INTERNATIONAL JOURNAL of ENGINEERING SCIENCE AND APPLICATION
E. Amiri et al., Vol.4, No.4, December 2020

Detection of Topographic Images of Keratoconus Disease Using Machine Vision

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Received: 26.11.2020 Accepted: 26.12.2020

Abstract- The human eye is one of the most important and first senses (vision) of the five senses. Each eye disease creates its own problems for the patient, and measures are needed to diagnose and treat these diseases. One of these diseases is keratoconus, which is the basis of this article. In this article, first, explanations about this progressive disease are presented, then the important and basic factors used in the programming of this project are briefly and usefully expressed and using 33 topographic images (both healthy eyes and eyes with keratoconus). Four prominent features of this disease were studied and diagnosed with the help of MATLAB software. Proper images of keratoconus are not available, so images were collected. These images were taken in a medical center in Shiraz under the supervision of a corneal specialist and with a size of 1024 * 1024. Any eye that has one of four characteristics is known as a keratoconus. In the end, all the results are compared with the results provided by the expert and the accuracy of the obtained result is measured.

Keywords Corneal diagnosis, image processing, measurement criteria, topographic image characteristics

1. Introduction

The eye, like other parts of the body, has its own diseases, which are impossible to ignore and have irreparable consequences, such as blindness, the most important sense of disability. Acne is one of the eye diseases that is a gradual and non-inflammatory process of thin cornea. It is a relatively common complication of unknown cause, which destroys the thin, transparent layer of the cornea, pulls the cornea forward, and loses its original shape; The same disorder affects light refraction upon entering the eye and often leads to high myopia associated with astigmatism.

Keratoconus can be well defined and easily detected through slit-lamp bio microscopy and corneal Placido reflection-based topography [1]. However, the definition of subclinical KC itself is ambiguous [2]. The information acquired from traditional imaging methods is limited, and using these methods, the diagnostic capacity is insufficient in identifying subclinical KC. Recently, new ophthalmic imaging modalities have been applied in the screening of KC at its earliest stage [3, 4]. Among these modalities, Scheimpflug-based camera imaging and spectral domain optical coherence tomography (SD-OCT) have been the most widely studied methods. Both approaches have provided unique imaging advantages in recognizing early changes in the cornea (e.g., depth information, corneal microstructures, etc.) and have been proven to provide diagnostic value in detecting subclinical KC [2]. Hwang et al. reported a direct statistical approach using a mixed topography variable from a Scheimpflug-based camera and SD-OCT that reached high discrimination [5]. However, in clinical settings, combined machine-derived parameters from these instruments are often too complicated for clinicians to interpret [6].

This disease can be well diagnosed by color imaging called topography. The images obtained from this photography are a collection of color spectrums.

Machine vision is an interdisciplinary field that deals with how computers are built to achieve a high level of understanding of digital images or videos. The machine's vision is exactly what it looks like (computer or machine sees objects) and differs slightly from its related fields. The current goal of machine vision systems is to implement a general framework for solving many open (and previously unresolved) problems in this field and, finally, to create an operational and applied system in the field of artificial intelligence and robotics.

The best way to detect and accumulate color pixels in images is MATLAB software. In this article, using four features, topographic images of eyes with corneal disease are examined and this disease can be detected by using machine vision and completely systematically without human intervention.

2. Overview of Diagnosis of Keratoconus

Early identification of keratoconus is imperative for preventing iatrogenic corneal ectasia and allowing for early corneal collagen cross-linking treatments to potentially halt progression and decrease transplant burden. However, early diagnosis of keratoconus is currently a diagnostic challenge as there is no uniform screening criteria [7]. Keratoconus is a no inflammatory disorder characterized by progressive thinning, corneal deformation, and scarring of the cornea. The pathological mechanisms of this condition have been investigated for a long time. In recent years, this disease has come to the attention of many research centers because the number of people diagnosed with keratoconus is on the rise. In [8], solutions that facilitate both the diagnostic and treatment options are quickly needed. The main contribution of this paper is the implementation of an algorithm that is able to determine whether an eye is affected or not by keratoconus.

Machine learning is an artificial intelligence technique that seeks to train machines to mimic human learning outcomes. As defined by an early pioneer, Arthur Samuel, machine learning "gives the computer the ability to learn without explicit planning." In general, the machine is programmed to maximize output (e.g., the accuracy of classifying natural signs versus abnormal topographies) using a case data set of known inputs and outputs. Machine learning techniques have been used in diabetic retinopathy screening, optic nerve head analysis, visual field interpretation, premature retinopathy, new vascular macular degeneration, vascularity, and cataract surgery [9].

Artificial intelligence has a wide variety of applications. These include examining the behaviour of warrior robots [10], medical processes, and disease detection [11].

In [12] The use of support vector machine for the clinical diagnosis of keratoconus and keratoconus by topography and tomography data studied. In [13] on the diagnosis of keratoconus using targeted corneal topography to review the topographic patterns associated with keratoconus suspects and provide criteria for keratoconus screening.

Objective [14] To create a robust and low-cost computer system (CAD) for early detection of keratoconus for clinical use, combining a custom mathematical model, a neural network (NN) and a Grasberg used for diagnosis.

3. Keratoconus

3.1. Keratoconus disease

A cornea is the transparent part of the front of the eyeball that we can see the innermost structures of the eyeball from behind it, such as the iris and pupil. The cornea of the eye can be compared to window glass, if the window glass be dirty, objects can be seen opaque. If there had been a smudge or blur on someone's cornea, the person sees the objects blurry. One of the most common corneal diseases is Keratoconus, which in some cases has a hereditary history, but in most cases, there isn't any specific cause for appearing this disease. Keratoconus is a degenerative disease of the eye's cornea. It usually occurs in adolescence or early third decade of life [9].

In this disease, the constituents of the main cornea tissue (stratum Struma) dwindle for unknown reasons, and this problem causes the cornea loses both of its natural thickness and its strength due to the above analysis. As a result, the cornea becomes thin and thinner and changes its shape. The cornea is naturally round or spherical in shape but in the Keratoconus, the cornea protrudes and its shape is gibbous and conical.

Therefore, due to the lack of natural curvature in the cornea, the patient vision with Keratoconus [5] is reduced, patients get infected various types of corneal refractive defects such as hyperopia, myopia and astigmatism, or a combination of them.

3.2. Symptoms of keratoconus

Diagnosis of keratoconus may be difficult due to outbreak and growth is very slowly. The disease may be associated with myopia and astigmatism. As a result, it may cause blurred vision and because of lack of clarity, the patient's eyes becomes sensitive to light and sees objects like halo, and their prescriptions usually change each time that they recourse an ophthalmologist.

Fig. 1. Image simulation seen by a person with keratoconus.

3.3. Causes of Keratoconus

Despite much researches, the cause of Keratoconus hasn't known yet. Although the disease is not hereditary, but genetics, the environment or some diseases, such as Down syndrome, can be effective. Although rubbing the eyes tightly is not the cause of Keratoconus, but it is not ineffective in the process of its creation, so is recommended to patients with Keratoconus avoid rubbing their eye [8].

3.4. Diagnosis of Keratoconus

Corneal topography is based on corneal curvature radius analysis. The topographic devices reflect light rings on the surface of the cornea, then a computer device measures the light refractive power of the in different parts of cornea surface by reflecting the shape of these rings [8]. Different powers of light refraction from the corneal surface are designed and specified with different colors, which makes it easier to diagnose different corneal diseases.

Topography is a method for examining the strength and shape of the cornea. With the help of computers generate topographic images, that with to analyze this images can measure and determine the cornea refractive power, existence and extent of irregular astigmatism and especially Keratoconus [9].

4. Detection Features of Topographic Images of Patients With Keratoconus

First Characteristic: The density of a red circular rang, that is seen mostly in lower part of the cornea than in the center. (It indicates that the cornea is stretched downward)

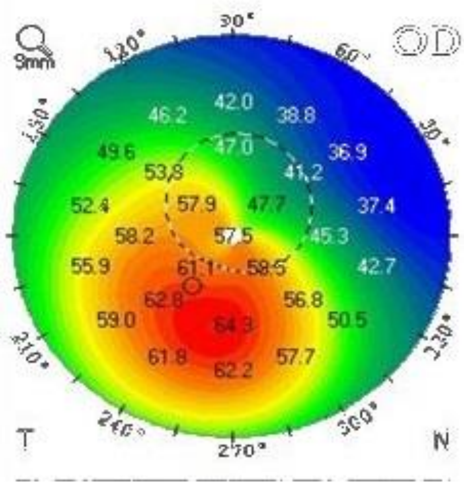

Fig. 2. Topography of the keratoconus with downward elongation

Second characteristic: the presence of a sign such as an hourglass indicates the absence of Keratoconus in the eye. The figure below shows a topographic image of the astigmatic eye.

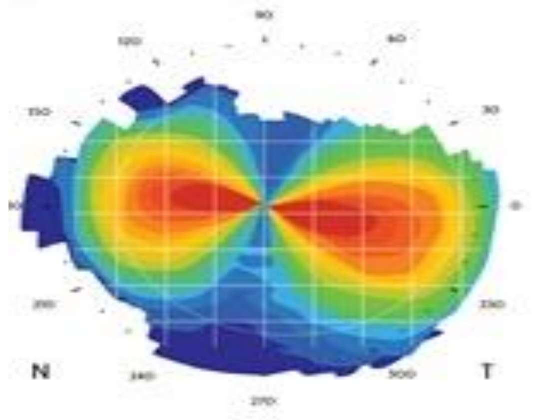

Fig. 3. Topographic image of the astigmatic eye

Third feature: the presence of warm colors (range of red to black, especially red, purple, pink) indicates there is an increase in corneal protrusion. (Also, cool colors have less slope)

Fourth feature: Corneal slope measures based on the difference between the numbers on the image, which in case of large differences between numbers indicates that there is a sharp slope in the cornea. (Whatever, having more differences, shows the slope is sharper, the normal range is in the red range of 42-45, a higher the number represents an abnormal slope and the presence of a Keratoconus.

5. Proposed Algorithms

The scope of work of this project has entered the medical sciences and help to improve ophthalmology. The basis of work and examination of images has done by MATLAB software. Using 33 topographic images of eyes with Keratoconus disease as well as astigmatic eyes and applying the traits of keratoconus disease, only images with Keratoconus were detected. The procedure is as follows:

Initially, all topographic images of the eyes of all patients with Keratoconus as well as healthy astigmatic eyes are collected in one folder. All images are stored in the program database so that processing can be performed on each image. The 33 images collected in one template are shown in the image below.

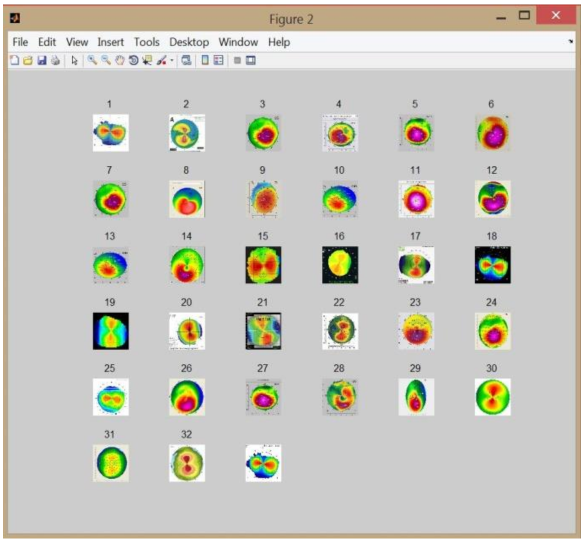

Fig.4. Display all images without deleting the background and with the same size

The images entered in the database each have different sizes. For making a more accurate processing, it is better to resize all the images to the equal, in this part, all the images will be resized to (300 × 300 cm).

In the next step, to perform the processing only on part of the eye's cornea, the background of all images must be removed; This means that all useless areas of the image that are ineffective in the final processing must be removed.

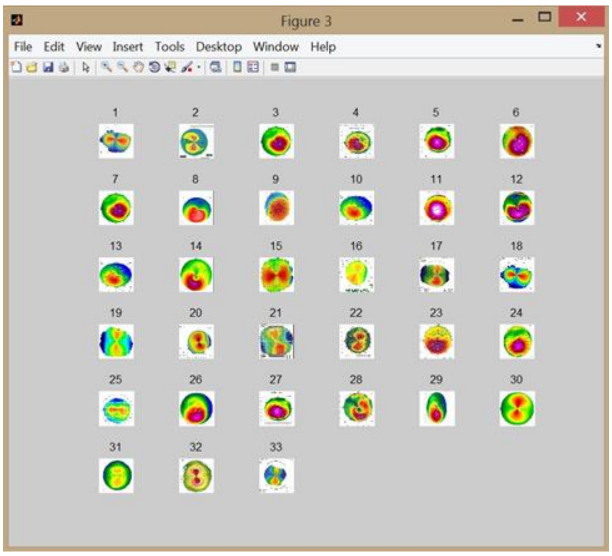

Fig.5. Display all images with the same size and remove the background

5.1. Performing the eye's cornea processing process and finding the images with Keratoconus by applying the first feature (Density of one red limited area in the shape of a circle):

In the first feature, for finding images with Keratoconus, segmentation method is used to find this feature among image databases; in this method, each image is divided into four equal parts, and in each part, the number of red pixels is counted and stored inside a 2 × 2 matrix. In the next step, first time the matrix columns are summed together (the first segment sums with the third segment and the second segment with the fourth segment) and the second time the matrix rows is summed together and the result of sum of these two columns and two rows are placed in variables a1, a2, a3 and a4, respectively. The segmentation is done as follows.

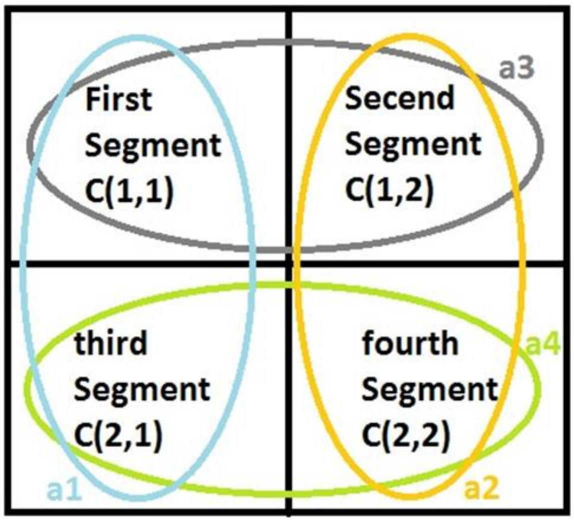

Fig.6. A sample of the sum of each row and column in the segmentation method

Then, by obtaining the difference of red pixels in each segment, the highest red color density is found in one of the segments. The aggregation of red pixels in one area indicates Keratoconus.

Based on this feature if the density of red pixels found in each image be more than 2000 pixels can find Keratoconus images also images smaller than 2000 red pixels can be called image without Keratoconus.

5.2. Performing the eye's cornea processing process and finding the images with Keratoconus by applying the second feature (the presence of a sign such as an hourglass indicates the absence of keratoconus in the eye):

The presence of the hourglass symbol in ocular topographic images indicates astigmatism eyes, it is noteworthy that all eyes with Keratoconus are exempt from this rule.

In this feature, using the edge finder, the hourglass symbol is searched in all images, after finding this symbol in each image, this image is known as the eye of astigmatism and the rest of the images are Keratoconus. The search result with edge finding is similar to the images below.

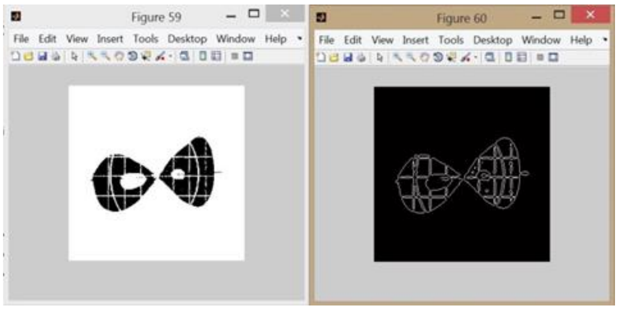

Fig.7. detection eye astigmatism by edge finding

According to the differences obtained, approximately can be estimated that number op pixels between 2,000 and 8,000 images contain Keratoconus.

All the digits in the table are obtained by all of the red pixels convert to black and applying the edge detection function and examining average of the pixels found in the edge finding. The second feature algorithm can find all the topographic images of the Keratoconus by applying numbers more than 2.5000 with a relatively low error coefficient.

5.3. Performing the eye's cornea processing process and finding the images with Keratoconus by applying the third feature (warm colors proportion):

The presence of warm colors (red to black, especially red, purple, pink) indicates an increase protrusion in the corneal (also cold colors have lower slopes). The constituent colors of the Keratoconus topography start with cold colors (blue-green-yellow) with a low slope, whatever the warmer colors be more (red-purple), slope in the corneal increases more. In other words, there is many different between slope of blue and purple.

In this step, blue is assigned the number 1, green is assigned the number 2, yellow is assigned the number 3, red is assigned the number 7, and purple is assigned the number 12. The large distance between the two colors yellow and red (3-7) indicates a sharp slope between these two colors in topographic images.

At this steep, the clustering model can be implement on this algorithm. Clustering means dividing data records into groups and they situate in a group; that the members of each groups are more similar than the others groups, similar records are placed in one group. In this method, similar data obtained using the third feature can be clustered.

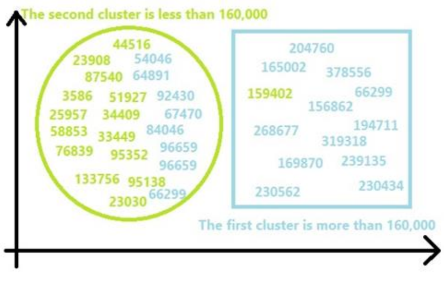

Fig.8. Clustering of values in the third algorithm, Numbers written in blue are with keratoconus, Numbers written in green are astigmatism

With the digits obtained, by applying clustering on the third feature with estimating relatively close, cells more than 160,000 are keratoconus. The error coefficient of this algorithm is more than prior two features due to the presence of red color congestion in both astigmatic and keratoconus eyes. This method does not detect 7 images of the keratoconus (they are considered an astigmatism but these 7 images will have detected with prior two features).

Note: It should be noted that the fourth feature of topographic images is based on the numbers written on the colors; That is, the more numbers on the colors, the greater the slope in that area, which is omitted from the color range of the pixels.

5.4. Evaluation of 3 proposed algorithms using measurement criteria

In evaluating models, one of the most important evaluations is the Actual model, which in different cases, creates a matrix as follows.

Table 1. Accuracy model assessment

	Predicted Class		
Actual class		Class = Yes	Class = No
	Class = Yes	a	b
	Class = No	c	d

TP: This value indicates the number of cells whose actual bunch is positive, and the classification algorithm correctly identifies the bunch as positive.

FN: This value indicates the number of cells whose actual batch is positive and the classification algorithm has erroneously detected them as negative.

FP: This value indicates the number of cells whose actual bunch is negative and the classification algorithm has erroneously identified them as positive.

TN: This value indicates the number of cells whose actual bunch is negative and whose classification algorithm correctly detects as negative.

There is a general and widely used measurement criterion called accuracy, which is calculated from the following equation, and states what proportion of cells, the model has identified correct. According to the following formula a + b is correct, so the sum of a + b relative to the total items model, gains model accuracy. This relationship shows that all the items must follow grouping in order to be considered the desired performance for them that all of them have included in the accuracy criterion.

$$\text{Accuracy}=(a+d)/(a+b+c+d) \quad (1)$$

The Recall (r) criterion indicates the accuracy of classifying bunch r with respect to all records labeled r. The Precision (p) criterion indicates the accuracy of the p classification with respect to all items that the p tag has been proposed for the record examined by the classifier. Note that the Recall (r) criterion indicates the classification performance according to the number of events in bunch r.

The Precision (p) criterion, on the other hand, is essentially based on the accuracy of the classification prediction and indicates what extent to which the classification output can be trusted. Another important point to note is that in the categories that are specified on the label of some unknown records, the denominator of the relationships to the Recall (r) calculation must be equal to the total number of records labeled r. The F-Measure (f) criterion represents a combination of the Recall (r) and Precision (p) criteria and is used in cases where no special significance can be given to either Recall (r) and Precision (p).

(2) PRECISION(p) = a/(a+c)
(3) RECALL(r)=a/(a+b)
(4) F-MAESURE(f)=2a/(2a+b+c)

6. Conclusion

Now you can select the top model using the table below. According to the definition of measurement criteria given below, the result shows that:

Table 2. General comparison of 3 applied features

Features \ Measurement		Accuracy	Precision	Recall	F-measure
1	Density of one red limited area	93.13	94.94	94.72	94.20
2	Edge finding	84.11	88.41	83.33	85.75
3	Ratio of numbers to colors	75.50	100	55.09	71.42

The implementation of different classification methods on different data shows that the performance of these methods is not the same; Each of them performs well on a specific data set Therefore, should according to the nature of the data as well as applications, different models be extracted on the data set and then performance improvement techniques use to increase the accuracy of the models. Considering the comparison of all methods in the table above, shows, the first feature with 93.93 Accuracy is preferable to the other two characteristics.

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