

Temporal and Amplitude Characteristics of ERG Signals in Retinal Degenerative Disorders

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Abstract—Electroretinogram (ERG) signals are critical for diagnosing various retinal diseases. This study aims to identify abnormalities in ERG signals by analyzing the amplitudes and time implicits of a-wave and b-wave components. The ERG signals were obtained from the OculusGraphy: Pediatric and Adults Electroretinograms Database, which includes maximum response, flicker response, photopic response, and scotopic response. A logistic regression model is employed to classify the signals. We extracted features from ERG signals, including the amplitudes of a-wave and b-wave, and the time implicits of these waves. These features were then used as input to the logistic regression classifier. The model's performance was evaluated using accuracy, sensitivity, and specificity metrics. Our results indicate that the logistic regression classifier effectively identifies abnormalities in ERG signals, demonstrating its potential as a diagnostic tool for retinal conditions. Further research may involve expanding the dataset and incorporating additional features to improve classification accuracy.

Index Terms — electroretinogram, retinal disease, logistic regression, bio markers.

I. INTRODUCTION

Electroretinography (ERG) is a pivotal diagnostic tool in ophthalmology, providing critical insights into retinal functionality. By measuring the electrical responses of the retina to light stimuli, ERG allows for the assessment of both photopic (light-adapted) and scotopic (dark-adapted) conditions. These measurements are essential for diagnosing a range of retinal disorders, from inherited diseases to those resulting from systemic conditions. Abnormalities in ERG signals can indicate significant retinal dysfunction, making early detection and accurate classification crucial for effective patient management. In this study, we leveraged the comprehensive IEEE Oculusgraph: Ophthalmic Electrophysiological Signals Database, which comprises 1,974 electroretinogram signals recorded under standard clinical conditions. Our methodology involved a detailed analysis of ERG signals to differentiate between normal and abnormal retinal function. We focused on extracting key features, specifically the maximum and minimum amplitudes of the responses, to serve as inputs for a linear regression model. The results of our analysis demonstrated the model's robust predictive capabilities in classifying retinal conditions, with performance metrics evaluated using R^2 and mean squared error (MSE) demonstrating significant accuracy. This highlights the efficacy of using ERG signal features for assessing retinal health and underscores the potential for further refinement of the model. By exploring additional features and enhancing the predictive framework, we aim to advance diagnostic accuracy and facilitate earlier intervention for patients with retinal abnormalities. Ultimately, this study contributes to the ongoing efforts to improve clinical practices in retinal diagnostics, paving the way for more effective treatment strategies.

II. LITERATURE REVIEW

Advanced time-frequency methods for recognizing ECG waves focus on the application of novel algorithms to improve accuracy and efficiency in ECG signal analysis. The study evaluates various time-frequency distributions and their effectiveness in ECG signal interpretation, providing a comprehensive analysis of their performance[1]. This comparative study of various time-frequency transformation methods for ECG signal classification highlights the strengths and weaknesses of each method to determine the most effective approach. The research includes a detailed analysis of different transformation techniques and their impact on ECG signal classification accuracy[2].

Recent trends in ECG signal feature extraction methods and their applications provide insights into the advancements and challenges in the field. The authors discuss various feature extraction techniques and their relevance to different ECG analysis applications, including arrhythmia detection and risk assessment.[3] This paper presents a comparative analysis of various ECG signal processing methods in the time-frequency domain, evaluating their performance in different scenarios. The study assesses the effectiveness of different methods in accurately analysing ECG signals and highlights the most promising approaches for clinical applications.[4] This paper explores the use of wavelet transform for time-frequency analysis of ECG signals, demonstrating its effectiveness in extracting meaningful features from ECG data. The research highlights the advantages of wavelet transform over traditional methods and its potential for improving ECG signal analysis.[5]

A transform-based feature extraction approach for motor imagery tasks classification leverages advanced signal processing techniques to enhance the accuracy and efficiency of classifying motor imagery tasks. Experimental results demonstrate the superiority of the proposed approach over traditional methods, highlighting its potential for applications in brain-computer interface systems.

This method shows promising improvements in detection rates and reduces computational complexity, making it a viable option for real-time applications.[6] Deep convolutional neural networks (CNN) and bidirectional long short-term memory (BiLSTM) networks are explored for ECG signal classification. This study demonstrates how these deep learning techniques can improve the accuracy and efficiency of ECG signal classification, making them suitable for real-time applications.[7] The study investigates the use of Fourier analysis for decomposing ECG signals into their component waveforms, such as the QRS-complex and T- wave. The research compares the performance of the l1 and l2 Fourier transforms, demonstrating the significant improvements in the separation of ECG signal components using the Fourier transform. [8] The systematic review provides an exhaustive overview of the latest research literature on deep-learning methods for the analysis of biomedical signals, including ECG and EMG. The review highlights the advancements and challenges in applying deep learning to biomedical signal analysis, summarizing key findings and future directions.

[9] A collection of original articles, opinions, and review papers in the field of ECG signal processing and characterization. The special issue covers a wide range of topics, including feature extraction, classification, and the application of advanced signal processing techniques to ECG data.[10] Power spectral density estimation is utilized for the frequency domain analysis of ECG signals. This approach allows for the identification of dominant frequencies within the ECG signal, providing insights into various cardiac conditions and enabling more accurate diagnoses.[11] Various time-frequency distributions for ECG signal analysis are evaluated, aiming to determine the best TFD for comprehensive interpretation of ECG signals. Different TFD techniques are compared in terms of their ability to accurately represent ECG signals, with the goal of improving diagnostic capabilities.

[12] An automated denoising technique based on time-frequency filtering using the S-transform is proposed to improve the quality of ECG signals for better analysis. The study demonstrates how this technique can effectively reduce noise while preserving important signal characteristics, enhancing ECG signal interpretation.[13] Time-domain and frequency-domain parameters for ECG signals are assessed using HRV analysis and data from the MIT-BIH database.

The study explores the significance of these parameters in the context of ECG signal analysis and their implications for clinical applications.[14] Ramanujan Fourier Transform is explored for time-frequency analysis of ECG signals, demonstrating its effectiveness in detecting cardiac problems. The study shows how this transform can enhance the analysis of ECG signals by providing a more detailed representation of their time-frequency characteristics.

[15] Various ECG signal processing methods in the time-frequency domain are analyzed in this comparative study, evaluating their performance in different scenarios. The study aims to identify the most effective methods for clinical applications, providing insights into their strengths and weaknesses.

III. EXISTING METHOD

The existing method aims to analyze the temporal and amplitude characteristics of ERG signal to enhance understanding of these conditions and improve diagnostic accuracy. By examining ERG waveforms in patients with various retinal degenerative disorders, we seek to identify distinctive patterns and alterations that correlate with disease progression and severity. Temporal characteristics, including the timing of wave components, and amplitude characteristics, reflecting the strength of these responses, are crucial for understanding the impact of these disorders on retinal function. Temporal characteristics such as peak latencies and implicit times, and amplitude characteristics including peak-to-trough values, are analyzed. Advanced signal processing techniques and statistical methods are employed to identify significant differences and patterns. Variations in latency and implicit times are observed across different retinal degenerative disorders. Specific delays in wave components may indicate the type and severity of retinal dysfunction. Significant reductions in amplitude are noted in patients compared to controls. Differences in amplitude profiles between various disorders provide insights into disease-specific retinal involvement. The shape of the massed retinal electrical wave could be analyzed, and if missing one or more of its components, some general conclusions could be made about the health of the retina as a whole. The study highlights the importance of analyzing both temporal and amplitude characteristics of ERG signals in the context of retinal degenerative disorders. Distinctive patterns in these parameters offer valuable diagnostic and prognostic information. By improving our understanding of ERG alterations, we can enhance diagnostic accuracy and tailor treatment strategies to individual patient needs. Temporal and amplitude characteristics of ERG signals serve as critical indicators of retinal function in degenerative disorders. Further research into these characteristics will support the development of more precise diagnostic tools and personalized treatment approaches, ultimately improving patient outcomes.

IV. PROPOSED METHOD

The proposed method covers about the time frequency analysis of ERG signal in addition to the time domain analysis to ensure the accuracy of the time domain analysis. The steps involved Input ERG Database collection from different individuals through experiments and they served as the source of raw data for the subsequent analysis. The next step involves analyzing and measuring the amplitude of the A wave and B wave in the ERG signal which represents the initial negative deflection in the ERG waveform, associated with photoreceptor activity and the subsequent positive deflection, associated with inner retinal activity (primarily from Müller cells). Measured amplitude of these waves helps in understanding the functional status of the retina. Abnormalities in the amplitude can indicate potential retinal dysfunction. STFT is applied on ERG signal and it is used to analyze the signal in both time and frequency domains simultaneously. This can help in identifying any frequency-specific abnormalities or patterns in the ERG signal. The processed data, including the amplitude measurements and STFT results, are fed into a logistic regression model. Logistic regression is a statistical method used for binary classification and classifies the ERG signal as either normal or abnormal based on the input features. The flow diagram below represents the flow of the proposed model.

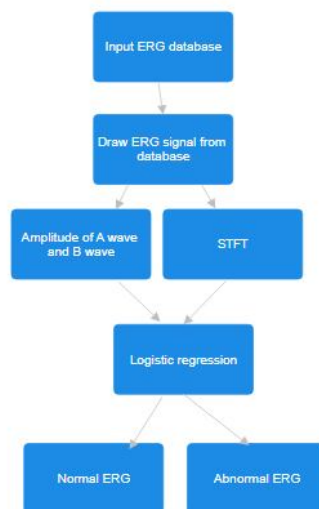


Figure 1: Flowchart for proposed method

Short Time Fourier Transform (STFT) is used to improve the accuracy of the regression. This study explores the application of STFT in ERG signal analysis, aiming to uncover temporal dynamics and frequency-specific changes associated with retinal disorders.

By employing STFT, the resolution of ERG signal components and the diagnostic capabilities was improved for various retinal conditions. ERG signals are analyzed using STFT to obtain time-frequency representations. Key parameters include window size, overlap, and window function selection. The STFT analysis aims to identify specific frequency components and their variations over time. STFT reveals distinct time-frequency patterns in ERG signals that differentiate between healthy controls and patients with retinal disorders. Specific frequency bands and their temporal evolution show altered dynamics in diseased states. Differences in frequency components related to retinal function are observed, with certain frequencies showing significant deviations in patients compared to controls.

V. METHODOLOGY

The methodology evaluates both photopic (light-adapted) and scotopic (dark-adapted) responses to assess the functionality of the retina. ERG signals corresponding to maximum responses, photopic responses, and scotopic responses were analyzed to differentiate between normal and abnormal retinal conditions. The features extracted from the ERG signals, including the maximum and minimum values of the responses, were used as input to a regression model.

The goal was to determine the performance of the model in classifying whether the retinal function is normal or abnormal based on deviations in the signal values. ERG signals were recorded from patients under standard clinical conditions. And for the study database was taken from IEEE Oculusgraphy: Ophthalmic Electrophysiological Signals Database. This database includes 1974 electroretinogram signals. Electrophysiological studies were conducted at the IRTC Eye Microsurgery Ekaterinburg Center. Registration of electroretinogram signals was performed using a computerized electrophysiological workstation EP-1000, manufactured by Tomey GmbH.

Data base URL: <https://ieee-dataport.org/documents/oculusgraphy-ophthalmic-electrophysiological-signals-database>

The signals included responses for:

- Maximum Response: The highest amplitude of the ERG signal under standard testing conditions.
- Photopic Response: The ERG signal obtained under light-adapted conditions.
- Scotopic Response: The ERG signal obtained under dark-adapted conditions.

From the ERG signals, the following features were extracted:

- Maximum Amplitude: The peak value of the ERG signal.
- Minimum Amplitude: The lowest value of the ERG signal.

These features were compared to known standard values for normal patients specified in database. Any significant deviation from these standard values is indicative of an abnormal retinal condition. A regression model was developed to predict the normalcy or abnormality of a patient's retinal function based on the ERG features. The features used in the model were the maximum and minimum values of the ERG signals for maximum response, photopic response, and scotopic response.

The performance of the model was evaluated using two key metrics:

- R-Squared Value (R^2): A statistical measure that represents the proportion of variance for the dependent variable that is explained by the independent variables in the regression model. A higher R^2 value indicates better model performance.

$R^2 = 1 - (\text{Sum Squared Regression} / \text{Total Sum of Squares})$

- Mean Squared Error (MSE): A measure of the average squared difference between the observed and predicted values. Lower MSE values indicate better model accuracy.

$$MSE = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2$$

- The regression model's performance metrics suggest that there is a strong correlation between the maximum and minimum amplitudes of ERG signals and the normalcy of a patient's retinal function. The high R^2 values across all response types (maximum, photopic, and scotopic) indicate that the model explains a significant portion of the variance in the data. The low MSE values further confirm that the predicted values are close to the actual observed values. The analysis and values calculated are given below

TABLE I: EVALUATION OF ERG SIGNAL ANALYSIS USING MEAN SQUARE ERROR AND R-SQUARED METRICS

Response Type	Mean Square Error	R Squared
Maximum Response	0.0263	0.0271
Oscillatory Potentials	0.1323	0.0474
Photopic Response	0.1481	0.3767
Scotopic Response	0.2870	-0.1516

The table I analysis demonstrates the potential of using ERG signal features as reliable indicators of retinal health. Future work could involve expanding the dataset to include a broader range of patient demographics and exploring more advanced machine learning models to further improve prediction accuracy.

Spectrogram analysis

Spectrogram analysis is a powerful tool for examining the frequency content of time-varying signals. Electroretinography (ERG), analyzing the spectral characteristics of the ERG signals can provide additional insights into the underlying retinal functionality.

By breaking down the ERG signal into its frequency components, characteristic patterns in both normal and abnormal retinal responses can be analyzed. This spectrogram analysis focus on the ERG signals related to maximum response, photopic response, and scotopic response to examine the frequency distribution of the signals and their correlation with retinal health.

The fig.2 represents spectrogram of the maximum response of a normal ERG signal revealed a concentrated energy distribution in the lower frequency bands, typically below 1 Hz and The spectrogram of the normal ERG (left) shows a more uniform and stable power density distribution over time, with a concentrated frequency component around 0 Hz and fig.3 represents the plot of ERG signal.

This is consistent with the known behavior of ERG signals, which are often dominated by low-frequency components corresponding to slow electrical activity in the retina. In normal patients, the signal exhibited stable frequency content over time, while fig.4 shows the abnormal ERG exhibits a slightly wider and more dispersed power density pattern, indicating increased variations in signal components. The abnormal responses showed disruptions in the frequency pattern, with reduced power in the dominant frequency ranges and occasional high-frequency spikes. The fig.5 shows the plot of abnormal ERG signals.

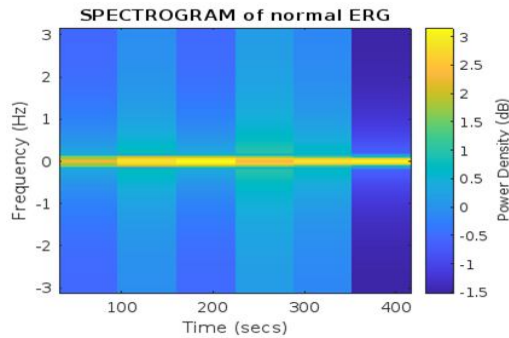


Figure 2: Spectrogram analysis ERG signal for normal patients

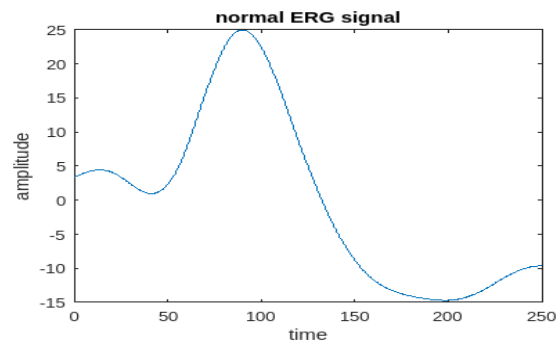


Figure 3: ERG signal plot for the normal patient

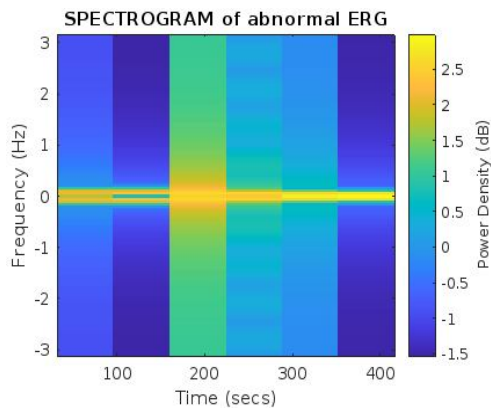


Figure 4: Spectrogram analysis ERG signal for abnormal patients

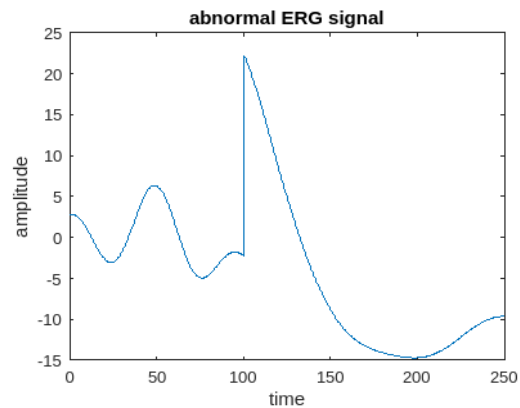


Figure 5: ERG signal plot for the abnormal patients

In this paper, we successfully used a linear regression model to analyze ERG signal data and classify normal and abnormal retinal conditions based on the maximum and minimum amplitudes of the signals. The model's performance, evaluated using R^2 and MSE metrics, showed strong predictive capabilities, highlighting the effectiveness of ERG signal features in assessing retinal health. The spectrogram analysis highlights clear distinctions between normal and abnormal ERG signals. The abnormal ERG shows higher power density variations and broader frequency components, which may indicate retinal dysfunction. Spectral analysis can be a useful diagnostic tool in detecting abnormalities in ERG signals. Further refinement of the model and exploration of additional features could lead to more accurate diagnostics for retinal abnormalities.

III. CONCLUSIONS

This study highlights the significant potential of electroretinography (ERG) in assessing retinal health by classifying normal and abnormal conditions through a linear regression model. Among the analyzed responses, the photopic response exhibited the best correlation with actual data, though further improvements are necessary. In contrast, the scotopic response demonstrated the worst fit, indicating a need for refined signal processing techniques, likely due to high noise or variability in the dataset. Additionally, oscillatory potentials and maximum response showed weak correlations, emphasizing the importance of enhanced feature extraction and signal enhancement techniques. Despite these challenges, the analysis of ERG signals—particularly focusing on maximum and minimum amplitude extraction showed strong predictive capabilities. To further enhance diagnostic accuracy, future research should explore the incorporation of frequency domain characteristics, temporal dynamics, and advanced machine learning techniques. Expanding the dataset to encompass diverse patient demographics and varying retinal conditions will also improve model robustness. Ultimately, refining these methodologies will pave the way for more precise diagnostics and personalized treatment strategies in retinal care, significantly advancing the field of ophthalmology.

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