get a view of the fundus of the eye. The process of opening the pupil wider is known as dilation of the pupil. Dilation of pupil is often done before funduscopy by using a medicated eye drop also known as a mydriatic agent. Although the dilation of the pupil is an ideal scenario, undilated examination is often more useful and easier.

### *2.3. Fundus Photography*

Fundus Photography is a complement of funduscopy or ophthalmoscopy. In this process, an image of the fundus is captured. A medical professional can examine the image later.

There are two types of fundus photography:

1. **Mydriatic:** In this method, the patient's pupil is first dilated using the dilation drops. Then fundus camera is used to capture the fundus image.
2. **Non-mydriatic:** In this method, no dilation drop is necessary. The pupil is dilated naturally by keeping the patient in a dark room for a few minutes. Then a special non-mydriatic fundus camera is used that can capture image in a completely dark environment.

### *2.4. Fundus Camera*

To capture a high-quality fundus image, a complex optical system is required. Traditionally a fundus camera is used in medical clinics to capture the fundus images. These fundus cameras have the capability of illuminating and imaging the retina at the same time. Right image of Figure 2 shows a typical fundus camera which consists of an intricate microscope attached to a flash enabled camera.

## 3. Related Works

In Sections 3.1 and 3.2, we discuss the existing work on mydriatic and non-mydriatic fundus photography, respectively. A summarized version of the relevant related works can be found in Table 1.

**Table 1.** Summary of different works pertaining to smartphone based fundoscopy

| Work | Device | Principle | Third party app | Capturing Mode | Quality |
|---|---|---|---|---|---|
| Lord et al. (2010) | iPhone | Mydriatic | None | Still image | Good quality |
| Bastawrous (2012) | iPhone | Mydriatic | None | Video | Good quality |
| Haddock et al. (2013) | iPhone | Mydriatic | Filmic Pro | Video | High quality |
| Myung et al. (2014) | iPhone | Mydriatic | Filmic Pro | Video | High quality |
| Russo et al. (2015) | iPhone and Samsung Galaxy S4 and S5 | Mydriatic | Special software to control light intensity and switch between auto and manual focus | Still image | 20 degree field of view (FOV) |
| Giardini et al. (2014) | Android | Mydriatic | Dedicated software to mark disk diameter and cup diameter to determine the ratio | Video | Images can only be use to determine VCDR |
| Raju & Raju (2015) | Android | Mydriatic | Camera FV-5 | Video | High quality |
| Shen & Mukai (2017) | Raspberry pi | Non mydriatic | Special software to run the pi camera module | Still image | Acceptable for making general diagnoses with FOV of 4 to 5 disk diameter |

### *3.1. Mydriatic Fundus Photography*

Lord et al. (2010) introduced the use of smartphones in ophthalmoscopy in 2010. In their study, the uses of smartphones as a testing device in ophthalmoscope as well as a container of clinical videos, diagrams and photographs are described. The authors found that in a non-ideal situation like in the emergency room, smartphones can be used to document external photographs of the eye and slit-lamp pictures of the anterior segment. The authors also described a method of indirect ophthalmoscopy by holding a 20 diopter indirect lens in one hand and a pen torch with the smartphone in the other. This technique is cumbersome and it is difficult to capture good quality images with this technique.

Bastawrous (2012) proposed to use the video-mode of iPhone for capturing good-quality fundus images and set the flash to on for the continuous illumination. The examiner holds a 20D or a 28D lens in one hand and the smartphone in the other hand. This allows the examiner to have control of the smartphone. After completion of the video, an image is captured manually from the video sequence.

Haddock et al. (2013) also used an iPhone and a 20D lens, and developed an application called FilmicPro to capture the fundus video. This application has some necessary features like controlling light intensity, focus and exposure. Again, in their technique, the fundus image is manually selected from the video and edited using iPhone's photo editing applications.

Myung et al. (2014) made the technique proposed by Haddock et al. (2013) easier by using a special 3D printed adapter. In Haddock et al. (2013), the lens was manually held in front of smartphone, whereas in Myung et al. (2014), the adapter is designed to hold the lens in a predefined but adjustable distance from the camera.

Russo et al. (2015) used a hardware attachment named D-eye adapter on the iPhone. This adapter, attached magnetically to the iPhone, captures the fundus images of an approximately 20 degree of field of view while operating on a dilated pupil. It works on the principle of direct ophthalmoscopy and depends on the smartphone camera's auto focus capability. The adapter alone costs 395 USD.

All of the above-mentioned works are based on iPhone. Next we discuss the techniques that use android phones for mydriatic fundus imaging.

Giardini et al. (2014) proposed to use an adapter for Samsung Galaxy S3 to capture high-quality fundus images. This adapter is made of a plastic shell that is attached to the back of the phone. On the adapter, the white LED of the smartphone is deflected through an optical assembly. This is necessary because to get a good quality fundus image, the illumination path and the field of view of the camera should align. A metal shield is used to screen the camera lens from the light back-scattered by the prism surface imperfections. In this study, they captured fundus images using a smartphone software. This software turns the smartphone camera to video to illuminate the fundus. After a video is captured, it is then manually clipped to extract a frame in which the fundus can be visualized best. It also has the feature to manually set two cursors on a full vertical disc diameter and on the vertical cup diameter to determine the "cup:disk ratio". The main goal of this study was to determine vertical optic disc to cup ratio (VCDR).

Raju & Raju (2015) suggested a method to capture the fundus images of the dilated patients using android devices. The method is similar to the method described by Haddock et al. (2013), which works only with iPhone. The author suggested to use an app named Camera FV 5 as an alternative of the Filmic Pro app used by Haddock et al. to control focus and exposure.

Ademola-Popoola & Olatunji (2017) demonstrated that descent quality fundus images can be captured with Blackberry Z-10 smartphone without using any special camera controlling software such as Filmic Pro (for iPhone) or Camera FV-5 (for android). Clear retinal images were obtained in different clinical conditions in adults and children which could be used in many clinics of destitute areas in Nigeria.

Lin et al. (2014) also described a technique of smartphone based fundus photography mainly to detect retinopathy of prematurity (ROP) which works both on iPhone and android. The technique uses an iPhone 4 or a HTC One smartphone and a 30D lens and captures a video of the fundus with the camera of the smartphone with the flash light on. Similar to Ademola-Popoola & Olatunji (2017), it does not use any third party app. To reduce the intensity of the flash, a micropore tape was used to cover the flash light. This study was successful in testing of ROP on 6 infants with dilated pupil. The required fundus images are manually selected from the captured video.

### *3.2. Non-mydriatic Fundus Photography*

In Shen & Mukai (2017), the authors have developed the only technique of non-mydriatic fundus imaging by using a smartphone, a 20D lens, a raspberry pi, a NoIR camera board, and a dual infrared and white LED board. Their system is not readily available since the NoIR camera board and dual LED used are not currently available in the market. Also, the system can only capture still images, and is not compatible for the video mode. Thus, this method is not suitable for non-experts and requires an ophthalmologist for capturing the quality fundus images. Our work investigates the challenges in developing a system for smartphone based non-mydriatic fundus photography without incorporating the NoIR camera board and dual LED.

## 4. Mydriatic Fundus Photography

In this section, we propose a system to capture the fundus images using the mydriatic fundus imaging procedure with the help of a smartphone and a 20D ophthalmic lens. We first capture a video that records the attempt to focus a 20D ophthalmic lens so that the fundus can be viewed. When the focusing procedure is completed and the fundus can be viewed clearly, the video recording is turned off. After that we extract the frames from the video, which contain the properly focused high quality fundus images with all the necessary features such as vein, optic disk and macula present in them, in an automated way. These frames are then sent to ophthalmologists for the diagnosis.

### *4.1. Equipment*

The main equipment for capturing an image is a smartphone and an ophthalmic lens (usually 20D). The detailed description of the equipment we used is described below:

1. Huawei P8 Android Smartphone with 13 Megapixel Camera (Any android smartphone will do)
2. Volk 20D Double aspheric Ophthalmic Lens. Other alternatives (e.g., 28D, 30D) will also work. The lens can be glass or plastic made, the plastic made ones are cheaper but the glass made one gives marginally better quality fundus images due to less reflection of the smartphone flashlight.
3. Micropore to dim out the smartphone flashlight intensity since android smartphones do not allow controlling flashlight intensity

We assume that everyone already has a basic android smartphone. Thus, basically the only thing that one needs to buy is the ophthalmic lens that costs from $100 to $300, with even the cheapest one working fine.

### *4.2. Capturing Video*

The steps in capturing fundus video are detailed below.

- First, we open the smartphone camera app and set it to video mode. The flashlight of the camera should be set to constant on mode so that the fundus can be illuminated properly. Modern smartphone camera apps provide ample opportunities of manual focusing and exposure control, which we use as per our requirement.
- We use a 20D ophthalmic lens to focus inside the pupil. We hold the 20D lens in the non-dominant hand while the smartphone is held in the dominant hand. The 20D lens is held between the dilated eye and the camera lens. Now focusing is done so that the fundus is clearly visible. This is done by adjusting the distance between the eye and the 20D lens, also the distance between the 20D lens and the camera lens.
- When the fundus is properly focused and can be seen clearly in the video mode, we stop recording video and turn off the camera app. The video is saved in the android device, which will be analyzed in the next step to extract the frames containing fundus images.

### *4.3. Best Frame Extraction*

After capturing the video, it is difficult to send the whole video to an ophthalmologists for people living in destitute areas. The major problems are:

- **Communication Overhead:** The size of a video of only 1 minute can be more than 150 MB, depending on the video quality. For an untrained or little trained personnel the focusing procedure may even take more time. It is not feasible for people in rural areas with poor Internet connection to send a file of this size.
- **Cumbersome Manual Procedure:** To manually select the perfect frame from a video of one or two minutes, which contains around 3000-4000 frames, can be very time consuming and cumbersome for an ophthalmologist.

In order to overcome these hurdles, we automatically extract some candidate frames that contain the fundus images. Firstly, we extract all possible frames from the captured video. There can be thousands of frames which need to be analyzed to select the frames containing the fundus images. In Figure 3, two example frames from a video are shown. We need to select the left frame as it is perfectly focused and properly illuminated while the right image needs to be discarded as the image is not illuminated and focused. The selection process consists of three major steps which are: lens extraction, image enhancement and feature extraction.

**Fig. 3.** Focused Fundus (left image), Unfocused Fundus (right image)

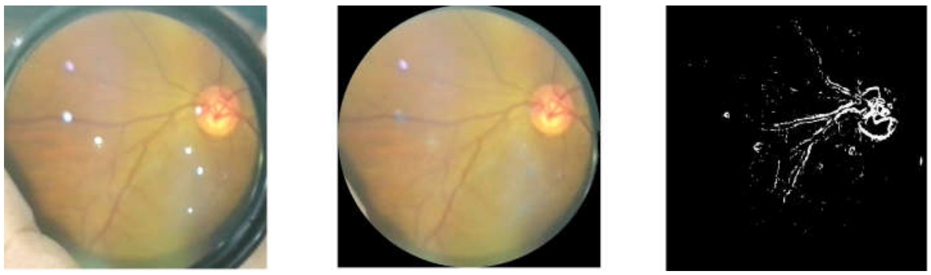


**Fig. 4.** A cropped image from the video (left image), an enhanced image (middle image), an extracted vein feature (right image)

### *4.3.1. Lens Extraction*

For each extracted frame from the video, we first convert it to a binary image using the binary threshold. Then the binary image is blurred using median blur so that it can be used as input to Hough Circle Detection algorithm. We use this algorithm to detect the lens portion of the image. If multiple circles with a little variation in coordinate of center and radius are detected, we take the average coordinate and radius. Then we crop the image so that it contains only the lens portion. If the frame is too blur or there is uneven lighting due to the placement of smartphone flashlight, circle can not be detected and we ignore these frames. We also ignore those images where the lens is cropped but there are large number of dark pixels (due to the absence of flash light) or the average intensity of red pixels inside the lens is very low. From the left image of Figure 3, we get the image shown in the left image of Figure 4.

### *4.3.2. Image enhancement*

After cropping the lens portion of the frame, we then enhance the quality of the cropped image by reducing glare and reflection from the smartphone flashlight using the built-in image inpainting function of opencv. Specifically, we used the algorithm implemented by Telea (2004) which enables us to remove or reduce the noisy points such as glare and reflection of the smartphone flashlight and produce an image as shown in the middle image of Figure 4.

### *4.3.3. Feature Extraction*

Next we extract features from the remaining frames to determine their quality. Now, it would be optimal to use the whole enhanced image to extract the features but the limitations of the smartphone's computation capability makes it very difficult. For this reason, we first re-size the frame to be 400x400 and then extract features from the resized image. We use the feature detection algorithm implemented in Li & Chutatape (2000). They used Kirsch's method Kirsch (1971) to detect blood vessels, which computes the gradient of eight different directions by convolving the image with eight different template impulse response arrays as shown in Figure 5. The gradient of the different direction is obtained by convolving the image with a particular impulse response in that direction. The final gradient is set to the largest gradient and thus edges are enhanced. After that, a threshold is set to determine if a pixel belongs to an edge or not. Following this procedure, we get the image shown in the right image of Figure 4. After that, we check the average intensity to detect uneven illumination or absence of optic disk or vein. The complete algorithm is shown in Algorithm 1.

## *4.4. Evaluation*

We describe our experimental settings and performance of our proposed smartphone based fundus photography system in this section. The captured fundus image quality was judged and scored manually by an ophthalmologist. Scoring is based on how well the images can be used to detect the retinal diseases and in what extent it can replace the use of fundus images captured by the fundus camera.

### *4.4.1. Data Collection*

Following the procedure described in 4.2, we collected data from the volunteer patients. Few of them were very sensitive to light thus were unable to keep their eyes open for long enough to capture decent quality fundus video. We discarded those data. Aside from those we collected 15 fundus videos(9 males, 6 females). The length of each video is around 2 to 3 minutes and includes at least a few decent quality fundus images. The

**Algorithm 1** Fundus image extraction

**Input:** A video of capturing fundus image, $V$, the number of frames that need to be extracted, $nframes$
**Output:** A set of $nframes$ number of fundus images, $F$
$F \leftarrow ExtractAllFrames(V)$
**for** each $image$ in $F$ **do**
  $original \leftarrow image$
  $processedImage \leftarrow preprocess(original)$
  $circle \leftarrow HoughCircleDetection(processedImage)$
  **if** $circle$ is empty **then**
    $F \leftarrow F - \{original\}$
    continue
  **end if**
  $x, y \leftarrow average(circle.coordinates)$
  $r \leftarrow average(circle.radius)$
  $cropped \leftarrow CropImage(original, x, y, r)$
  $blue, green, red \leftarrow averageIntensity(cropped)$
  $gray \leftarrow ConvertToGray(original)$
  $maxPixelRange \leftarrow max(gray) - 0.05 * maxIntensity(gray)$
  $minPixelRange \leftarrow min(gray) + 0.05 * minIntensity(gray)$
  $light \leftarrow percentage(pixelIntensity > maxPixelRange)$
  $dark \leftarrow percentage(pixelIntensity < minPixelRange)$
  **if** $red < blue$ or $red < green$ or $red < 70$ or $light > 5.0$ or $dark > 5.0$ **then**
    $F \leftarrow F - \{original\}$
    continue
  **end if**
  $enhanced \leftarrow RemoveGlareAndReflection(cropped)$
  $vein \leftarrow DetectVein(enhanced)$
  $th \leftarrow FindThreshold(vein)$
  $minThresh \leftarrow 5.0$
  **if** $averageIntensity(th) < minThresh$ **then**
    $F \leftarrow F - \{original\}$
    continue
  **end if**
  $F \leftarrow F - \{original\}$
  $F \leftarrow F \cup \{enhanced\}$
**end for**
Return $nframes$ images from $F$ according to higher $averageIntensity(th)$

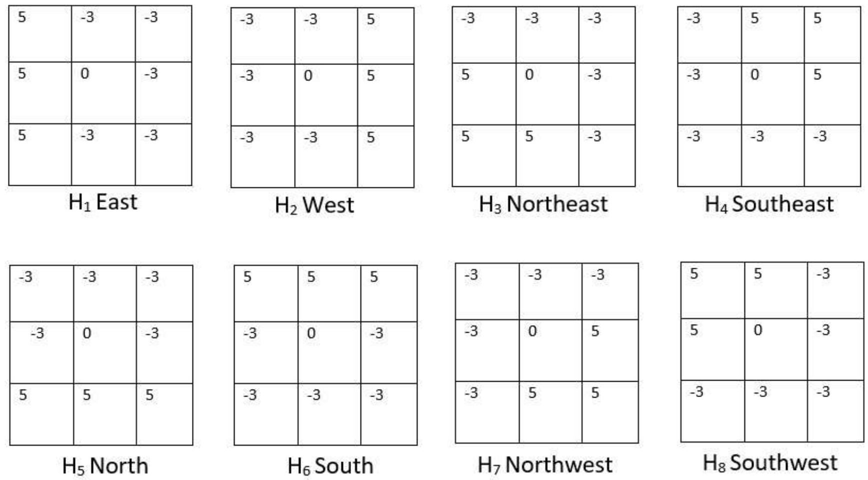



**Fig. 5.** Impulse response arrays of Kirsch's method

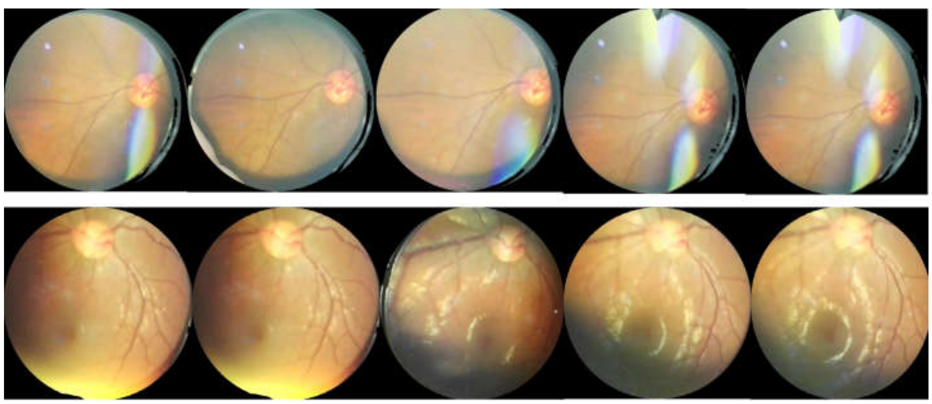


**Fig. 6.** Sample output sets

collected fundus videos are from 6 males and 9 females. However, the gender of the patient doesn't have any effect on the quality or characteristics of the fundus image.

After capturing the videos from patients, we automatically extracted the frames containing fundus images using our proposed algorithm and then validated the quality of the images by an ophthalmologist. Generally a video of two minutes can contain around 1500 frames from which we extracted a set of five, ten and fifteen image frames for the doctor to examine. Two sample sets of five output images are shown in Figure 6.

*4.4.2. Accuracy*

The accuracy mentioned here refers to a score in the range of 0-10 based on how well a particular set of fundus images can be used to detect retinal diseases. The ophthalmologist pointed out few redeeming qualities of a good fundus image and scored based on that. These qualities are:

- Fundus visible within the FOV(Field of View) of the lens must be illuminated evenly and properly
- Smartphone camera must be focused properly (preferably manually) inside the lens so that the fundus image is not blurred
- Smartphone flashlight reflection must be minimal and should not occlude important parts of fundus like optic disk and macula

*4.4.3. Findings*

We validated the frames extracted by our algorithm by an ophthalmologist. Since the captured fundus images are used by an ophthalmologist and not a machine, there is no exact and objective measure of the quality of the captured and extracted fundus images. Thus, the quality of the fundus image is subjective and depends on how well the ophthalmologist can diagnose diseases with that fundus image. Therefore, we involved an ophthalmologist to rate the fundus images captured and extracted by our smartphone based fundus photography system with respect to the fundus images captured by traditional fundus camera, assuming that the images from the fundus camera have 100% quality. According to the ophthalmologist, the quality of the fundus images captured by our system varies between 40% to 70% of the fundus images captured by traditional fundus camera. We divided our data into 4 different sets depending on the quality of the captured image. Set 1 consists of samples whose overall

**Table 2.** Division of data

| Set | Average Quality (Compared to typical fundus camera) | Number of videos |
|---|---|---|
| Set 1 | 40-49% | 4 |
| Set 2 | 50-59% | 3 |
| Set 3 | 60-69% | 5 |
| Set 4 | >70% | 3 |

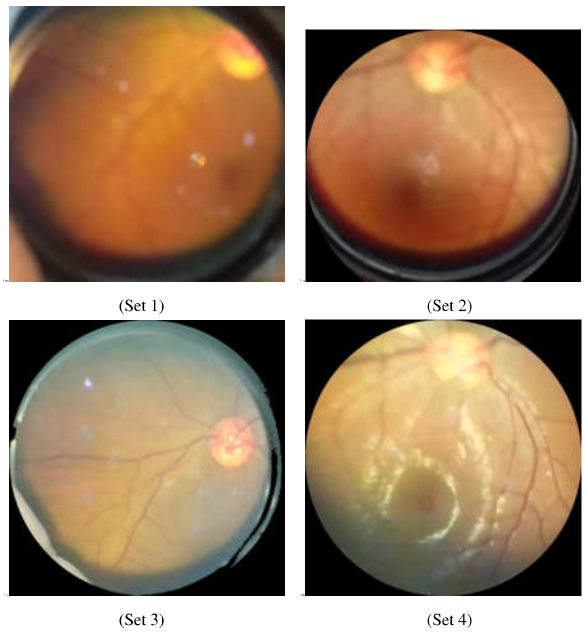



**Fig. 7.** Sample Fundus images

quality is 40% to 49% of the fundus camera. For Set 2 it is 50% to 59%, for Set 3 it is 60% to 69% and for Set 4 the image quality is above 70% . The division of our input videos into four different sets is shown in Table 2 along with a sample image from each set in Figure 7.

The ophthalmologist also rated the images by their ability to detect retinal diseases like diabetic retinopathy, macular degeneration and papilloedema in the range of 0-10 as shown in Figure 8. The higher the score the higher is the probability that a particular retinal disease can be diagnosed accurately using a particular set of frames. We observe in the figure that the overall quality increases with the increase of the number of the extracted images. This is because the higher number of images in the final output increases the chance of having the highest quality fundus images included in the output set. Figure 8 shows that the overall quality increases more if we increase the number of extracted images from 5 to 10 than the case when we increase from 10 to 15.

Before applying the feature extraction algorithm, we resized our frame to 400x400. We varied the resolution by 600x600 or 800x800 (original size). The less we down sample our original frame, the better performance our algorithm provides. However, increased pixel size (from 160000 to 360000 or 640000) greatly increases the computation time. For this reason, we resized our frame to 400x400. The average time to extract best fundus images is around 4 to 7 minutes.

The number of output images do not have any impact on the computation time since irrespective of the number of frames our algorithm computes the intensity of all frames selected in the last step (Section 4.3.3) and then returns the required number of frames with higher intensities. However, the lower number of extracted frames incurs less communication overhead while sending it to an ophthalmologist for diagnosis.

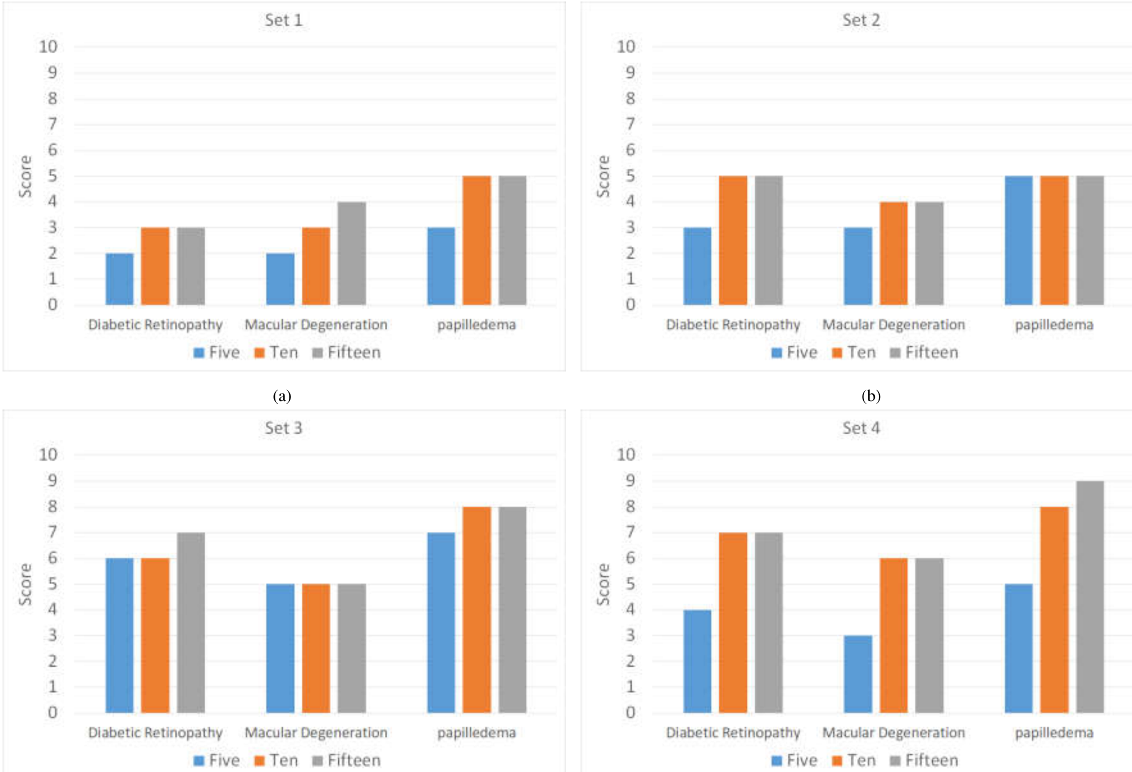
## 5. Non-mydriatic Fundus Photography

In this section we describe our attempt at Non-mydriatic fundus photography using video mode of the android smartphone. Ultimately, we failed to construct a smartphone based device that was able to successfully capture non-mydriatic fundus image using video mode, but we were able to identify the challenges of this procedure which will hopefully aid in future research in this area.

### *5.1. Capturing Fundus Image*

There are two ways to capture non-mydriatic fundus image using smartphone. They are:

- Still Photo capture method
- Video method




(a) (b)

(c) (d)

**Fig. 8.** Fundus image scores

The problem with the still photo method is:

- it requires a trained or experienced personnel since focusing properly, then holding that focusing steady and pressing the shutter button are really hard to achieve
- since non-mydriatic procedure does not use dilation drugs to achieve dilation so it is temporary. As the image is captured using normal flash light of the camera, the dilation of the pupil does not remain dilated anymore and the patient has to be kept in the darkness for a few minutes again if subsequent images are to be taken

Due to the above reasons we try to use the video method to capture our non-mydriatic fundus images.

The equipment required to capture non-mydriatic fundus video is almost the same as described in Subsection 4.1 with some distinct difference due to the need to capture video in the dark environment. The required equipment for this method are listed below:

- An android smartphone without Infrared (IR) filter. Most recent android smartphones are pre-installed with IR filter, thus cannot be used to capture photos using the IR light. But older android smartphones did not come with the IR filter so those can be used. The alternative is using old android smartphones which came pre-installed with the IR filter but the filter can be removed easily and simply. For our research, we used Symphony V90 phone that does not have an IR filter.
- An IR light source to illuminate the retina. We built an IC with four IR LEDs that are available in the market for our purpose. This IR LED board costs around $5.
- An external power source to power the IR light source. We used a 9V battery to power our IR IC. It costs around $2 - $3.
- A 20D ophthalmic lens to focus inside of the retina. We used Volk 20D ophthalmic lens for our purpose. It costs around $100 - $300 depending on whether it's plastic or glass built and brand, with the cheapest one working fine.

We attached the infrared LED board and the 9V battery to the back of the smartphone using scotch tapes. Glue can be also used. The build is quite crude but functionality-wise it has no problem. The device is shown in the left image of Figure 9.

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We use the same procedure described in Section 4.2 to capture the video except the dilation of the pupil is done by keeping the patient in a completely dark room for a few minutes which naturally dilates the pupil. Also instead of smartphone flashlight, we use the IR LEDs to illuminate the fundus.

We attempted to capture the non-mydriatic fundus images using the method described above. However, we were not able to get the full view of the fundus. An image (extracted from the video) of the partial view we got is shown in the right image of Figure 9.

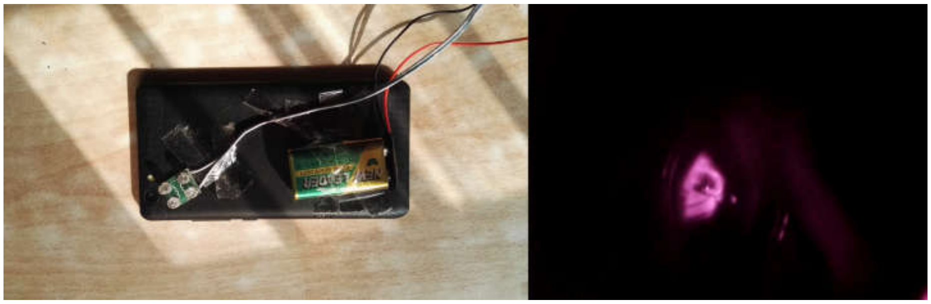

**Fig. 9.** Smartphone and IR LED board (left image), Partial view of fundus in infrared light (right image)

### *5.2. Challenges and Possible Solutions*

As explained above, we were not able to capture full view of the fundus in our non-mydriatic fundus image. This happened because:

- The IR light source and the camera lens were not properly linear making it very hard to focus perfectly and get the full fundus view.
- The IR LEDs we used did not have the required level of intensity. So, the whole fundus was not illuminated resulting in only partial fundus image.

To address the first issue, we built another IC board containing 5 IR LEDs but this time the LEDs were arranged circularly with the camera lens to be positioned in the center. This solved the issue of uneven lighting but the IR LEDs themselves weren't strong enough to make the video mode feasible. Hence, the only way to capture non-mydriatic fundus image using android smartphone for now is to focus properly using 20D lens and then capture still image using smartphone flashlight. However recently some new android phones have been released like Lumigon T3 which come with secondary night vision IR sensitive camera and also IR flashlight to facilitate the night vision. Using these will make the whole non-mydriatic procedure using smartphones in video mode simple and easy for non-professionals. Integrating these new technologies for our purpose can bring progress in the non-mydriatic fundus photography.

## 6. Conclusion

In this paper, we developed a readily deployable and cheap mydriatic smartphone based fundus photography system for the detection of the retinal diseases of the people in destitute areas who do not have access to the costly fundus camera and ophthalmologists. We propose an automation technique to automatically extract the best fundus images from the captured video of the fundus by a non-expert. We validated the effectiveness of our proposed system in real settings. On the other hand, though our non-mydriatic smartphone based fundus photography system is unable to capture high quality non-mydriatic fundus images in video mode, we identify the challenges and shortcomings in this regard and show the future research directions. We expect that these recommendations along with the introduction of the android devices with built-in infrared flash light and extra infrared sensitive camera lens, like Lumigon T3, it will be possible to develop a non-mydriatic smartphone based fundus photography system to capture high quality fundus images.

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