A Guide to Obtaining Fundus Images Using Low-Cost Smartphone-Based Techniques

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Abstract. This paper describes developing a cost-effective system for capturing fundus images using smartphones. The techniques used to achieve this are also described, providing an alternative to the expensive solutions currently available. A smartphone with a 3D printed PLA adapter arm, based on the Odocs Fundus open-source project [1], and a +20 optical diopter condenser lens were used to capture images. The adapter arm was used to align the smartphone camera with the optical center of the lens and flashlight. It was confirmed that the lighting adhered to the safety limits ISO 15004-2.2 set. Clear images of the optic nerve, papillary excavation, excavation/disc ratio, and vascularization were obtained at high resolution. This system can be helpful for early prevention of blindness and low vision. Its application can be applied to human and veterinary use. Its connectivity can also aid in the development of telehealth systems. The system's techniques have a short learning curve, enabling healthcare professionals to work in resource-limited settings or where imaging systems are unavailable. Low-cost cell phones have proven to yield good results. The captured videos were used to extract images, then transmitted via Wi-Fi and 4G for later review. Additional clinical trials will be required to validate the system for widespread use.

Keywords. Smartphone, fundus, fundoscopy, ophthalmoscopy, low cost, imaging, photography

1. Introduction

The fundus study is a routine examination widely used to evaluate the retina's health, optic nerve (ON), and vascularization. Any anomalies detected during this examination alert healthcare professionals to initiate treatment or refer the patient to a specialist. As a result, it is a crucial tool in preventing blindness and low vision and treating various pathologies. Traditional fundus observation equipment is often difficult to transport and expensive. Patients are required to travel to the ophthalmologist's office for the exam.

For over a decade, numerous studies have proven that obtaining fundus images through smartphones is a safe, effective, and low-cost method [2], [3], [4], [5], ... by eliminating limitations and increasing accessibility, pathologies can be detected through image analysis. [6], [7].

Fundus imaging has the potential to be used in a variety of healthcare settings, including primary health services, emergency departments, general medical clinics, and general practitioners. [8]. This technology has the potential to be highly effective in veterinary procedures. [4].

The paper aims to describe a smartphone-based system for capturing fundus images using a 3D-printed adapter arm based on the open-source Odocs Fundus project. [1], an aspheric condensing lens with +20 optical diopters and a cell phone with appropriate features. The adapter arm was used to align the smartphone camera and lens and adjust the flashlight angle for proper illumination and focus. The native smartphone app was used to capture images, but it may be beneficial to consider other paid apps with more significant resources.

2. Method

2.1 Principles

When capturing an image, the process is similar to using an indirect ophthalmoscope. This means that the resulting image will be real and inverted.

Instead of using the light source of an ophthalmoscope, a smartphone flashlight is utilized, and the camera functions as the observer's eye. Refer to **Fig. 1** for more information [9].

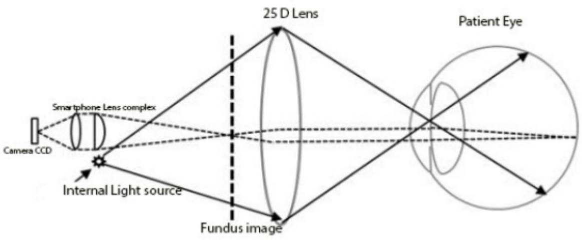

Fig. 1 - Here is a method for taking fundus images using a smartphone.

2.2 Lighting

The flashlight should be between 6.00 mm and 11.00 mm from the camera for best illumination results. Refer to **Fig. 2** for reference.

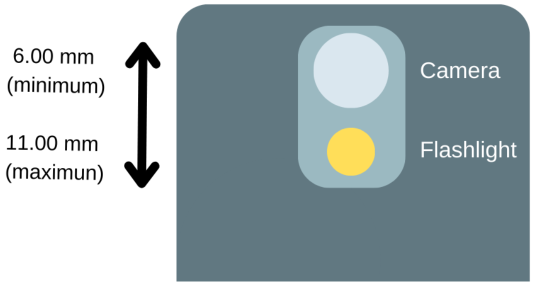

Fig. 2 – Recommended distances.

For optimal results, conducting the procedure in a dimly lit or dark environment is recommended to prevent any unwanted reflections. Before beginning, dilate the pupil using 1% Atropine and position the smartphone 20cm away from the eye being observed. Once the camera app is open, activate the video mode and flashlight.

Following these steps makes it possible to obtain the retinal reflection through the cell phone screen, as shown in **Fig. 3**. Note that if these parameters are not respected, the light may not reach the retina with the same efficiency, as shown in **Fig. 4**.

Fig. 3 - The retinal reflection is at its optimum in the right eye (OD)

Modern smartphones could not capture this image due to the distance between the camera and flash exceeding 11mm. The camera had to be positioned 15 degrees from the center of the pupil.

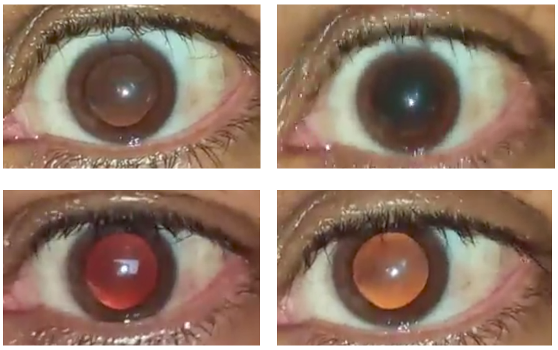

Fig. 4 - The reflex in the OD retina is insufficient.

Two smartphones were used for this study: a Motorola E7™ (48 MP) and a Huawei Y625™ (8 MP). Both devices provided excellent illumination for retinal reflection. However, due to the higher camera resolution, all images were captured with the Motorola E7™.

After reviewing the specifications, it was confirmed that the flashlight's spectral irradiance on the retina meets the ISO 15004-2.2 standard. This standard calculates the retina's spectral irradiance (W/cm2/nm) for both thermal and photochemical effects. A study by Kim et al. [10] showed that a 1-minute exposure to the flashlight on a smartphone resulted in retinal irradiance levels that were 150 times below the limit for thermal damage and 240 times below the limit for photochemical damage.

2.3 Lenses

After careful consideration, it was decided to go with the +20.75 condensing aspheric lens made of PMMA (polymethylmethacrylate) instead of the +20 diopter Volk™ lens. This option proved to be more cost-effective. The specific lens that was chosen is shown in **Fig. 5**.

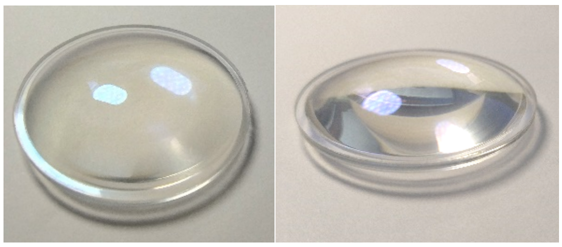

Fig. 5 – Condensed lens

The image formed by the fundus will appear inverted on the lens surface. With image editing apps, it was repositioned to its correct orientation.

2.4 The arm

In order to improve the angle and focus between the lens and camera, an adapter arm was utilized to easily adjust the required working distances and optimize the video recording process. Additionally, it ensured that a consistent light source at the appropriate angle was maintained.

The Odocs Fundus Project's open-source CAD files were slightly modified to adapt them to the lens size before 3D printing the arm model using PLA, a durable and biodegradable material. The camera and flashlight should work behind the small targeting ring, and the distance between the target ring and the smartphone holder is 20 cm. See **Fig. 6**.

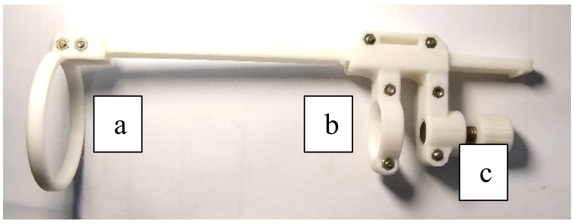

Fig. 6 – Printed 3D arm a) target ring, b) small targeting ring, c) smartphone holder

If the smartphone holder is tightly fastened, it may cause issues with the touchscreen system. That can be mistaken for a constant touch of a finger. Fortunately, adjusting the smartphone holder slightly can quickly solve this problem. Using an arm to capture fundus images reduced recording time to an average of 1 minute and 30 seconds, significantly decreasing patient light exposure.

2.5 Video capture

Before beginning, it was necessary to attach the lens and smartphone to the arm of the fundus capture system. It is essential to inform the patient that the LED light from the smartphone will be pointed toward their eye for 1-2 minutes, but this will not cause any harm to their health. It is also crucial to explain the mydriatic procedure, which typically lasts 15-20 minutes. Start recording the video once the patient's pupil has dilated. Ensure higher contrast during video recording by verifying dimly lit or dark environments.

Place the lens 5cm from the patient's eye to create a retinal reflex. Adjust the camera angle to about 15 degrees to obtain an optimal reflex. It may be challenging at first to determine the correct angle and distance, but exceptional results can be obtained with some training. See **Fig. 7**. Start recording when it finds the optimal retinal reflex. Set the camera to zoom x3. It usually takes 30 seconds to find the correct angle and focus and 60 to 90 seconds to record.

Fig. 7 – Positioning

2.6 How are images obtained?

After completing the video capture process, PowerDirector™ was used for editing. Were captured images during the video playback to conduct further analysis. Typically, was captured around 15 images for every 60 seconds of recording. Additionally, it could use the native screenshot feature on the smartphone to capture images. These images were then rotated 180 degrees to obtain their accurate aspect ratio, as illustrated in **Fig. 8**.

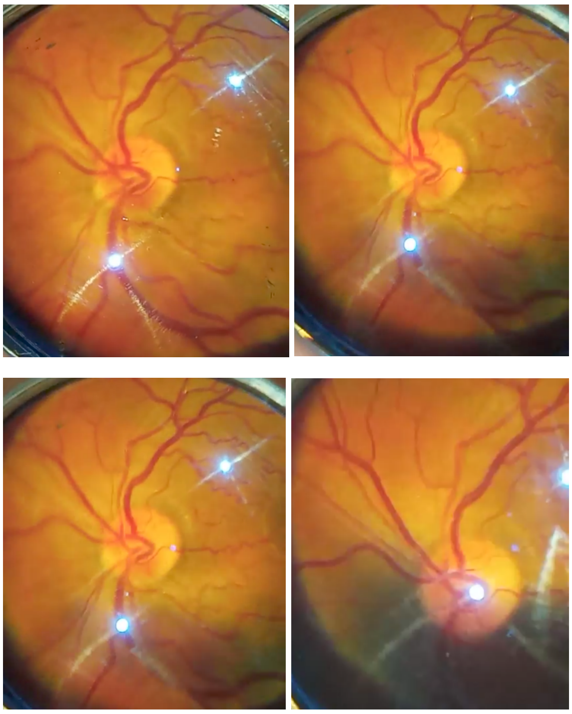

Fig. 8 – OD fundus imaging

It is important to remember that the flashlight's light can be reflected on the lens, as seen in the images above. External ambient illumination can also significantly impair image capture, as shown in **Fig. 9**.

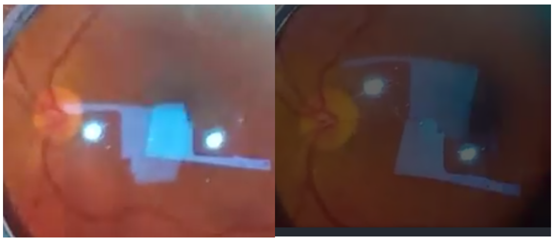

Fig. 9 – External light reflections

The images were captured and promptly shared through Google Drive, WhatsApp, and email. They have maintained their quality for the specialist to analyze further. The optic nerve (A), arteriovenous vessels (B), macula (C), and retinal tissues are all visible in **Fig. 10**.

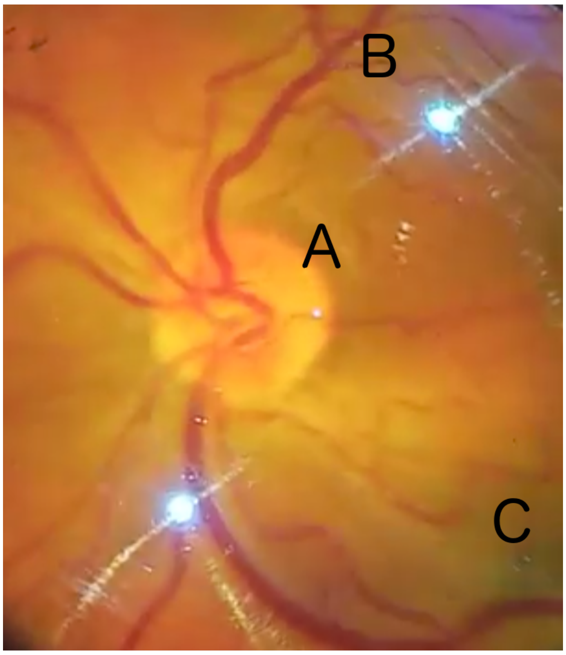

Fig. 10 – Main structures

A non-mydriatic imaging procedure was applied in cats, and the results were satisfactory. That was due to the Tapetum lucidum [11], which reflects light in low light conditions. Overall, the video recording time was 15 to 30 seconds, shorter than that required for humans. That helps to alleviate the stress of the cats during the examination. See **Fig. 11**.

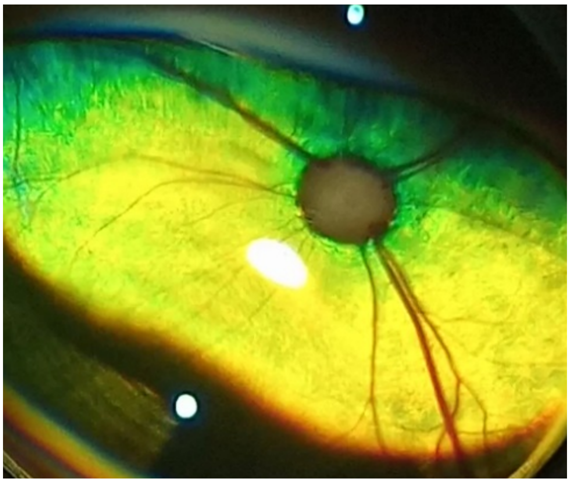

Fig. 11 – Cat's eye fundus

2.7 Field of view

To calculate the angle of view in radians, use this equation (1), which needs to know the sensor size in meters (S), the focal length of the lens in meters (f), and the angle of view (α). The power of a lens is measured in diopters, which is the inverse of the focal length in meters.

$$\alpha = 2 \times \arctan\left(\frac{S}{2f}\right) \quad (1)$$

The 20-diopter lens has a focal length of 0.05 meters and a size of 43.3 mm.

$$\alpha = 2 \times \arctan\left(\frac{0{,}0433}{2 \times 0{,}05}\right)$$

$$\alpha = 0.8666\ radians$$

To convert radians to degrees, multiply by $\frac{180}{\pi}$ (2). Then, the field of view would be:

$$\alpha = 0{,}8666 \times \frac{180}{\pi} \quad (2)$$

$$\alpha = 49{,}65^{\circ}$$

The field of view obtained is nearly 50^{0} wider than direct ophthalmoscopes, which typically reach a range between 3^{0} and 16^{0} using mydriatics. [12].

3. Conclusion

The system described can capture high-quality fundus photographs in humans and animals using low-cost, portable elements. It is easy to learn and affordable.

Its ability to transmit images over Wi-Fi and 4G presents potential for telehealth and AI image analysis in pathology detection. It has the potential to contribute to integrating ophthalmic care into universal health coverage. [13].

Multidisciplinary clinical trials will be necessary to improve the image capture technique further and create new adapters for the latest smartphones.

4. Acknowledgement

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