Novel Keratoconus Detection Method Using Smartphone

Behnam Askarian, Fatemehsadat Tabei, Grace Anne Tipton, and Jo Woon Chong*

***Abstract*—Keratoconus is a progressive corneal disease which may cause blindness if it is not detected in the early stage. In this paper, we propose a portable, low-cost, and robust keratoconus detection method which is based on smartphone camera images. A gadget has been designed and manufactured using 3-D printing to supplement keratoconus detection. A smartphone camera with the gadget provides more accurate and robust keratoconus detection performance. We adopted the Prewitt operator for edge detection and the support vector machine (SVM) to classify keratoconus eyes from healthy eyes. Experimental results show that the proposed method can detect mild, moderate, advanced, and severe stages of keratoconus with 89% accuracy on average.**

Keywords— Keratoconus, Smartphone, Cornea, Corneal Topography, Support Vector Machine.

I. INTRODUCTION

Recently, there has been a tremendous advance in the field of smartphones. Portable health monitoring devices and smartphone health applications have gained a lot of attention due to their convenience. Smartphones are at the center of mobile health devices due to their ubiquity, affordability, and convenience. Data acquired from smartphone' sensors can be used for remote healthcare in remote areas while images captured by smartphone cameras can be used for monitoring the progression of the disease or be stored for further analysis. As a result, smartphones have been used as aiding tools to detect a variety of diseases from heart disease to skincare and eye diseases due to their powerful and robust processors and sensors [1-8]. Moreover, smartphones have been used as an aiding device for detecting eye diseases by magnifying and managing the images captured from ophthalmology and optometry devices [9, 10]. Smartphones which are capable of connecting to fundus camera and optical coherence tomography (OCT) device are used to aid eye specialists detecting certain eye diseases such as macular degeneration, diabetic retinopathy, cataracts, etc. [2, 5, 6, 9-27]. Smartphone applications have been proposed for detecting various stages of keratoconus using gradient slope detection method without using any additional gadget by simply using a 90-degree image from the eye [2-4]. Moreover, smartphones have been only used as a recording and magnifying tool to aid the eye specialists in their diagnosis.

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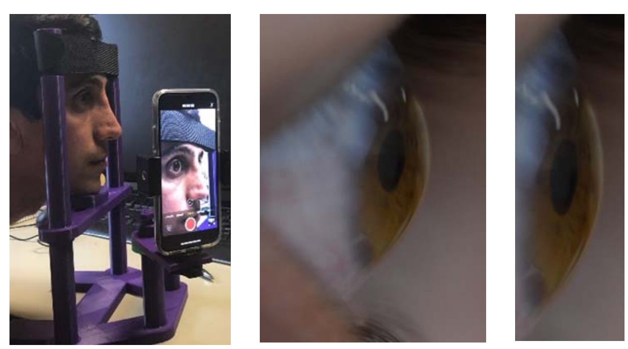
In this paper, we propose a novel image processing method with a newly developed gadget for detecting keratoconus using a smartphone. Prewitt operator is adopted for edge detection and the support vector machine (SVM) is applied to classify keratoconus eyes from healthy eyes. The rest of this paper is organized as follows: Section describes data collection, preprocessing, feature extraction, and classification. The results from our proposed method are presented in Section . Finally, Section concludes the paper.

II. MATERIALS AND METHODS

A. Experimental Protocol

A major problem encountered in studies related to eye disease diagnosis is the head and eye movement during image acquisition. The focus issue, light conditions, and lens distortion also altogether result in blurry and noisy images with bad focusing. To address these issues and acquire a high-quality clean image, we proposed a novel image acquisition tool (see Fig. 1) manufactured by 3-D printing to capture panoramic 180-degree images from the eye. The gadget was attached to an iPhone smartphone for the acquisition process. The iPhone X is equipped with a 12-megapixel rear camera, and we used the maximum resolution in the measurement procedure. We recruited 10 volunteers and recorded their eye data using our proposed smartphone-based keratoconus detection tool in their clinics. Here, ophthalmologists' diagnoses on subjects' eyes were used as a gold standard. Following the Texas Tech University (TTU) Institutional Review Board (IRB) (IRB#: IRB2018-964), we analyzed the de-identified eye image data recorded by the smartphone.



(a) (b) (c)

Figure 1. Data acquisition process. (a) The image acquisition device using a new gadget, (b) the image captured from the eye, and (c) the cropped image of the cornea.

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B. *Preprocessing and Parameters*

After the 180-degree panoramic picture was captured from the participant's eye, the images were cropped to extract the cornea as the region of interest (ROI). In our previous study, we adopted the Canny filter for edge detection. The Canny edge detector algorithm is an operator which uses a multistage algorithm including Gaussian filter, gradient intensity, non-maximum suppression, double thresholding and edge tracking by the hysteresis for edge detection. The multistage algorithm adds noise to the images and picks noises like salt-and-pepper noise which requires extra preprocessing steps to acquire smooth edges with no noises. The preprocessing stages include a Fourier transform and high pass filters to bold the edges and extract noise; the median filter to filter out salt-and-pepper noise; dilation for filling the holes; and boundary extension to detect a wide range of edges in the image. All which only adds more noise and results in rough edges which requires edge smoothing and further complication to our previous method. To address these issues from our previous study, we adopted a novel Prewitt operator for edge detection.

The Prewitt operator was adopted for detecting the exterior edges of the cornea. This operator calculates the gradient of the image intensity at each point indicating the largest possible increase from light to dark in the image providing perfect edge detection. Prewitt operator is calculated using the following equations [28]:

$$G_x = \begin{bmatrix} +1 & 0 & -1 \\ +1 & 0 & -1 \\ +1 & 0 & -1 \end{bmatrix} \times A, \quad G_y = \begin{bmatrix} +1 & +1 & +1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix} \times A, \tag{1}$$

where A is the source image, and G_x and G_y are the horizontal and vertical derivative approximation images.

By combining the gradient approximations, the gradient magnitude G can be calculated using the below equation:

$$G = \sqrt{{G_x}^2 + {G_y}^2}. \tag{2}$$

The gradient direction Θ is calculated using the following equation:

$$\Theta = \arctan^2(G_y, G_x). \tag{3}$$

The results of both edge detection operators without any noise cancelation and filtering is shown in Fig. 2. The results of the Canny edge detector operator is shown in Fig. 2a. The result of the Prewitt edge detection operator is shown in Fig 2b which provides a cleaner image with much smoother edges.

The images were cropped to eliminate the background and pupil from the cornea image. After the edge detection and binarization process, the dilation was used for probing, expanding the edges, and connecting the structure. Next, we extended the ROI by a one-pixel wide border to separate objects from the ROI margin and to fill holes and close the gaps.

The corneal curvature was extracted after the preprocessing stage. Finally, the participant's corneal gradient slope was compared with a perfectly normal cornea confirmed by an ophthalmology device and ophthalmologist opinion as a gold standard.

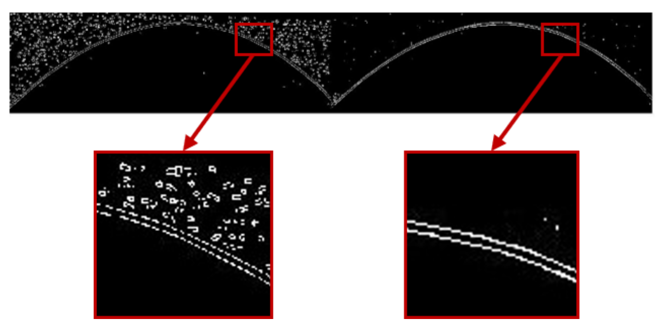
III. Results

Our proposed method uses a slope detection-based method, which is different from the corneal topography methods. In our previous study, we implemented a threshold and boundary technique to classify different stages of keratoconus, and to differentiate healthy eyes from diseased eyes [2]. The Canny filter combined with a thresholding classifier had an average accuracy of 87% for detecting any keratoconus eye from a healthy eye. We increased the accuracy of detection by changing the edge detector algorithm and the classifier. Using the SVM classifier and the Prewitt operator as our edge detector, we classified our images into healthy eye and diseased eye with an average accuracy of 89%. Moreover, to improve the classification of our previous study, 70% of data was used as the training subset and 30% was used as the testing subset in our SVM classifier. The results of different classifiers are presented in Table 1.

The classification was done by SVM where the input is a vector computed from the projections of the object at several angles to overcome orientation problems. Other advantages of the algorithm are its robustness against different illumination and scaling, and also its simplicity.

IV. Conclusions

In this paper, we propose a novel image processing method with a newly developed gadget for detecting keratoconus using a smartphone. The SVM classifier was adopted to distinguish healthy eyes from keratoconus eyes. Using the SVM classifier, we divided our data set by allocating 70% of the volunteers' images for training the classifier and 30% for testing the algorithm.



(a) (b)

Figure 2. Results of edge detection operators. (a) The Canny operator, and (b) the Prewitt operator.

Table 1. Classification accuracy results.

	Classifier	
	Thresholding	***SVM***
Accuracy %	87%	89%

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The proposed keratoconus detection algorithm using the Prewitt operator gives accuracy, specificity, and sensitivity of 89%, 91%, and 88%, respectively, while the previous detection algorithm with the Canny operator gives accuracy, specificity, and sensitivity of 87%, 90%, and 84%, respectively.

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