An Affordable EOG-based Application for Eye Dystonia Evaluation

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***Abstract*—This paper evaluates the risk of ocular dystonia—a condition marked by excessive blinking—using electrooculography. A commercial bioamplifier is employed to capture the electrical activity of the eyes using dispensed surface electrodes. The continuous wavelet transform of the electrooculogram was estimated to identify the features related to involuntary eye-blinking behavior and make the classification. The signal processing is integrated into a novel application with a simple graphical user interface oriented to be used by physicians. The performance is evaluated using multiple evaluation measures. Results show that the proposed method succeeded in identifying an abnormal frequency of blinks with respective accuracy, precision, sensitivity, and specificity scores of 98.46%, 96.51%, 99.13%, and 96.41%.**

Keywords—blinking, continuous wavelet transform (CWT), diagnosis, eye dystonia, graphical user interface (GUI)

I. INTRODUCTION

Blepharospasm, most known as eye dystonia, is a neural disorder characterized by excessively involuntary closing of the eyelids [1]. This disease belongs to the family of focal dystonia, which causes involuntary muscles to contract parts of the body. It starts as twitching and can progress to not being able to open the eyes. Botulinum toxin injections into the eyelid protractor muscles could help patients get relief. Around 2,000 people in the United States alone are diagnosed with eye dystonia each year [2].

Blinks are easy to measure and process. Many techniques can be used to record the frequency of blinks such as the dual-Purkinje-image method, search coils, video oculography, infrared oculography, and electrooculography (EOG) [3]. EOG is the simplest technique, which uses surface electrodes around the eye socket to measure the corneal and retinal potential, as well as eye blinks. Neuropathological information is provided by EOG, which is widely used by clinicians and scientists [4]. Human–computer interfaces can also be controlled using EOG without speech or hand operations [5]. This technique allows for predicting the presence of eye dystonia disease cost-effectively and simply by identifying an abnormal frequency of blinks in the electrooculogram. Fig. 1 shows the four typical features obtained by measuring the vertical derivation of the eye potential. In saccadic movements, both eyes move simultaneously and voluntarily. A saccade's peak angular velocity and response delay are around 900°/s and 200 ms, respectively. In fixation, the gaze is focused on a specific location. During this time, micromovements of involuntary

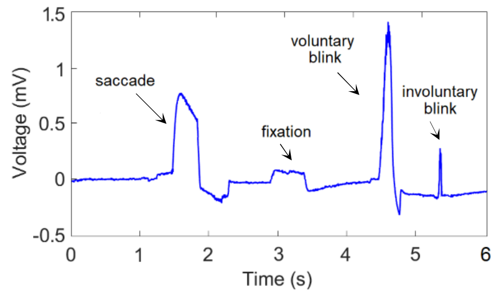

Fig. 1. An EOG signal in which saccades, fixations, and blinks (voluntary and involuntary) are distinguished.

nature (drifts and flicks), can be observed at amplitudes below 1°. Drifts are slower eye movements (0.1°/s), whereas flicks are faster. In intervals of about 20 to 30 ms, the flicks can reach an amplitude of 1° of visual angle. Involuntary blinks are the object of study in this work and can be easily distinguished from voluntary blinks and saccades [6]–[11].

As far as the authors are aware, only one previous work addressed the diagnosis of ocular dystonia based on the identification of the frequency of involuntary eyeblinks in electrooculograms. In that study, auto-regressive (AR) and power spectral density (PSD) parameters of the electrooculogram were computed to then carry out a classification of the involuntary eyeblinks based on a kernelized radial basis function (RBF), a support vector machine (SVM), and a feed-forward neural network classifier [12]. In contrast, in our study only three electrodes and a commercial bioamplifier are used to record the electrooculogram. The identification of involuntary eyeblink features is made employing only the continuous wavelet transform (CWT). Then, involuntary blinks are counted, and if it is found to be an abnormal rate, the person would be diagnosed as having ocular dystonia and referred to a neurologist for further examination. All this signal processing is integrated into a novel software application that includes a graphical user interface (GUI) geared toward clinical assessment of eye dystonia.

The remainder of the paper is organized as follows. The second section reviews the methodology for collecting EOGs, extracting features, and classifying blinks. Section III describes the proposed software application to evaluate the risk of eye dystonia. The experimental results are covered and discussed in Sections IV and V, respectively. Finally, in Section VI conclusions are drawn.

II. Materials and Methods

Fig. 2 describes the three stages of the method proposed to assess the risk of eye dystonia in a subject: signal acquisition, processing, and application. The first stage is carried out using a commercial device; the other two are carried out using a novel software application.

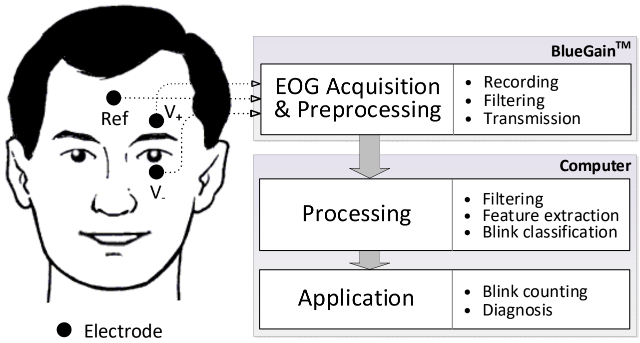

Fig. 2. A block diagram illustrating the proposed methodology.

A. Electrooculogram

According to EOG foundations, the eyeball can be modeled as an electrical dipole where the retina and cornea represent the positive and negative poles, respectively. Whenever an eye movement occurs, a differential potential appears that is dependent on the angle of rotation and its amplitude. The bandwidth of the electrooculogram typically ranges from 1 Hz to 50 Hz. Most useful information, however, does not exceed 38 Hz [13].

Involuntary eyeblinks are easily distinguished on the electrooculogram from saccades and voluntary eyeblinks. Unlike saccades, both kinds of eyeblinks contain two large peaks in a short sequence: a positive maximum and a negative minimum related to eyelid opening and closing. The interval between these peaks is shorter than the interval between two successive rapid saccades performed in the opposite direction. It is because saccades usually have a short fixation period between them, as can be seen in Fig. 1. Therefore, a maximum threshold can be applied to this time difference to detect blinks [14]. The time between the peaks is also shorter in involuntary eyeblinks than in voluntary eyeblinks. The amplitude of saccades is greater than involuntary eyeblinks. An eyeball movement ranges between 0.05 and 3.5 mV with a duration of around 80 ms. Both the amplitude and the duration of the pulse produced by upward or rightward eye movement are nearly the same as those produced by downward or leftward eye movement. Voluntary eyeblinks have 10 to 20 times the amplitude of mutual involuntary eyeblinks, even higher than saccades. An average voluntary eyeblink lasts 100 to 400 ms (instead of less than 100 ms for involuntary ones) [15].

B. Data Acquisition

The electrooculogram was recorded by placing three surface electrodes on the face and connecting them to a commercial bioamplifier [16]. The differential potential resulting from blinking was recorded by two electrodes above and below the left eye. A third electrode placed on the subject's forehead served as a reference potential for reducing the common-mode voltage. Unlike another study [12], in this study only three electrodes were used. Ag/AgCl disposable surface electrodes connected to the lead by a self-adhesive pad embedded with a conducting gel were used. A 16-Bit analog-to-digital converter digitizes the signal from the electrodes at a rate of 1 kHz, and the signal is transmitted to a computer using Bluetooth protocol.

C. Blink Feature Detection and Classification

To suppress unwanted data, MATLAB's signal processing toolbox implemented a high-pass filter with a cutoff frequency of 0.1 Hz followed by a low-pass Butterworth filter of 30 Hz. The three primary sources of interference to be removed are the electrical coupling between the powerline and the patient, the charging effect due to the electrode–skin interface impedance, and the electromyographic biopotential [17].

Once the electrooculogram is filtered, the method proceeds to detect the involuntary eye-blinking pattern in the electrooculogram. Fig. 3 illustrates the overall methodology, which begins with the normalization of the signal with mean 0 and standard deviation 1. The CWT mathematically represented in (1) can be expressed as an integral over the entire time interval t of a signal $x(t)$ multiplied by the scale of a shifted version of the mother wavelet function $\Psi(t)$ defined in (2). The CWT returns coefficients that depend on the variables a and b of $\Psi(t)$. Variable a (scale) controls the bandwidth, and variable b (translation) gives the location in the time domain. Therefore, the mother wavelet function must best approximate the involuntary eyeblink in a morphological sense to identify it.

$$CWT\ (a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t) \Psi \left(\frac{t-b}{a} \right) dt \qquad (1)$$

$$\Psi_{a,b}(t) = \frac{1}{\sqrt{a}} \Psi \left(\frac{t-b}{a} \right) \qquad (a,b)\ \epsilon\ R,\ \ a \neq 0 \qquad (2)$$

Sym8, bior1.5, and coif3 are the wavelet functions that have been reported in the literature as the most suitable for identifying blinks [18]–[20]. These wavelets, shown in Fig. 4, are compared to attain the best one that closely resembles the involuntary eyeblink shape. The dimensions of the coefficient matrix $CWT(a,b)$ obtained with them depend on the number of electrooculogram samples to be analyzed and the number of scales to be decomposed by the CWT. The number of samples in the analysis window is 600,000 (10

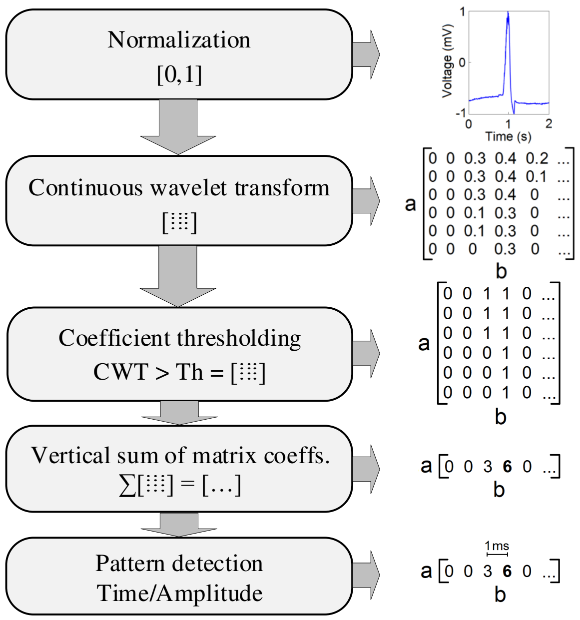

Fig. 3. Overall scheme of the detection of involuntary eyeblinking in the electrooculogram using continuous wavelet transform.

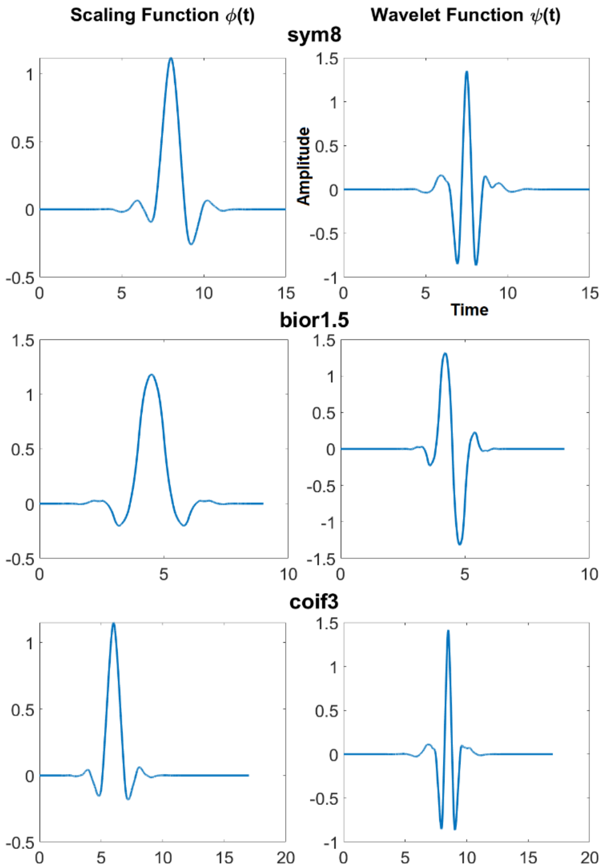

Fig. 4. Scaling and mother wavelet functions for (a) sym8, (b) bior1.5, and (c) coif3. These functions are responsible for analyzing the general and detailed behavior, respectively, of a signal in the transformation process.

minutes at a sampling frequency of 1 kHz) with 6 decomposition levels, which implies obtaining a coefficient matrix of 6 × 600,000 elements. Next, the thresholding of the CWT coefficients defined in (3) is applied to identify the involuntary blinks in the electrooculogram, where the threshold value ($\text{Threshold}_{\text{fixed}}$) is calculated using Otsu's method [21]. This also allows for the binarization of the wavelet coefficient matrix.

$$T\,(a,b) = \begin{cases} 0 & \text{if } CWT(a,b) < \text{Threshold}_{\text{fixed}} \\ 1 & \text{otherwise} \end{cases} \qquad (3)$$

Then, the number of rows in the matrix $T(a,b)$ is reduced to just one. An array of the same length as the original signal was created to store the locations where the threshold was exceeded due to the similarity with the sought pattern. To perform this dimensional reduction, the columns of $T(a,b)$ were added as shown in (4), where n is the number of samples. The indices of where this array is set to "6" were used to determine how far apart blinks are detected. If the indices are less than 500 ms apart, they indicate a single blink; if they are more than 500 ms apart, they indicate separate blinks [19].

$$V(1,2,\ldots,n) = \sum_a T(a,b), \quad b = 1,2,\ldots,n \qquad (4)$$

D. Diagnosis

Features are extracted by recording and processing an interval of 10 minutes. Based on the classification results, eyeblinks made by the subject during this period are counted. While at rest, a healthy person blinks between 12 and 22 times per minute in an environment that is properly conditioned (light and air) [22], [23]. Environmental and physical factors, such as relative humidity, temperature, brightness, cognitive workload, and fatigue, influence this rate [24]. There is a reasonable assumption that people with eye dystonia blink more than 25 times per minute, with a margin of 15%. If the blink count for classification of the 10-min EOG data is greater than 250 (10 × 25 = 250), it is concluded that the person probably suffers from eye dystonia and should be referred to a physician specialized in neuromuscular affections for further evaluation and consequent treatment.

III. Software Application

Fig. 5 shows the GUI developed with MATLAB R2022a software. It is an interface wherein the simplicity of use has prevailed for physicians. The application's executable file installs a shortcut that can be run on any operating system without the need to have the MATLAB program installed. By pressing the Start button, the bioamplifier sends the signal to the computer via Bluetooth, and the electrooculogram is plotted. The BlueGain toolbox includes the following MATLAB functions for connecting the commercial device and getting the data into the software application to be processed according to the methods presented in the previous section:

- BlueGainRequestData requests BlueGain for a packet of data.
- BlueGainRetrieveData retrieves BlueGain data.
- BlueGainResetSampling resets the sampling and clears the buffer of BlueGain.
- crsFindSerialPort returns the serial port of the connected Bluetooth device on the computer.
- crsOpenSerialPort opens the serial port that was previously found by the crsFindSerialPort function.

The signal noise is removed, the involuntary eyeblinks are identified, and the rate of blinks (ROB) is calculated by pressing the Evaluate button. The ROB measures how many involuntary eyeblinks occurred during a test in minute units. Based on (5), this parameter is calculated by dividing the number of unintentional blinks (N) by the period (10 min) of the test.

$$\text{ROB} = \frac{N}{T} \qquad (5)$$

The electrooculogram and the ROB value obtained are displayed on the GUI, as can be seen in Fig. 5. Two possible messages "Risk of Eye Dystonia" or "No Risk of Eye Dystonia" will be indicated in the diagnosis field. By pressing the Save button, the recording is stored in ASCII-formatted files whenever it is necessary to visualize the data again (or to reprocess them). Finally, by pressing the Exit button the application can be closed.

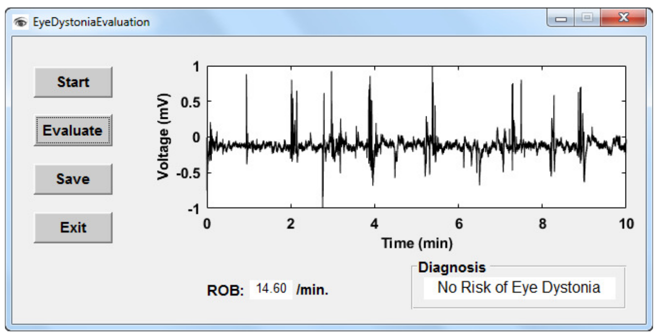

Fig. 5. GUI of the application developed to evaluate the risk of eye dystonia.

IV. EXPERIMENTAL RESULTS

In the first tests, data from a 35-year-old man with no known pathologies was collected. After describing the methodology and objectives, he provided informed written consent to donate the samples for this study approved by the University of Oviedo's institutional review board. Tests were conducted in a well-lit, airy room. The electrodes and subject placements are illustrated in Fig. 2 and Fig. 6, respectively. The subject must stare at a blank wall, without the presence of any type of stimulus that could cause an increase in the number of involuntary eyeblinks.

Fig. 7a shows a section of an EOG signal recorded during a test where several involuntary eyeblinks (small spikes), four saccades, and one voluntary blink can be observed. The methodology of involuntary blink detection illustrated in Fig. 3 is applied to this section. The coefficient matrix of the CWT is plotted in Fig. 7a in a grayscale graph representing scale vs. time (i.e., coefficients "a" vs. "b"), respectively, for the three mother wavelets considered. The color indicates how well the wavelet function agrees with the signal. A color closer to white represents the higher-value components. In Fig. 7a, the vertical white lines represent the detection and location of the searched pattern. The first horizontal band corresponds to the first level of wavelet decomposition (i.e., the high frequency). Therefore, the searched pattern has no high-frequency presence. The red rectangle identifies the level of decomposition from which the pattern is clearly identified. Fig. 7b shows in detail the first involuntary eyeblink of Fig. 7a. As can be seen, the bior1.5 and coif3 wavelet functions identify all events in the EOG signal, whereas the sym8 function mainly identify involuntary blinks. The percentage of energy for the recorded signal in wavelet coefficients shows that the wavelet function sym8 closely resembles the shape of the involuntary eyeblinks and discriminates other events in the electrooculogram shown in Fig. 7a.

The confusion matrix shown in Fig. 8 was constructed from 20 tests to evaluate the accuracy, precision, sensitivity, and specificity performance of the application employing equations (6) to (9). In these equations, TP, TN, FP, and FN represent the number of involuntary blinks classified as true positive, true negative, false positive, and false negative, respectively. The sensitivity specifies the accuracy with which the application can identify an involuntary eyeblink as such, while specificity indicates the accuracy of not categorizing involuntary eyeblinks as such. On average, 98.46% accuracy, 96.51% precision, 99.13% sensitivity, and 96.41% specificity were obtained.

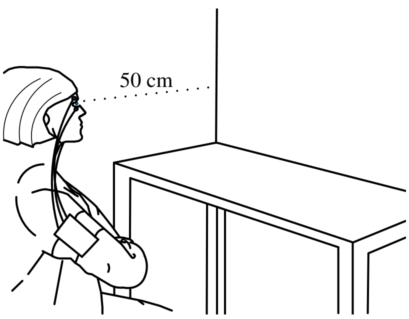

Fig. 6. To minimize interference, the electrode leads should be twisted to test the application software while wearing the device attached to the volunteer's arm. By looking at the confluence of two blank walls, visual stimuli could be avoided easily.

$$\text{Accuracy (\%)} = \frac{\text{TN} + \text{TP}}{\text{TN} + \text{FP} + \text{FN} + \text{TP}} \times 100 \quad (6)$$

$$\text{Precision (\%)} = \frac{\text{TP}}{\text{TP} + \text{FP}} \times 100 \quad (7)$$

$$\text{Sensitivity (\%)} = \frac{\text{TP}}{\text{TP} + \text{FN}} \times 100 \quad (8)$$

$$\text{Specificity (\%)} = \frac{\text{TN}}{\text{TN} + \text{FP}} \times 100 \quad (9)$$

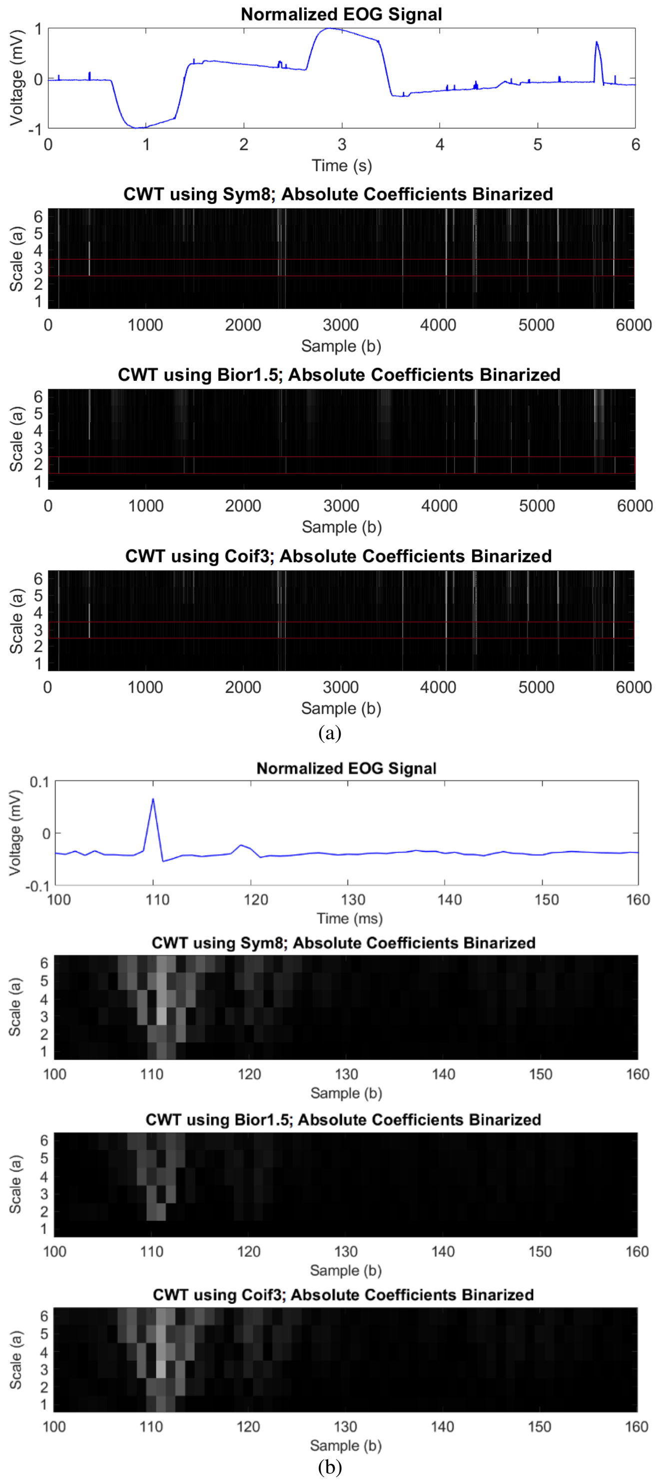

Fig. 7. (a) Section of an EOG signal recorded during a test. (b) Detail of the first involuntary blink; grayscale graphs represent scale vs. time (i.e., coefficients "a" vs. "b"), respectively, for the three mother wavelets considered.

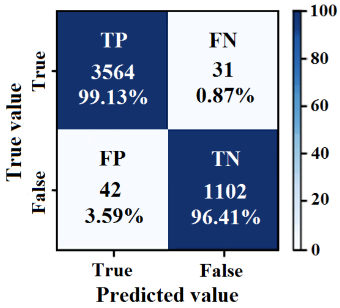

Fig. 8. Confusion matrix constructed from 20 tests to evaluate the application's performance.

V. Discussion

The wavelet-based methods can perform better than nonparametric and parametric approaches in the case of nonstationary signals like the electrooculogram [14]. It is because of the multiresolution time-frequency analysis capability of the wavelets. On other hand, the nonparametric techniques suffer from poor frequency resolution due to the limited number of samples available for a given observation window, and the parametric approaches are less flexible and are typically used for problems of a simpler nature. The use of a wavelet transform shows comparative advantages over other techniques. The main advantage is a multi-resolution analysis that involves comparing multiple versions of the signal at the same time, where each version is band-pass filtered and scaled. As shown in Fig. 1, waveform patterns associated with involuntary eye blinking have many similarities with some families of wavelets. Wavelet transform analysis can use those wavelets based on similarity due to their variant pattern with different scale and translation versions, which is an issue to be resolved during the analysis.

The proposed methodology has been tested with several electrooculograms, proving to be robust in the identification of involuntary eyeblinks and a quick alternative for the preliminary diagnosis of risk of eye dystonia. To find closely spaced eyeblink features, the use of wavelet functions with smaller support is recommended to separate the features of interest. However, the best results were achieved using the sym8 wavelet function. As the speed of each processing stage is very important, a limited number of decomposition levels were established in the CWT calculation. In one study, a maximum accuracy of 95.33% was obtained using a more complex methodology based on RBF-SVM and a feed-forward neural network classifier [12].

This work was conducted on an individual without known pathologies to validate the proposed methodology. Future scopes could include the extension of this methodology to patients with ocular dystonia to assist them in obtaining cost-effective and accurate diagnoses.

VI. Conclusion

In this work, a simple application is proposed to diagnose whether eye dystonia may affect an individual. The methodology lies in the calculation of the continuous wavelet transform of an electrooculogram of an individual. The sym8 wavelet function with 6 decomposition levels, together with setting thresholds given by the physiology of the ocular system, allows the detection of an abnormal number of involuntary eyeblinks per minute. An average accuracy and precision of 98.46% and 96.51% were obtained with a sensitivity and specificity of 99.13% and 96.41%, respectively.

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