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Early Recognition and Grading of Cataract Using a Combined Log Gabor/Discrete Wavelet Transform with ANN and SVM

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***Abstract*—**Eyes are considered to be the most sensitive and important organ for human being. Thus, any eye disorder will affect the patient in all aspects of life. Cataract is one of those eye disorders that lead to blindness if not treated correctly and quickly. This paper demonstrates a model for automatic detection, classification, and grading of cataracts based on image processing techniques and artificial intelligence. The proposed system is developed to ease the cataract diagnosis process for both ophthalmologists and patients. The wavelet transform combined with 2D Log Gabor Wavelet transform was used as feature extraction techniques for a dataset of 120 eye images followed by a classification process that classified the image set into three classes; normal, early, and advanced stage. A comparison between the two used classifiers, the support vector machine SVM and the artificial neural network ANN were done for the same dataset of 120 eye images. It was concluded that SVM gave better results than ANN. SVM success rate result was 96.8% accuracy where ANN success rate result was 92.3% accuracy.

***Keywords*—**Cataract, classification, detection, feature extraction, grading, log-gabor, neural networks, support vector machines, wavelet.

I. Introduction

THE eyes consists of many complicated components such as the lens. The eye lens is like a camera lens as it focuses light onto the retina at the back of the eye so that the image can be recorded. It also controls the eye's focus, to see things whether they are close or far away. Lenses are made of water and protein and are always transparent, but sometimes the protein clumps up behind the lens which clouds small area of the lenses with white color and causes troubles in the sight. This area may grow larger by time which leads to blindness when it covers the whole lens; this cloudy area is the cataract. When the cloudy area is relatively small, the cataract is considered to be in its early stages, but when the cloudy area is almost or fully covering the lens, the cataract is considered to be in advanced stage, moreover, the cataract can be detected in the pupil area when the eye is being examined externally. The only treatment for cataract is surgery and it is preferred to be treated at early stages to decrease the surgery risks and saves the patient from total blindness. If cataract is left untreated for long time or covers the whole eye lens which is an advanced stage of cataract, this will lead to total blindness since the removal of the cataract will be very difficult causing serious complications such as excessive bleeding, severe and lasting inflammation and Glaucoma also it impairs the view of retina which complicates the surgery for the surgeon, furthermore, One of the common reasons behind the difficulty of removing cataract at advanced stage is that it may convert to a hyper mature cataract in which the lens becomes solid, shrinks and wrinkles or becomes soft and liquid [1]-[3], leading to a complicated surgery for the surgeon with dangerous, unsuccessful results on the patient. Thus, the ophthalmologists will have to weigh the surgery risks against the regain of the patient' sight. A recommendation will be given to leave the cataract untreated in such case. Ophthalmologists advice to have the cataract surgery at an early stage. Cataracts usually affect people above 50 years old, or because of diabetes, long exposure to sun, smoking, obesity and eye injuries. Cataract is the main reason behind 51% of blindness around the world (2010) according to World Health Organization (WHO) [4]. There exist obstacles which prevent the patients from getting through eye examination and surgery, such as ignorance, war zones, poor villages that suffer the lack of clinics or the rarity of finding an ophthalmologist and long waiting lists to be treated. In this paper, a model of cataract detection, classification and grading system is proposed to help with the cataract diagnosis since the system can be used to help the ophthalmologist in diagnosing cataract patients in less time with high accuracy, also it can be used to develop an application to serve patients in needs who live in areas that lake health care centers or eye clinics. This could be done by uploading digital images of their Iris that can be photographed by digital camera and smart phones.

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II. Review of Related Work

Different Cataract detection and classification systems have been modeled and implemented by many researchers. Acharya et al. [5] used tiff natural eye images as the image set, then the histogram equalization was used for enhancing the images contrast, after that, k-means clustering algorithm extracted the images' features that were fed to Neural Network classifier, also The ANN classified the images into different eye diseases which were Cataract, Corneal haze, Iiridocycleitis, Corneal arcus and Normal with accuracy of 90%. Moreover, Acharya et al. [6] used optical RGB eyes' images, histogram equalization was used as a preprocessing step, then fuzzy k means was the feature extraction method and ANN was the classifier, that system classified the pupils' images into three classes which were Cataract, Post Cataract and Normal with 90% accuracy. Anayet et al. [7] used microscope images of pupils then divided every image into fixed number of blocks. After that, they extracted the colors of each block by extracting the average of their R, G, B values, the images were classified into Normal, Grade1 of Cataract, Grade2 of Cataract, Grade3 of Cataract, Grade 4 of Cataract, Grade 5 of Cataract using K-means algorithm with accuracy of 92.5%. Digital images of patients with cataract and people with healthy eyes were used in [8] by Shen et al., and cataracts and healthy eyes were stored in RGB format, then they were converted to grayscale and were resized in the preprocessing phase. Moreover, the pupils were detected and extracted from the images and the mean of gray intensity of each image was calculated, then the mean of gray intensity of healthy eye is compared with cataract eye to distinguish them. Furthermore, the authors removed the noise from the pupil images then converted them into binary images for edge detection, also they measured the circularity of the cataracts to determine the cataract type, the image circularity was compared with a circularity threshold of nuclear cataract (NC) binary shape, or with Cortical cataract (CC) binary shape; thus, classifying the cataracts into two classes, nuclear cataract with 94.96% accuracy, and Cortical Cataract with 95.14%. Later in [9], Nayak used TIFF optical images of pupils, then detected the pupil area and the cornea area by using canny as edge detection method, the white pixels in every image were counted besides detecting the cataract perimeter using erosion. Also, The SVM classifier classified the images into Normal, Cataract and Post Cataract with average accuracy of 88.39%. Fundus eye images were later considered in [10] by Guo et al., they used the Haar Wavelet transform to extract the features and also used PCA to reduce the feature vector dimensions. The other feature extraction method was sketched based method with discrete cosine transform (DCT). The authors made feature vector of Haar wavelet coefficients, a feature vector of sketch method with DCT, and a feature vector that combined wavelet and sketch-based method with DCT together, the classifier was multi-fisher, and the classes were cataract, non-cataract, and cataract grading to mild, moderate or severe. The classifier results were 90% accuracy for two classes using wavelet transform, and 77.1% for grading cataracts, then the classifier scored 86.1% for classifying the two classes using the sketch based method and DCT and scored 74% for grading the cataract. The feature vector that combined both of feature extraction methods was fed to the classifier and scored 89.3% for the two classes and 73% for grading the cataracts. Fuadah et al. used manual cropping of the features in [11], the pupil area was manually cropped out of the eye images by the user and then they were converted to gray scale images, The Gray level Co-occurrence matrix (GLCM) was used to extract the features, and the K nearest neighbor was the classifier which classified the images into cataract or normal with an accuracy of 94.5%. The previous research papers used different approaches to detect and classify cataracts using different types of image data sets like fundus eye images and microscope images that need special medical equipment which may not be available in poor villages' clinics.

III. Processing Algorithms

The proposed system model for cataract detection, classification and grading is illustrated in Fig. 1. It consists of three phases, the first phase is preprocessing in which the images were prepared by resizing the images, removing the glare from the eyes and then the images will be converted to grayscale images. The second phase is the feature extraction in which the images were fed to Discrete Wavelet Transform combined with Log Gabor transform to form the feature vectors. In the third phase, the feature vectors were sent to support vector machines SVM and ANN, both of them classified the images into three classes: normal, early stage and advanced stage. The first class refers to healthy eyes that have black and clear pupil which indicates that they are free of cataract, the second class indicates early stages of cataract in which the pupil of the eye has relatively small affected area with cataract. Finally, the advanced stage class refers to the almost or completely covered pupil with cataract.

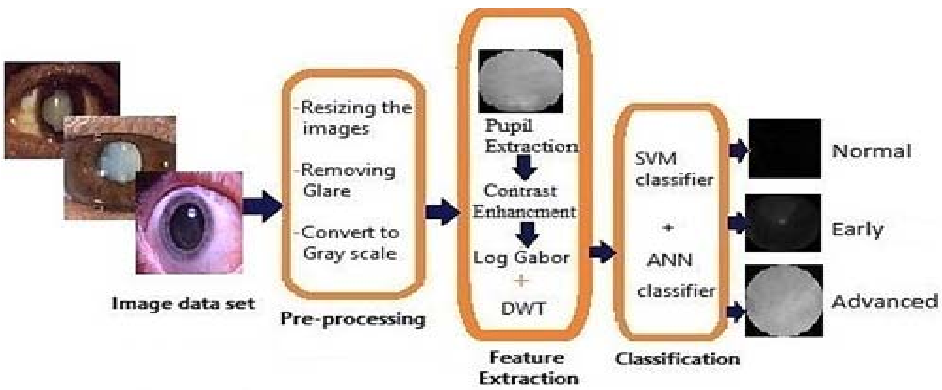

Fig. 1 Summary of the proposed system

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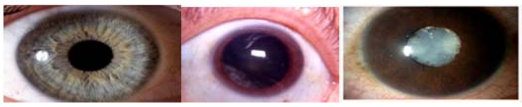
IV. Images Dataset

The image dataset contains 120 eye images that were in JPG format. It contains 25 images of normal eye, 39 images of early stage cataract, and 56 images of advanced stage cataract. The images were obtained from university of Aiwa eye rounds' Atlas of cataract [12] and Duane's Clinical Ophthalmology [13]. Samples of these eye images are shown in Fig. 2.



(a) (b) (c)

Fig. 2 Samples of eye stages: (a) Normal, (b) Early stage cataract, (c) Advanced stage cataract

V. Image Preprocessing

Image preprocessing techniques are applied on the given eye images dataset (120 images) for image enhancement. It was implemented as follows: resizing all of the images into 200x240, removing the glare, since the eyes' surface reflect the light, any source of light when it is focused on the eyes reflects on its surface as a spot of glare and without removing it, this glare spot will be considered as a white spot in a grey scale image which will confuse the classifier. The reflection areas are characterized by high pixel values close to 255. Thresholding and refilling techniques were used successfully to remove the glare, then converting the images to grayscale images. Fig 3 shows the image preprocessing steps.

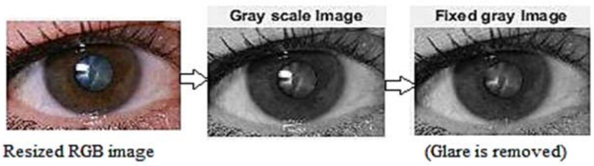


Fig. 3 Image preprocessing steps

VI. Feature Extraction

In feature extraction's first phase, the pupil was the target feature, thus an invisible circle was automatically drawn around the center of the pupil in the 120 images, and it was used as a mask to cut out the pupil. Finally, the images' contrast was enhanced as shown in Fig. 4.

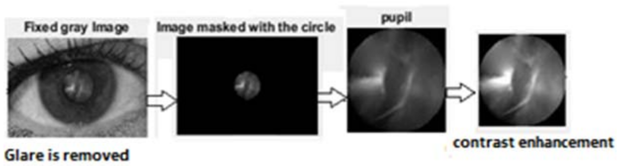


Fig. 4 Extracting the pupil

The second phase of the feature extraction process involved feeding the pupil images into wavelet transform combined with Log Gabor filters to obtain the feature vectors. Filters are discussed as follows:

- Gabor Filters**:** Gabor filters are group of wavelets that can be used to extract features from the images at certain orientations and scales. Gabor is consisting of sinusoid amplitude modulated with a Gaussian function. Daugman [14] proved that Gabor wavelets are close to the mammalian cortex cells in some characteristics, as selecting orientation, localizing objects, and spatial frequency. Gabor filters can be designed for number of orientations and scales but the filter cannot expand to cover the whole spectra, therefore, a filter bank consisting of Gabor filters with various scales and rotations is created. However, Gabor filters suffer from over presenting the non-zero DC components such as brightness or low intensity areas in the image, thus the filter bandwidth is limited to lower the dc components as possible, as a result, a larger number of filters is required to cover the image spectrum which increases the complexity, also the number of features that can be extracted is limited, thus The Log Gabor filter was introduced to solve these problems.
- Log Gabor: Log Gabor filter was suggested by Field [15], who pointed out that natural images are better coded on logarithmic frequency scale such as the log Gabor filter. According to field, logarithmic scales allow capturing more information and features than linear scale that the original Gabor has. The logarithmic scale is more suitable for simulating the measurements of mammalian visual systems more than Gabor. In addition to that, the Log Gabor filter always has no DC component [16]. Therefore, the background brightness will not affect the extraction of the pure information of the image also it enhances the contrast [17], as a result, no need to limit the bandwidth which lowers the needed numbers of filters, allowing more features to be captured and decreases the computationally load by one half compared with Gabor [18]. The log Gabor filter is constructed first in frequency domain by using a low pass filter as a Gaussian filter [19]. The band-pass filter is then constructed, which is the log-Gabor filter (lg) and (m) scales [19]. The combination of these functions is a 2D filter (L2Dg) in (1) [19].

$$L2Dg(\omega, \omega_m, \theta, \theta_l) = g(\theta, \theta_l) \times \lg(\omega, \omega_m). \qquad (1)$$

where (g) is the guassian filter, Θ is the orientation, Θ_L is the angle of the orientation, and (lg) is the log Gabor, where ω is the scale, and ω_m is the frequency at m scale [19]. To reach a spatial domain, the inverse of Fourier transform of the filter is calculated in (2) [19].

$$S(m)_{x,y} = \Im^{-1}\left(L2DG(\omega, \omega_m, \theta, \theta_l)\right)_{x,y} * P_{x,y} \qquad (2)$$

where S is the spatial domain at m scale and $\Im^{-1}$ is the inverse of Fourier transform, and P is the image. Log Gabor has been widely used in many applications such as iris recognition [20], feature extraction for disease detection and classification [17], face recognition [21], facial expressions recognition [22] and fingerprint recognition [23]. In this paper, 5 scales and 6 orientations were used, The sigma which is the standard deviation of the Gaussian was 0.55, The Ratio of angle of the orientations (thetaonsigma) was 1.2, the minimum wave length of the smallest scale's filter was set to 3, Then The mean amplitude and mean of squared Energy of Gabor's filters' responses matrices were calculated to form the first part of the feature vector.

- Discrete Wavelet Transform**:** Wavelet Transform describes the image in both the spatial and frequency domain [24]. It is a multi-resolution algorithm in which the image can be analyzed at different scales, also the image can be analyzed at three orientations which are horizontal, vertical, and diagonal. Wavelet transform passes the pixel values of an image through a low pass filter and a high pass filter. For a two dimensional signal as an image; the image is filtered in both the horizontal and vertical directions using high pass filter (HP) and low pass filter (LP) to produce the LL, HL, LH and the HH frequency bands for every decomposition level, for the first level of decomposition, LL1 represents the horizontal and vertical low frequency components of the image which are the approximation coefficients (A), HH1 represents the horizontal and vertical high frequency components of the image which are the diagonal features (D), LH1 represents the horizontal low and vertical high frequency components which are the vertical features (V), HL1 represents the horizontal high and vertical low frequency components which are the horizontal features (H) . Then the filter is down sampled by 2 by deleting every second coefficient. The approximation features of the image (LL1) gives a high representation of the low frequency components of image that is equal to the performance of HH1+LH1+Hl1 [25]. The first decomposing level's approximation features were taken after applying Daubechies-4 (db4) as the wavelet transfer function, then the standard deviation and mean of the approximation features were calculated to construct the second part of the feature vector. The combination of both wavelet transform and Log Gabor gave strength to the classification system, since Log Gabor filters gives the best orientations which can be in any angle from 360 degrees in high resolution and different scales ,also it has immunity against illumination effects and noise and it extracts high frequency features accurately better than other feature extraction methods [21], [26] besides the great ability of wavelet transform to extract the low frequency features at different scales better than any other filter. This constructed the most fitting feature extraction method for our purpose.

VII. Classification

SVM and ANN were used for classification in this research. SVM is a supervised machine learning algorithm. It is able to give effective results with small training samples, its learning output is robust and prediction accuracy is high. It successfully overcomes any training error [27]. SVM with a polynomial kernel function of order one was used and achieved the best result when compared with other kernel functions. A polynomial kernel detects the similarity of training samples in a feature space over polynomials of the original variables, allowing learning of non-linear models. A polynomial kernel is described in (3) [28], [29].

$$\mathrm{K}(\mathcal{X},\mathcal{X}') = (\mathcal{X}.\mathcal{X}'+1). \tag{3}$$

Using SVM, with a dataset of 120 eye images, 78 images were used for training, and 42 images were used for testing. The multiclass SVM was implemented using MATLAB [30]. ANN was also applied on the same 120 dataset eye images to compare its results with SVM's results; ANN is a supervised learning algorithm. It consists of layers which includes number of connected nodes with an activation function. Data inputs needed to be classified are fed to the network through an input layer, which passes them to one or more 'hidden layers' where they will be processed by weighted connections. The outputs are sent to the output layer through the hidden layers [31]. ANN has advantages as it can perform nonlinear tasks, if an element of the neural network failed, it can continue working. It can be implemented in any application. The ANNs can be designed to fit almost any type of data or problems [32], [33]. ANN used 70 neurons in hidden layer, and a dataset of 120 eye images, where 78 images were used for training and 42 images were used for testing.

VIII. Results and Discussion

The proposed model was built to be able to classify and grade pupils' images cataracts, also showing the classification results for each image solely. The classification system classifies each image into normal, early stage and advanced stage, in which normal describes a totally black pupil, early stage indicates early cataract in which a small cloudy area appears in the pupil, and finally the advanced stage is when the cloudy area covers almost or fully the whole pupil. Samples of the proposed model results are shown in Fig. 5, where Fig. 5 (a) showed a pupil that had no cataract and a Dialog box that explained its classification result, which was "normal case". Fig. 5 (b) demonstrated a pupil that had a small cloudy area and a dialogue box mentioned its classification which was an "Early Stage" cataract and Fig. 5 (c) showed a pupil that was fully covered with witness which indicated "Advanced stage" cataract as mentioned in the dialogue box.

For 120 dataset images using SVM classifier results obtained of success rate 96.89%., compared to ANN classifier that was used for the same dataset images to give results of success rate 92.3% as shown in Table I.

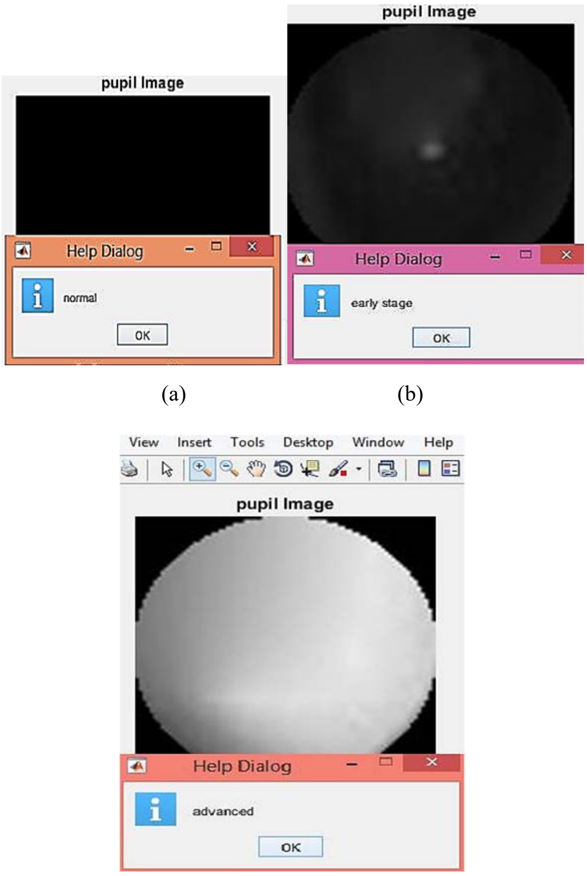
TABLE I
OUTPUT RESULTS OF THE PROPOSED MODEL

Feature extraction techniques	Classifiers	Success rate
DWT + Log Gabor	SVM	96.8%
DWT + Log Gabor	ANN	92.3%

This proposed model achieved a high successful classification rate using SVM when compared with previous research works as explained in Table I, due to the feature extraction method that proved its high potentials and the advantages of SVM. Wavelets combined with Gabor or Log Gabor was used as feature extraction method in texture analysis and in content based image retrieval systems with different classification systems for its well-known high accuracy in detecting features such as in [34] it achieved close to 99% accuracy in texture analysis and classification, and in [35] it achieved close to 98% and 100% correct classification percentage , In this paper the Log Gabor which is an enhanced version of Gabor as previously explained was used with Daubechies wavelets as feature extraction method for the first time for classifying cataracts. Table II shows a comparison between the proposed paper model's results with the previous related works.

TABLE II
COMPARISON BETWEEN THE RESULTS OF THE PROPOSED MODEL AND OTHER RELATED WORKS

Paper	Feature Extraction method	Classifier	Categories	Success rate
Detection, Categorization and Assessment of Eye Cataracts Using Digital Image Processing [10]	-Extract pupils -Compare the gray intensity of healthy eyes with cataracts eyes -Remove noise -Converting image to black and white -Edge detection and cataract circularity measurement were calculated. -Cataract severity was then calculated	Image Circularity measurement is compared with the circularity threshold of the ideal NC or CC binary shape. NC: nuclear cataract Cc: cortical cataract	Nuclear cataract (NC) Cortical cataract (CC)	NC: 94.96% CC: 95.14%
Performing High Accuracy of The System for Cataract Detection Using Statistical Texture Analysis and K-Nearest Neighbor [13]	Gray Level Co-occurrence Matrix (GLCM)	K-Nearest Neighbor	Cataract Normal	94.5%
The proposed model	Log Gabor combined with DWT	SVM ANN	Normal Early stage Advanced stage	SVM: 96.8% ANN: 92.3%



(c)

Fig. 5 Samples of the proposed system results: (a) Normal pupil, (b) Early stage cataract, (c) Advanced stage cataract

IX. CONCLUSION AND FUTURE WORK

In this paper, a model for detecting, classifying and grading cataracts using Daubechies Wavelets with Log Gabor as a feature extraction algorithm was proposed. SVM and ANN were used as classifiers. Dataset of 120 eye images were preprocessed to detect only the pupils, then the pupil images were sent to the DWT and Log Gabor to obtain the feature vectors where the feature vectors were fed to SVM and ANN to classify the images into Normal, Early or Advanced stage of cataract. The results obtained were 96.8% success rate using SVM and 92.3% using ANN. This high success rate (96.8%) was obtained due to the strength of Log Gabor and wavelets in detecting features as previously explained and the use of SVM that can process small training samples and datasets effectively. ANN classifier results were 92.3% which is less than the obtained results of SVM classifier as ANN cannot process small or moderate training samples effectively as SVM, but it needs large datasets. Also, it causes high complexity with small datasets. This proposed model was built to ease the process of detecting, classifying and grading cataracts for both ophthalmologists and patients in villages that lack well prepared clinics or for patients who cannot move easily to the clinics for any reason. For future work, this model can be further investigated and tested with larger dataset of images to check the classifiers' and the feature extraction method's results. It can be developed with Back-End and Front-End development to be used as a mobile application and a web application to be easily accessed where it will be connected with ophthalmology clinics around the city, with the ability of live video conversations between the patient and an ophthalmologist to save time and money.

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