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An Affordable and Easy-to-Use Diagnostic Method for Keratoconus Detection using a Smartphone

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ABSTRACT

Recently, smartphones are used for disease diagnosis and healthcare. In this paper, we propose a novel affordable diagnostic method of detecting keratoconus using a smartphone. Keratoconus is usually detected in clinics with ophthalmic devices, which are large, expensive and not portable, and need to be operated by trained technicians. However, our proposed smartphone-based eye disease detection method is small, affordable, portable, and it can be operated by patients in a convenient way. The results show that the proposed keratoconus detection method detects severe, advanced, and moderate keratoconus with accuracies of 93%, 86%, 67%, respectively. Due to its convenience with these accuracies, the proposed keratoconus detection method is expected to be applied in detecting keratoconus at an earlier stage in an affordable way.

Keywords: Keratoconus, Corneal topography, Image processing, Smartphone, Cornea

1. INTRODUCTION

Keratoconus has been the most common corneal dystrophy in the U.S. [1, 2] and it still affects 1 in every 2,000 Americans [3]. The keratoconus makes middle cornea thinner and bulged outward gradually, which changes the cornea into cone-shaped one. This abnormal cone-shaped curvature weakens cornea's refractive power since the cornea is normally responsible for around 70% of eye's refractive power [3]. Changes in the eye's refractive power results in nearsightedness, astigmatism, and blurred vision. Depending on the thickness, steepness, and morphology of the cornea, the keratoconus is usually classified into four stages: mild, moderate, advanced and severe stages. In the early stages, the keratoconus can be effectively treated by ophthalmologist's treatments such as corneal collagen cross-linking [4, 5]. Hence, early diagnosis of keratoconus is of great importance for patients who seek surgery [6]. However, current diagnostic methods for early keratoconus detection has limitations since they require large and expensive devices. As a result, an affordable and easy-to-use diagnostic method for keratoconus detection is highly demanded.

Currently, keratoconus is usually detected by one of the following laboratory or clinical methods: optical coherence tomography (OCT) [7], ultrasound bio-microscopy (UBM) [8], corneal topography [9], Scheimpflug camera [10], and laser interferometry [11, 12]. Among these methods, the corneal topography is a non-invasive medical imaging technique which detects keratoconus by measuring the surface curvature of the cornea. Corneal topography device projects light circles (known as Placido discs) on the surface of the cornea as shown in Figure 1. By measuring the differences between the reference and reflected circles, the corneal topography detects any irregularities in cornea's shape. However, this topography device is large and expensive. Furthermore, the topography device needs to be operated by a trained technician. OCT, UBM, Scheimpflug camera, and laser interferometry also have these limitations. Recently, there have been studies of using smartphones to aid ophthalmologists to detect eye diseases. For example, smartphones with attached lens adaptor are proposed for ocular pathology [13] , digital retinoscopes for smartphone are devised [14], and smartphone-based ophthalmoscope are introduced [15]. Moreover, there has been study using a smartphone with an additional gadgets which projects the Placido discs over the surface of the cornea to diagnose the keratoconus [16]. However, to the authors' knowledge, there have not been any smartphone-based detection methods for diagnosing keratoconus without additional adaptor lens, gadgets or topographer tools.

In this paper, we propose a novel keratoconus detection method based on smartphones for diagnosing keratoconus without additional gadgets. Our proposed method is affordable and easy-to-use with maintaining detection accuracy.

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Especially for detecting the keratoconus, the proposed method adopts slope-based detection method. We evaluate the performance of the proposed method in terms of detection accuracies. Here, ophthalmologist's diagnoses, which is based on the corneal topography device, are considered as references. The rest of this paper is organized as follows: In Section 2, the data acquisition, image analysis, and classification procedures are described. The classification results of the proposed algorithm are presented in terms of detection accuracy in Section 3. Finally, Section 4 concludes this paper.

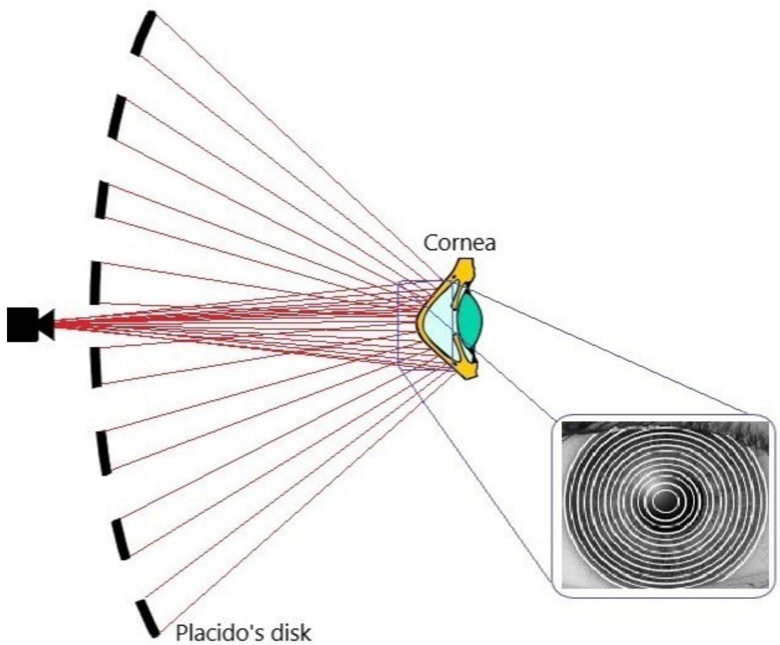

Figure 1. The operation principle of corneal topography device. The corneal topography device projects light circles (known as Placido discs) on the surface of the cornea [12].

2. MATERIAL AND METHOD

2.1. Materials

For the data collection, 10 participants were recruited at Poostchi Eye Hospital. Photos of participants' 20 eyes were taken using smartphone cameras. To evaluate the performance of the proposed method, 10 participants' eyes (20 eyes) were also examined by a corneal topography device. Among 20 eyes, 6 eyes were diagnosed to have keratoconus while 14 eyes were diagnosed to be normal. The participants were instructed not to move when the photos of eyes were taken by smartphones. Here, the smartphone pictures are taken from the side as shown in Figure 2a. Each picture taken by smartphones has 8-megapixel (3264×2448) resolution. Figure 2a shows an example of normal eye captured by the smartphone camera. A part of an original photo is selected to be used in detecting keratoconus as shown in Figures 2b and 2c. Figure 2d shows an example of a keratoconus eye.

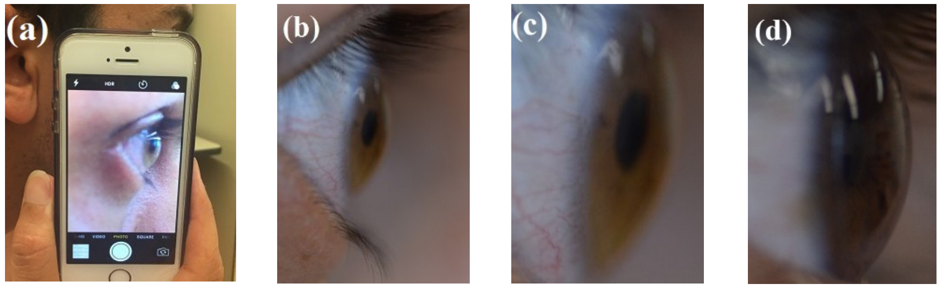

Figure 2. Example images taken by smartphones for keratoconus detection. (a) A smartphone and its image taken from the side, (b) an eye image extracted from the image taken in (a), (c) a cropped image of a normal eye, (d) a cropped image of a keratoconus eye.

2.2. Image analysis

Our proposed method performs image analysis (or processing) on the raw image obtained in Section 2.1. Figure 3 is a flow chart of the proposed method. It consists of *1)* preprocessing, and *2)* classification as shown in Figure 3 and they are described in Subsections 2.2. (1) and 2.2. (2).

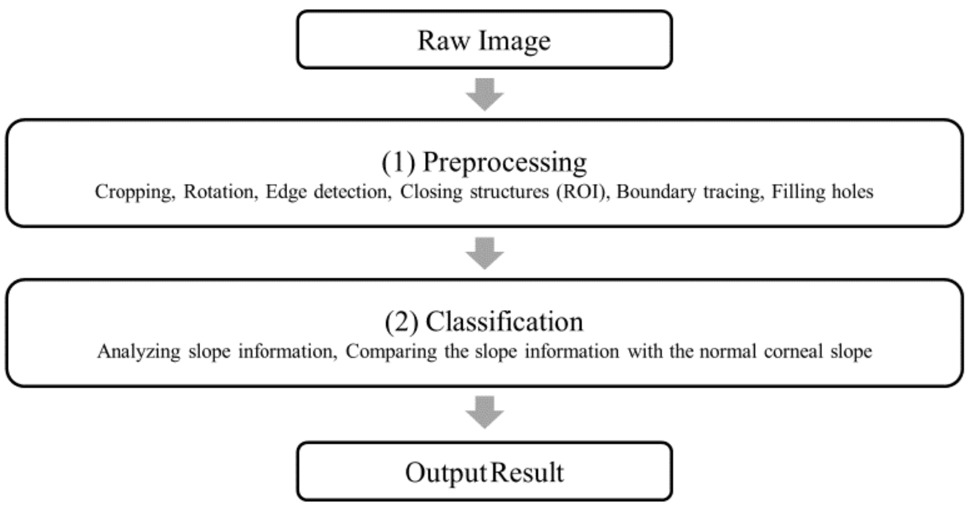

Figure 3. A flow chart of our proposed method. I It consists of preprocessing and classification steps.

(1) *Preprocessing*

Raw images taken in Subjection 2.1 usually have skin, eyelash, eyelid, sclera, and eye. Since the proposed method does not use objects other than the cornea, the objects except for the cornea are cropped in our proposed method. Then, the selected cornea image is converted to grayscale and rotated by 90 degrees as shown in Figure 4. The proposed method then performs edge detection [17] to detect the boundary of the cornea, and also performs morphological dilation to obtain smoother boundaries. After that, the method extracts a single region of interest (ROI) [18], and finally detects the final boundary of the ROI using boundary tracing technique.

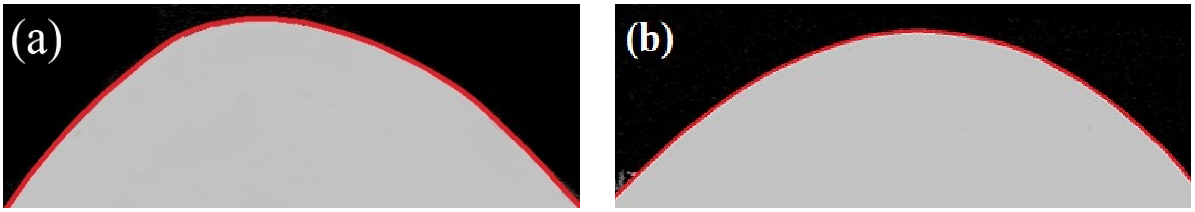

Figure 4. Rotated keratoconus and normal cornea images in grayscale. (a) Keratoconus cornea, and (b) normal cornea.

(2) *Classification*

The proposed method classifies keratoconus eyes from normal eyes using the slope of corneal curvature. Specifically, the proposed method detects the slope to measure the corneal curvature [12]. Slope angles of the corneal curvature are measured at N different points. Assuming that $N = 18$, for example, slope angles are sampled at every 10 degrees. Based on the difference between each sampled value at every 10 degrees, the proposed algorithm classifies keratoconus eyes from normal eyes.

3. RESULTS

We evaluate the performance of the proposed method in terms of keratoconus detection accuracies. Here, we consider ophthalmologist's diagnoses as references.

The topography examination result of the keratoconus eye (see Figure 4a) is shown in Figure 5a while that of the normal eye (see Figures 4b) is shown in Figure 5b. As shown in Figures 5a and 5b, the keratoconus eye has higher elevation and steeper curvature compared to the normal eye. Ophthalmologists interpret the stages of the keratoconus from these topography results.

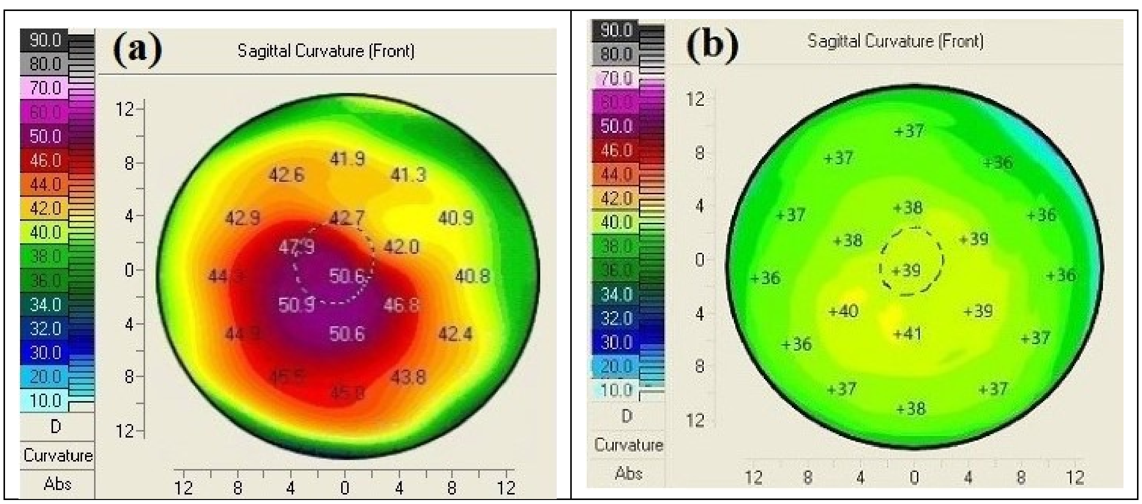

Figure 5. The topographies of keratoconus and normal eyes obtained from CT-6 corneal topographer device. (a) Keratoconus eye, and (b) normal eye.

Figures 6a and 6b show output results of the proposed method for keratoconus and normal eyes, respectively. Here, we set $N = 18$. slope values are measured at every 10 degrees as shown in Figure 6The corneal surface of the keratoconus eye has a cone shape with irregular slope variations as shown in Figure 6a while that of the normal cornea has round curvature and regular slope variation as shown in Figure 6b.

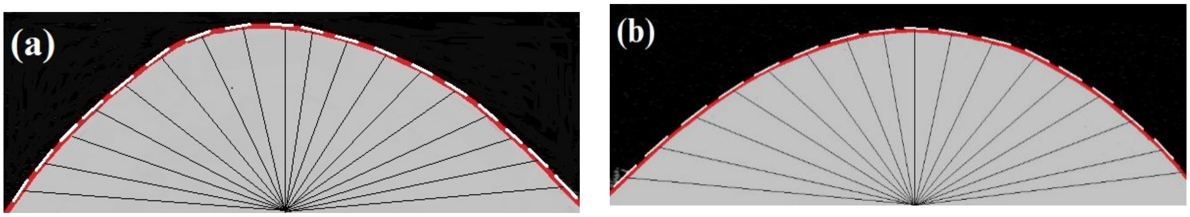

Figure 6. Output results of the proposed method for keratoconus and normal eyes. Slope values are measured at every 10 degrees. (a) Keratoconus cornea, and (b) normal cornea.

From the curvature information of the eyes, the proposed method detects severe, advanced, and moderate keratoconus with accuracies of 93%, 86%, 67%, respectively.

4. CONCLUSION

In this paper, we have proposed an affordable and easy-to-use keratoconus detection method using a smartphone. The proposed method detects keratoconus using smartphones without additional gadgets. Our proposed method acquires eye photos taken from the side, and performs image processing on the acquired photo, and finally detects keratoconus based on the difference of cornea curvature values sampled at each angle. We have evaluated the performance of the proposed method in terms of keratoconus detection accuracy. We consider ophthalmologist's diagnoses as references. The results show that the proposed method detects severe, advanced, and moderate keratoconus with accuracies of 93%, 86%, 67%, respectively. Our proposed method is expected to be implemented on various types of smartphones to detect keratoconus in the early stage. We are able to implement our method on both Android and iOS smartphone operating systems with a re-targeteable application platform [19] which results in a portable, versatile, and novel technique for detecting keratoconus with maintaining detection accuracy. Our method could be implemented on any smartphone with adequate hardware configuration and a proper camera.

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