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Research paper

Mobile Screening Framework of Anterior Segment Photographed Images

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Abstract

This work presents a qualitative measurement of anterior segment photographed images (ASPIs) to identify between normal eyes and eyes with pterygium and pinguecula through Otsu multi-thresholding approach without contrast enhancement. In addition, we also propose a mobile screening framework of ASPIs through smartphones. ASPIs were directly sent to the cloud storage once an ASPI was captured using a smartphone camera, and then each image was processed through a digital image processing approach in a processing platform. Three important steps, namely, pre-processing, image segmentation and qualitative assessment, are involved in the processing platform of the mobile screening framework. The ASPIs are pre-processed to minimise or eliminate any unwanted areas within the image. Then, these ASPIs are segmented through multi-thresholding Otsu approach with clustering number $n = 3$. Segmentation result shows that the accuracy of the proposed method is 87.5%, which is comparable with the previously established work that has applied three-step differencing (3SD) method. However, the proposed approach has better computational time which is six times faster than the 3SD method. These results demonstrate a remarkable effort to produce a simple but straightforward digital image processing approach to be implemented in cloud computing for future studies.

Keywords: *ASPI; computational time; mobile screening system; Otsu multi-thresholding approach; pterygium.*

1. Introduction

Healthy eyes are important for humans in performing their routines regardless of their age or commitment. However, most people abuse their eyes and are disregarding the long-term consequences of this abuse. In Malaysia, 1.3 million people who are above 50 years old have visual problems [1]. Anterior eye disease is the disorder of the cornea, conjunctiva, and anterior segment of the eye. The disorder that affects the cornea can cause severe vision loss, and the common disorder that affects the conjunctiva is called conjunctivitis.

Pterygium is an anterior ocular surface disorder. It is a condition in which a mucous membrane grows on the sclera, which is the white layer of the eyeball, and extends to the circular line of the cornea. This noncancerous tissue commonly grows from the nasal and is in a wing-shaped [2]. In addition, pinguecula, another eye disorder, is a benign thin layer of fleshy tissue that appears as a yellow spot that grows on the conjunctiva [3]. However, these tissues do not grow towards the cornea region in contrast to the pterygium. Pinguecula is the relatively common growth of abnormal tissues near the eye's nasal, which is close to the cornea. However, untreated pinguecula will tend to grow towards the cornea, thereby possibly leading to pterygium. Fig. 1 illustrates the normal, pterygium and pinguecula anterior segment photographed images (ASPIs). Pterygium and pinguecula do not require any crucial treatment unless they cause discomfort in certain cases. For example, if the tissue becomes large, then the patient must consult an ophthalmologist for further treatment. Moreover, the growth of benign tissues might be caused by excessive exposure to ultraviolet ray, wind or dust. Clinically, the existence of these abnormal tissues can be validated through a screening examination by using specific instruments performed by eye specialists or ophthalmologists.

a) b) c)

Fig. 1: ASPI of a) normal, b) pterygium, c) pinguecula

Several previous studies have proposed appropriate methodologies to detect ocular diseases, such as pterygium, pinguecula and cataract, through image processing techniques. For example, in [2] utilised Otsu and Circular Hough Transform (CHT) techniques for pterygium tissue segmentation, in [4] implemented a diverse segmentation procedure to automatically screen diabetic retinopathy disease and in [2] proposed glaucoma recognition method by computing the cup-to-disc ratio. Image processing techniques have been used and implemented extensively as a platform for assisting ophthalmologists in locating any ocular ailment and reducing the diagnostic time [5]. For example, anterior segment views are used in diagnosing cataract and other ocular conditions [6]. Applications, such as computer-aided diagnosis (CAD) are also used by researchers in screening ocular diseases automatically [7]. Corneal

topography is a CAD technique used to diagnose ocular diseases, where a special instrument projects a series of light rings of cornea [8]. Therefore, CAD can assist in promptly detecting and providing easy access for patients. These instruments do not substitute the expertise of doctors, but rather support and help minimise their time in interpreting medical imaging.
The Internet of Things (IoT) associated with health care connects medical instruments to information technology (IT) applications through the Internet. This technology has been increasing rapidly. Recently, several efforts have been exerted to enhance filter processing and ocular disease diagnosis by using advanced image and data analysis techniques [7]. In addition, various applications related to health care can be accessed broadly by any individual who owns a smartphone. In [9] stated that utilising mobile devices is a 'run-of-the-mill' in a health care milieu. This effort encourages rapidly developing software applications related to medicine. Currently, smartphones have various functions such as information searching, medical decision-making and educational applications [10]. For example, iSTART is a smartphone application that is used in medical education, a randomised trial as an evolution platform of IT in an educational application was proposed by [9]. According to Statista [11], more than 2.2 million medical-based applications are available in Google Play store and Apple's App Store in 2018. In addition, there are exhaustive infrastructure of portable telemedicine system based on smartphones for diabetic eye disease [12]. Moreover, mobile devices are more often used among teenagers and elderly with the convenience of wireless access to get patient care information as a mobile medical platform [13]. This finding shows that this evolution with trend will lead to establishing connected health care systems. Thus, this work proposes a framework of mobile screening ocular disease system by using ASPIs. This system may promptly detect ocular diseases, especially for pterygium cases through a digital image processing approach, in which a potential multi-level segmentation technique will be exploited in processing the locally collected ASPIs.

2. Methodology

2.1. Database Collection

In this work, 86 ASPIs are captured using a Huawei P9 smartphone with a Leica camera with 12 megapixels × 2 (dual-tone flash). The captured images consist of 52 normal, 28 pterygium and 6 pinguecula cases, as illustrated in Fig. 1. The collected images are in a .jpeg format with varied sizes. The Leica camera technology with backside illumination, (BSI) sensor, a type of image sensor for digital cameras, uses imaging elements to accurately capture an image in low light condition (low noise) and high resolution [14]. These images were collected during the 'Operasi Khidmat Masyarakat Optometri ke-26 (OPKOM-26)' held in Padang Terap Community Centre, Kedah, organised by the Department of Optometry and Health Vision at the Faculty of Health Science, Universiti Kebangsaan Malaysia, Malaysia, from 30 March to 1 April 2018. Based on the statistics of the Malaysian Journal of Health Science, 88.6% of the farmers in Cameron Highlands and 94.4% in Bachok and Pasir Puteh are positive with pterygium [1]. The risk of having pterygium is high for people who are working outdoor given their extended exposure to high UV radiation [4]. Therefore, people who are living in rural areas, such as Padang Terap, Kedah, are frequently exposed to UV radiation directly from the sun because most of them are as farmers and bus drivers who work outdoors. Moreover, they are likely to encounter various cases of pterygium and pinguecula considering their living environments.

2.2. Proposed Mobile Screening Framework

The proposed cloud-based mobile screening system of ASPI aims to provide a mobile screening of pterygium to the public. The proposed system will provide an easy access to the public through the mobile application, as depicted in **Error! Reference source not found.** because the current method for detecting pterygium is mostly performed by a qualified eye practitioner in hospitals through manual examination of a patient's eyes [2]. The users can simply upload their captured ASPI through the developed mobile application to the cloud server, and the ASPI will then be used as inputs to the processing platform. The images will be processed using the proposed methods in the platform, and their results will be archived in the cloud database. The medical experts who have access to the database will validate the results, and the validated results can be accessed by the users through the mobile apps.

2.2.1. Proposed Methods in the Processing Platform

Three important steps, namely, pre-processing, image segmentation and qualitative assessment, are used in the processing platform, as demonstrated in **Error! Reference source not found.**.

2.2.2. Pre-Processing

ASPIs are prone to noises that can be obtained when the images were being captured. The noises can produce undesirable effects that can affect the processing of images, thus resulting in inaccurate segmentation. Pre-processing methods, such as contrast enhancement (CE), can help to reduce or remove the noises. In the previous method for pterygium segmentation, an adaptive contrast manipulation technique by using a sigmoid function was applied in a pre-processing step [2, 7]. The adaptive contrast manipulation technique by using sigmoid function has parameters that can control the brightness and contrast level of the images. The technique can highlight the iris as the region with the highest contrast in the sclera; this technique also rendered the overlapping of pterygium tissues on the iris to improve contrast [7]. In this work, two approaches are used on the ASPI in the pre-processing step. The first approach is by applying the CE technique from the previous work [2] and the second approach which is a proposed method is not applying the CE technique. Both approaches are implemented to the ASPI in the pre-processing step to determine the approach that generates enhanced segmentation results.

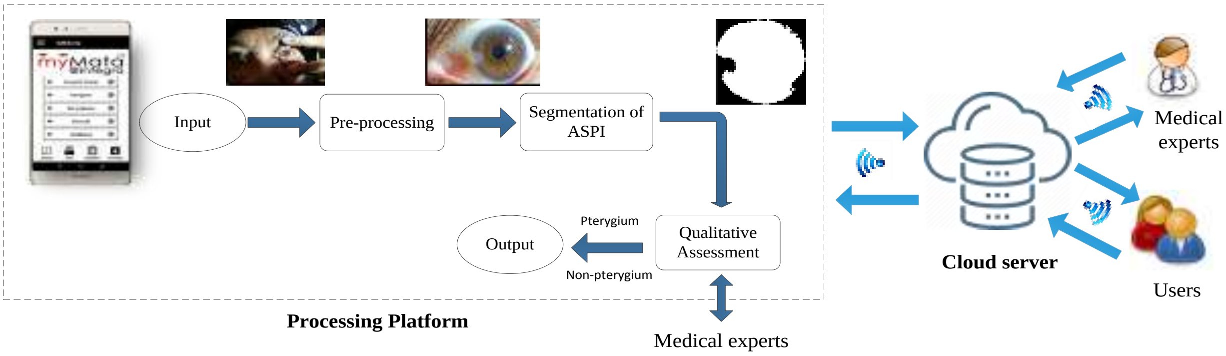


Fig. 2: Proposed mobile screening framework

2.2.3. Segmentation of ASPI

In previous works [2, 7, 15], a three-step differencing (3SD) method is used in the segmentation step. This method requires converting the ASPI colour format in the pre-processing step from red, blue and green (RGB) to hue, saturation and value (HSV).
This method is crucial for detecting the pterygium region on the basis of the segmented cornea. The segmented cornea will commonly appear as a perfect circular shape for a normal case. However, for the case of pterygium, the segmented cornea will show a slightly distorted shape on its side given the encroachment of fibrovascular tissues. The segmentation module will be performed using the selected threshold to segment the differential image after performing the 3SD method.
Another approach for pterygium segmentation is Otsu's multi-thresholding method. Otsu's method is a global thresholding that depends only on the grey value of an image [16]. A method used to automatically select a threshold from a grey-level histogram was derived from the viewpoint of discriminant analysis [17]. An optimal threshold is selected from the discriminant criterion by maximising the discriminant measure η or the measure of separability of resultant classes in grey levels. The following equations express the optimal threshold k^* that maximises η in (1) and the optimal threshold k^* in (2) [17].

$$\eta(k)=\frac{\sigma_\beta^2(k)}{\sigma_T^2}, \quad (1)$$

$$\sigma_\beta^2(k)=\frac{\left[\mu_T\omega(k)-\mu(k)\right]^2}{\omega(k)\left[1-\omega(k)\right]}, \quad (2)$$

$$\sigma_\beta^2(k^*)=\max_{1\le k<L}\sigma_\beta^2(k), \quad (3)$$

where σ_β^2 and σ_T^2 are the class and the total variance of levels, respectively, and σ_β^2 is based on first-order statistics (class means). In addition, $\omega(k)$ and $\mu(k)$ are the zeroth- and first-order cumulative moments up to the kth level, correspondingly, and μ_T is the total mean level of the original picture.
A segmentation of the image into multiple classes is performed using Otsu's multi-thresholding [18]. This approach differs from the method proposed in a previous work [2], wherein ASPIs were converted from RGB to greyscale instead of HSV to perform Otsu's multi-thresholding method. The threshold value is adaptively calculated on the basis of the selected number of clustering, thereby resulting in an improved corneal segmentation. In this work, the 3SD and Otsu approaches are used for pterygium segmentation, and the results are observed through a qualitative assessment.

2.2.4. Qualitative Assessment

A qualitative approach is conducted to differentiate among pterygium, non-pterygium (normal) and pinguecula ASPIs on the basis of the three criteria as follows:
1) Pterygium: A segmented corneal region will have an imperfect round shape. The fibrovascular tissue starts at the conjunctiva and extends towards the cornea [19]. The encroached fibrovascular tissues on the cornea will cause the cornea to have a slightly distorted shape, thus rendering an imperfect round shape.
2) Non-pterygium (normal): A segmented corneal region will have a nearly perfect round shape because the cornea is normal (no fibrovascular tissue encroachment).
3) Pinguecula: The segmented corneal region will have the same results with the non-pterygium case because the fibrovascular tissue does not encroach onto the cornea. However, the abnormality of the tissue can be identified qualitatively by applying Otsu's method with threshold $n = 4$.

Using the above defined criteria, all segmented ASPI will be categorized accordingly. Then, the results are validated with the ground truths provided by an experienced optometrist and two final year students from the Optometry and Vision Sciences Programme, School of Healthcare Sciences, Faculty of Health Sciences, Universiti Kebangsaan Malaysia, Kuala Lumpur, Malaysia. The validated results are used to calculate the accuracy percentage of number of correct segmented images based on the qualitative assessment.

3. Results and Discussion

A total of 86 ASPIs were captured in Padang Terap, Kedah, by using a Huawei P9's Leica dual camera with high-resolution lens. Participants were seated on an adjustable chair with their chin and forehead placed on a chinrest and their eyes Fig. 3 to be captured at a steady state using the mobile application that was developed for pterygium screening. The ASPIs used in this work consisted of 52 normal, 28 pterygium and 6 pinguecula images.
The pre-processing of the image uses two approaches namely applying the CE, which is adopted from a previous work [2, 7, 15] and without applying the CE. Fig. 4 exhibits the output images from the pre-processing that differentiate the use of CE. The first row of Fig. 4 displays the image with CE, whereas the second row presents the image without CE. The segmentation process also uses two approaches. First, the 3SD method based on a previous work [2, 7, 15] requires converting an image colour format from RGB to HSV. Second, Otsu's multi-thresholding method, which is the proposed method, requires converting the image colour format from RGB to greyscale. Fig. 5 illustrates the segmented images using different Otsu thresholds (n = 2, 3, 4 and 5) with CE (first row) and without CE (second row).

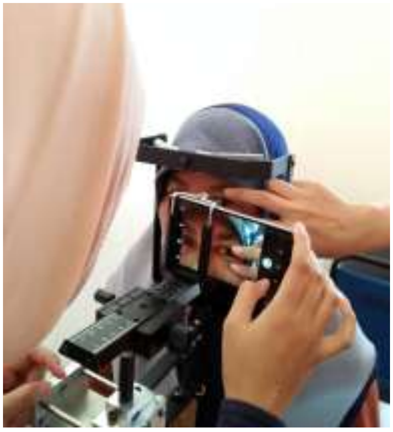
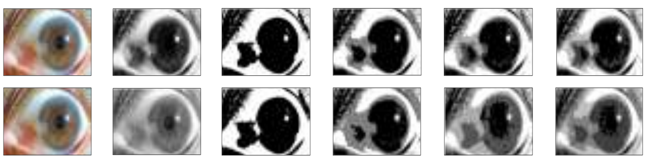


Fig. 3: Data collection using mobile screening application



a) b) c) d) e) f)

Fig. 4: Pre-processing images with CE and without CE. a) Original pterygium image, b) Grayscale image, c) Grayscale image with n = 2, d) Grayscale image with n = 3, e) Grayscale image with n = 4, f) Grayscale image with n = 5

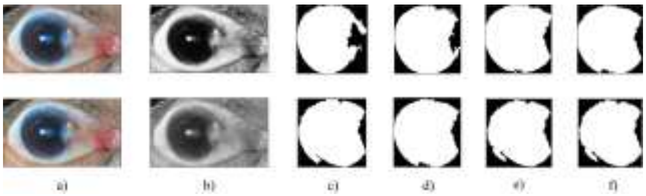


Fig. 5: Segmented images using different Otsu thresholds. a) Original pterygium image, b) Grayscale image, c) Binary image with n = 2, d) Binary image with n = 3, e) Binary image with n = 4, f) Binary image with n = 5

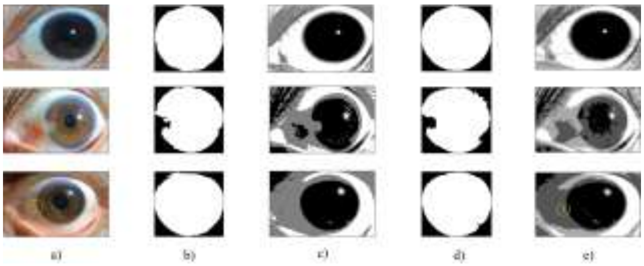


Fig. 6: Comparison segmented binary image. a) Original image, b) Binary image (Previous method), c) Grayscale image (n = 3), d) Binary Image (Proposed method), e) Grayscale image (n = 4)

Table 1: Accuracy percentage of the number of correct segmented images based on qualitative assessment

Criteria	Total No. of Accurately Segmented Images Based on a Qualitative Assessment (Total Images = 80)	
	Previous Method [2]	Proposed Method
Non-pterygium (Total = 52)	46	48
Pterygium (Total = 28)	23	22
Accuracy (%)	86.25%	87.5%

The most suitable value for the segmentation approach was n = 3 after experimenting different values of clustering, n, through Otsu's thresholding method. Based on the results, the input image did not require CE because these images were captured using a Huawei P9 smartphone with Leica dual camera with a black-and-white and a colour sensor, which can shoot high-contrast, vibrant colour pictures [20]. Therefore, the cornea of the ASPIs with a region encroached by pterygium from our database could be segmented well without using CE in the pre-processing step.

The result of the segmented binary images through the 3SD method with CE [2] and the proposed Otsu's multi-thresholding method without CE is depicted in Fig. 6. The first, second and third rows of the figure are the normal image, pterygium image and pinguecula image respectively. The segmented images were categorised as pterygium or non-pterygium on the basis of the qualitative assessment that had been discussed in the research methodology section.

Based on the qualitative assessment, the segmented binary images of the cornea in the first row of Fig. 6 showed that both methods qualitatively fit the first criteria (i.e. normal) because the segmented cornea had a nearly perfect round shape. The segmented binary image in Fig. 6 d) of the proposed method had a smoother edge of the segmented cornea than in the segmented binary image of the 3SD method in Fig. 6 b).

For the pterygium case, the segmented binary images of the cornea in the second row of Fig. 6 showed that both methods also qualitatively fit the second criteria (i.e. pterygium) because the segmented cornea has a slightly distorted shape, thus appearing to be imperfectly round. However, the segmented binary image in Fig. 6 d) mostly highlighted the segmented pterygium accurately through the proposed method compared with the segmented binary image using a previous method [2] in Fig. 6 b). For the pinguecula case, the segmented binary image could be qualitatively categorised as normal. Furthermore, the abnormality of the pinguecula eye image (existence of a dark grey region near the cornea) could be observed by applying Otsu's method with threshold n = 4 as depicted in the last row of Fig. 6 e). The abnormality is circled with orange on the image in Fig. 6 a) and e).

Furthermore, Table 1 summarises the results which indicated that the proposed method has a slightly higher total number of accurately pterygium segmented images (87.5%) than the previous method (86.25%). Factors that could contribute to the poor segmentation results were as follows: the position of the cornea not being at the centre of the eye image, occlusion of the eyelashes and blurred captured images. Thus, these factors should be considered during the image acquisition for favourable segmentation results to be produced.

In addition, we obtained longer average computational time (i.e. 2.543 s) in the previous method than in the proposed method (i.e. 0.478 s). Therefore, the computational time for the proposed method has remarkably improved by six times which is 81.2%.

4. Conclusion

This work proposes a mobile screening framework of ASPIs by using a smartphone in which is in-line with the current trend; smart devices are commonly used to facilitate a connected health care system. The segmentation step through the proposed method that is Otsu's multi-thresholding method without CE has been proven to qualitatively produce better segmentation results than those through the 3SD method developed by [2] tested using local collected ASPIs. The segmentation results of both approaches are compared and our proposed method has a slightly higher accuracy (i.e. 87.5%) than the 3SD (i.e. 86.25%) with six times faster computational time than in the 3SD method. Furthermore, Otsu's multi-thresholding method is shown to be suitable for the qualitative assessment of a local database for pterygium detection. The method can also detect the growth of other abnormal tissues such as pinguecula. Therefore, the proposed method can be a simple but straightforward image processing method to be implemented in cloud computing in a future work. In addition, the future work will focus on developing feature extraction and classification modules by utilising an intelligence classification approach such as a deep learning approach to identify pterygium and pinguecula ASPIs and adding local images to the database.

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