Abstract—The purpose of this paper is to extract features from retina digital images based on a further analysis of high frequency components (HH) obtained with the discrete wavelet transform (DWT). In particular, the DWT is applied to the retina photograph to obtain its high-high (HH) image subband. Then, a further decomposition by DWT is applied to the HH image subband of the previous step to obtain HH\(^{*}\). Finally, statistical features are computed from HH\(^{*}\). The support vector machines (SVM) are employed to classify normal versus abnormal images using leave-one-out cross-validation method (LOOM). The simulation results show strong evidence of the effectiveness of features extracted from HH\(^{*}\) than features extracted from HH. Thus, they are in accordance with our previous work where our approach was applied to mammograms. In summary, our methodology based on a further analysis of high frequency images using DWT helps extracting suitable features for automatic classification of normal and abnormal retina digital images.

Index Terms—retina digital image, discrete wavelet transform, high frequency subband, features extraction, support vector machines, classification

I. INTRODUCTION

Medical image analysis plays an important role in eye disease identification in the field of ophthalmology. Indeed, the automatic analysis of medical images has received a large scientific attention with the purpose of providing computational and intelligent tools to assist quantification of pathologies in the texture of digitized medical images. In order to extract features from retina digital images, different techniques have been employed; including co-occurrence matrices [1][2], Gabor filter banks [3][4], Fourier transform [4][5], and morphological measures [5]. However, the discrete wavelet transform (DWT) is the most commonly adopted approach to process retina digital images for features extraction [6]-[10]. The DWT [11][12] is a multi-resolution analysis of a signal that has the advantage of great ability to identify and extract signal details at several resolutions. For instance, the two dimensional DWT hierarchically decomposes a digital image into a series of successively lower resolution images and their associated detail images: the approximation subband (LL), the horizontal detail subband (LH), the vertical detail subband (HL), and the diagonal detail subband (HH). The LL, LH, HL, and HH subband are respectively low frequencies for both directions, low frequencies for the horizontal direction and high frequencies for the vertical direction, high frequencies for the horizontal direction and low frequencies for the vertical direction, and high frequencies for both directions. Then, the obtained approximation images (LL) are decomposed again to obtain second-level detail and approximation images.

In the previous studies [6][7][9][10], retina features were extracted from LL, LH, HL, and HH subband, whilst only high frequency subbands were considered for features extraction in [8] and low frequency subband (LL) was excluded because, according to the authors, the information at lower frequencies is not adapted to detect microaneurysms (MA) in retina. The role of high frequency; namely HH subband; features at characterizing changes in the biological tissue was also stated in [13]-[16].

The purpose of this paper is to perform an analysis of high frequency components of the HH subbands to extract valuable features from retina digital images. In particular, the DWT is applied to retina photograph and its high-high (HH) image is obtained. Then, a second DWT is applied to the HH image obtained in the previous step. The purpose of applying a second DWT uniquely to HH image is to accurately capture high frequency information from high frequency image. This approach has already proven its effectiveness in the problem of mammograms analysis and classification [16]. In this paper, the suggested approach in [16] will be applied to detect normal versus abnormal retina digital images.

The remaining of the paper is organized as follows: Section 2 presents the methodology. The results are presented in Section 3. Finally, we conclude in Section 4.

II. METHODOLOGY

As shown in Fig. 1, our methodology consists of applying second level decomposition DWT to retina digital image to obtain HH2 subband image, and applying a second DWT to the latter to obtain HH2\(^{*}\) from which statistical features are extracted. Then, classification is performed and our system performance is evaluated. The following subsections describe each step.
A. Wavelet Transform

The continuous wavelet transform of a one dimension signal $x(n)$, square-integrable function, is defined as follows:

$$W_{\psi}(a,b)=\int_{-\infty}^{\infty}x(n)\psi_{a,b}(n)dn$$  \hspace{1cm} (1)

where,

$$\psi_{a,b}(n)=\frac{1}{\sqrt{a}}\psi\left(\frac{n-a}{b}\right)$$  \hspace{1cm} (2)

The wavelet $\psi(t)$ is a real-valued mother wavelet, and $a$ and $b$ are respectively the dilation factor and the translation parameter.

For a given image, the discrete wavelet transform is applied following a process of subband decomposition that can be performed using low $-G(n)$- and high $-H(n)$-pass wavelet filters respectively (see Fig. 2) given by:

$$x_{low}(n)=\sum_{k=-\infty}^{\infty}x[k]G[2n-k]$$  \hspace{1cm} (3)

$$x_{high}(n)=\sum_{k=-\infty}^{\infty}x[k]H[2n-k]$$  \hspace{1cm} (4)

The two-dimensional (2-D) DWT is performed by consecutively applying a one dimension (1D) wavelet transform on rows and columns of the two dimension (2D) data. The 2-D WT, which is a separable filter bank in row and column directions, decomposes an image into four sub-images namely the LH, HL, and HH subband. In other words, a series of successively lower resolution images and their associated detail images are obtained: LL, LH, HL, and HH as shown in Fig. 2 where $\downarrow 2$ denotes the downsampling operation by a factor of 2 [17][18].

The LL subband can be regarded as the approximation component or the background of the image, while the LH (horizontal high frequencies), HL (vertical high frequencies), HH (high frequencies in both directions) subband can be regarded as the detailed components of the image. Then, the obtained approximation images (LL) are decomposed again to obtain second-level detail and approximation images.

In this paper, we rely on high frequency components to extract features from retina digital images as they are adequate to characterize biological tissue images [8][13]-[16]. Thus, the DWT is applied to the image to obtain its HH subband as shown in Fig. 2. Then, a second DWT is applied to the latter to obtain HH* as presented in Fig. 1 from which the statistical features will be computed. In this study, the mother wavelet used is the Daubechies wavelet of order 4 (DB4) at two-level decomposition shown in Fig.4. For comparison purpose, Fig. 5 exhibits the standard Daubechies wavelet of order two (DB2).

Note that; in contrary to DB2; the DB4 is near symmetric and smooth. This makes it suitable in biomedical image and signal processing. Indeed, various types of wavelets which can be used such as the Haar wavelet, Mexican Hat, Morlet wavelet, and Daubechies wavelet. However, the Mexican Hat and the Morlet wavelet are expensive to calculate; and the Haar wavelet is discontinuous; thus it is not suitable to approximate continuous signals. Besides, the popular Daubechies wavelet is a compactly supported orthonormal wavelet which is widely used in biomedical image processing [6]-[10][15][16].

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image1.png}
\caption{Flowchart of the proposed DWT-DWT approach.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image2.png}
\caption{Two-level DWT decomposition.}
\end{figure}
including skewness, smoothness, uniformity, and entropy. They are defined as follows [19]:

\[
\text{Skewness} = \frac{1}{L\delta^2} \sum_{i=0}^{L-1} (z_i - m)^3 p(z_i)
\]

(5)

\[
\text{Smoothness} = 1 - \frac{1}{1 + \delta^2}
\]

(6)

\[
\text{Uniformity} = \sum_{i=0}^{L-1} p^2(z_i)
\]

(7)

\[
\text{Entropy} = -\sum_{i=0}^{L-1} p(z_i) \log(p(z_i))
\]

(8)

where \(z\) is a random variable indicating intensity, \(p\) is the probability density of the \(i\)th pixel in the histogram, \(L\) is the total number of intensity levels, and \(\delta\) is the variance of pixels.

D. Support Vector Machines

In order to classify normal versus pathological retina images, support vector machines [20] are employed as the main classifier because of their scalability and ability to avoid local minima, and also because of their high classification performance shown in biomedical image recognition [10][15][16]. The discriminant function of the non-linear SVM for a binary classification problem is given by:

\[
g(x) = \text{sign} \left( \sum_{i=1}^{S} \alpha_i y_i K(x_i, x) + b \right)
\]

(9)

where \(x_i\) is the training data that belong to either \(+1, -1\), \(S\) is the training data size, \(\alpha\) are Lagrange multipliers subject to \(0 < \alpha < c\), \(b\) is a bias weight, \(K(\cdot)\) is the kernel function and \(c\) is a parameter that influences the tolerance to misclassifications. In this study, a polynomial kernel is used for the SVM since it is a global kernel, thus allowing data points that are far away from each other to have an influence on the kernel values as well. The polynomial kernel is given by:

\[
K(x, x_i) = ((x \cdot x_i + 1)^d)
\]

(10)

where the kernel parameter \(d\) is the degree of the polynomial to be used. For simplicity, it is set to 2 in this study.

Finally, the performance of the non-linear SVM is evaluated by computing the correct classification rate given by:

\[
\text{classification rate} = \frac{\text{classified samples}}{\text{total number of samples}}
\]

(11)

B. Features Extraction

As shown in Fig.1, in order to extract better features from HH subband, a three-step process is followed. First, the DWT is applied to retina photograph and its high-high (HH) image is obtained. Second, a second DWT is applied to the HH image of the previous step to obtain HH* (see Fig.3). Finally, four statistical features are extracted from the high frequency subband HH*;
III. DATA AND RESULTS

A set of 93 color retina images from STARE database [21] were employed to test our DWT-DWT processing approach. The dataset includes 23 normal images, 20 images with drusens, 24 with microaneurysms (MA), and 26 with exudates. Selected examples of the dataset are shown in Fig. 5. A normal image in double color format and its mesh representation are shown in Fig.6. The mesh of each DWT subband (LL, LH, HL, HH) is presented in Fig.7. Note that a mesh draws a surface representation of the image where each color is proportional to surface height. The SVM were trained and test based on their ability to classify normal retina image and abnormal one. In other words, it is a one against one classification problem. The performance of the SVM was measured using the correct classification rate which is defined as the ratio of correctly classified samples over total classified samples as defined in Equation (11). In order, to enhance the generalization capability of the proposed approach, the leave-one-out method (LOOM) is adopted. The description of the LOOM follows. First, the data is partitioned into $k$ equally (or nearly equally) sized folds, where $k$ is equals the number of instances in the data. Second, $k$ iterations of training and validation are performed such that in each iteration nearly all the data are used for training except for a single observation for which the model is tested. This type of cross-validation method is suitable when the number of available observations is small. Following the LOOM, both the average and standard deviation of the correct classification rate are computed to assess the effectiveness of our DWT-DWT approach.

The simulation results show evidence of the effectiveness of our DWT-DWT methodology. For instance, in the case of normal versus microaneurysms classification problem, the obtained correct detection (classification) rate is $0.7086\pm0.0950$ with HH (DWT) based features, and is $0.8030\pm0.1187$ HH* (DWT-DWT approach). In the problem of classification of normal versus images with exudates, the obtained correct detection rate is $0.7807\pm0.1370$ with HH based features, and is $0.8880\pm0.0673$ following the DWT-DWT approach. Finally, the obtained accuracy in the detection of drusen is $0.3416\pm0.1033$ using HH based features, and it is $0.6972\pm0.1127$ using HH* features. In other words, following the suggested DWT-DWT approach the classification rate improves by 9.44%, 10.73%, and 35.56% basis point for microaneurysms, exudates, and drusen respectively.

In sum, the application of the DWT to high frequency images allows improving the accuracy rate; particularly for drusen detection. Indeed, drusen, microaneurysm, and exudates yield to a proliferation of fibrous tissue which causes deterioration in the structure of the cell components in the biological tissue. This deterioration is well represented by high frequency variations in the wavelet domain. In contrary, low frequency variations in the wavelet domain only represent smooth parts of the analyzed image which are not affected by pathologies. Finally, the proposed approach is suitable for features extraction from both retina digital images and mammograms [16].
VII. CONCLUSION

A new methodology for features extraction from retina digital images in the frequency domain is presented. In particular, the discrete wavelet transform (DWT) is applied to retina image to obtain its high-high (HH) subband. Then, a second decomposition by DWT is applied to the HH subband obtained in the previous step to obtain HH*. Finally, statistical features are computed from HH* and support vector machines were employed to classify normal versus abnormal retina digital images. The simulation results from leave-one-out cross-validation technique show the effectiveness of our DWT-DWT methodology in comparison with features extracted from HH subband alone. This finding suggests that multiresolution analysis of retina high frequency components help characterizing its biological tissue. This result is similar to our previous work where we applied the presented DWT-DWT methodology to mammograms. For future work, the suggested methodology will be applied to cerebral images. Also, the accuracy of features extracted from horizontal and vertical high frequency subbands will be examined. Finally, different decomposition levels will be investigated.

REFERENCES


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