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ECG Signal Analysis for Heart Disease Detection Using Hybrid Machine Learning Techniques

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.Abstract*: Heart disease is one of the leading causes of mortality worldwide, making early detection essential for effective treatment and prevention. Electrocardiogram (ECG) signals provide a non-invasive way to monitor the electrical activity of the heart and identify cardiac abnormalities. This work focuses on developing an intelligent system for accurate detection of heart conditions such as Sleep Apnea, Atrial Fibrillation, and Heart Failure using ECG data. The system utilizes signal processing techniques to remove noise and enhance ECG signal quality, followed by extraction of important features such as RR interval, heart rate, QRS complex, P-wave, T-wave, and PR/QT intervals. In addition to time-domain features, frequency-domain parameters like Power Spectral Density (PSD) and signal energy are incorporated to better capture variations in ECG signals. Machine learning classifiers including Artificial Neural Networks (ANN), K-Nearest Neighbor (KNN), and Support Vector Machine (SVM) are employed to analyze these features and classify cardiac conditions. By combining multiple features and classifiers, the system improves diagnostic accuracy and reduces the chances of misclassification, even in noisy data conditions. This study contributes to the development of a reliable and efficient ECG-based diagnostic system that supports early detection of heart diseases and assists medical professionals in making accurate clinical decisions.
Keywords: Electrocardiogram, cardiac disease detection, machine learning, healthcare system.

I. INTRODUCTION

One of the most critical aspects of saving lives is providing accurate and early diagnoses of heart disease. Electrocardiography (ECG) is widely used throughout the world as a method of monitoring and diagnosing, through non-invasive means, the electrical activity of the heart. An ECG is an important tool for identifying abnormalities in cardiac function. Historically, ECG interpretation has been relied on manual interpretation performed by a medical professional; however, this method suffers from many drawbacks – such as length of time needed to review the data and human error stemming from fatigue or distraction. Furthermore, ECG signals are difficult to interpret because they often contain noise, motion artifacts, and power line interference. To combat these limitations, researchers have begun using advanced signal processing and machine learning techniques to automate ECG analysis. Traditional ECG systems concentrate on extracting simple time-domain features (R-R interval, heart rate, QRS duration) and then using classification algorithms (e.g., ANN, KNN, SVM) to detect cardiac conditions, such as atrial fibrillation, sleep apnoea, or heart failure. This enhanced ECG analytic approach provides efficient methods for cleaning up and reformatting signals; removing noise, correcting baseline, and extracting both time-domain and frequency-domain features like Power Spectral Density and Signal Energy. The integration of several machine learning classifiers also allows for increased accuracy and duplicate validation of detecting heart disease. All of these elements of the integrated approach provide for a reliable, fast, and automated diagnosis that will assist healthcare professionals with timely and correct clinical decisions.

II. LITERATURE SURVEY

Extensive research has been conducted in the areas of ECG signal analysis, signal processing and machine learning techniques used to support the development of systems for detecting heart disease from ECG records. ECG is a well established non-invasive technique used for monitoring the electrical activity of the heart; the P-wave, QRS complex, and T-wave are important segments of the ECG signal and contain important clinical information about the heart's condition. Changes in these segments can indicate very serious conditions such as; arrhythmias, atrial fibrillation, heart failure, and sleep apnea.

At first, ECG interpretation was a manual process performed by cardiologists, which took a considerable amount of time and expertise. The introduction of digital signal processing and automated EC analysis systems has allowed healthcare professionals to improve their diagnostic speed and accuracy. Over recent years, many researchers have investigated the use of machine learning algorithms for classifying ECG signals.

Research has demonstrated the effectiveness of machine learning algorithms such as SVM, KCNN and ANN for detecting abnormalities in the cardiac rhythm. Depending on the feature set of the ECG signals (i.e. heart rate, RR interval, mean value, wave shape etc.), machine learning methods can identify patterns of ECG signals that are consistent with a specific disease of the heart. Besides research on classification techniques, many studies have looked at enhancing the quality of ECG signals through better signal pre-processing methods. ECG signals often contain noise from sources like; power-line interference, motion artifacts and baseline drift. Filtering, wavelet transforms and statistical feature extraction techniques have commonly been used to remove noise while maintaining relevant features of the signal.

Another important aspect noted throughout the literature has been the use of publicly available ECG datasets (PhysioNet), these data sets contain annotated recordings on a variety of cardiac conditions. These ECG datasets are useful in training and testing machine learning models and allow researchers to conduct comparative analyses of different classification methods under controlled conditions.

There is a large body of research to suggest that combining ECG signal processing techniques with machine-learning classification techniques improves the ability to detect heart disease. However, there is still research continuing to develop new feature extraction techniques, improve noise reduction techniques, and develop new ECG based diagnostic systems that are accurate and reliable, which will ultimately improve how clinicians make decisions.

III. PROBLEM STATEMENT

Cardiovascular disease is among the highest mortality rates globally, indicating the importance of early diagnosis and accurate diagnosis. ECG signals are extensively used to monitor cardiac activity, and identify abnormal cardiac function. However, within traditional healthcare, ECGs are usually manually interpreted by professional medical personnel who take a considerable amount of time, are labour intensive, and can commit large errors when interpreting numerous tests or patients.

ECG signals are also impacted by many sources of noise, which include baseline drift, power line interference, and motion artifacts, and thus makes it difficult to accurately interpret the ECG waveforms. The ECG waveform can have only a small degree of variation from a typical waveform, which could represent possibly few serious (e.g., Atrial Fibrillation, Sleep Apnea, Heart Failure) conditions. Because of this, traditional methodologies for ECG analysis often overlook minor irregularities.

In addition, existing systems are primarily based on a limited amount of time-domain features that do not fully capture all aspects of the ECG signals, which can result in a decreased level of diagnostic accuracy, and delay diagnosis as most medical data keeps increasing. Automated processing of these tests will reduce the time taken to provide a diagnosis.

To adequately support healthcare professionals in clinical decisions, there is a need for an advanced automated electrocardiogram (ECG) analysis system that can effectively manage noise, extract a vast number of features from the time domain and frequency domain, and use robust machine learning algorithms to improve the accuracy, speed, and reliability of heart disease detection.

IV. PROPOSED METHODOLOGY

This paper presents an automated electrocardiogram (ECG) analysis approach to supporting the analysis of ECG signals for heart disease detection using advanced signal processing methods and machine learning techniques. The overall process comprises four main components: data collection, preprocessing, feature extraction, and classification. The ECG data required for this study is taken from the PhysioNet database, which consists of publicly available ECG recordings of patients who have various heart conditions, including Sleep Apnea, Atrial Fibrillation (AF), Heart Failure (HF), and normal. Each dataset provides a sound foundation for training and verifying the performance of machine learning algorithms by collecting data from a variety of different patient populations. The ECG data collected is split into 70% training data and 30% testing/validation data.

The step before using the ECG to see if there are signs of heart disease or other problems consists first of cleaning up noise, glitches associated with power lines and other problems that occur when the body moves around, as well as baseline drift. This includes using various methods to clean up the ECG so that they are cleaner and more easily identifiable by using filtering and wavelet based techniques. Once the data has been preprocessed, it can then be used to do feature extraction. Feature extraction provides different characteristics about the ECG signal in relation to how long sound waves are (time domain), and if during its waveform there is predominately high or low frequency components (frequency domain). In the time domain, we will extract time based features such as identifying R-peaks; RR Interval; Heart Rate; The QRS Complex; P-wave time; T-wave time; and the duration of both the PR and QT intervals. With frequency domain extracted features, we obtain other representative characteristics of ECG signals such as Power Spectral Density and Signal Energy, thereby enabling us to be able to describe the changes in how ECG signals are behaving as numerically as possible.

When completed the features that have been identified will be sent into a variety of different Machine Learning Classifiers such as ANN, KNN, and SVM where they can be classified into different categories such as Sleep Apnea, Atrial Fibrillation, Congestive Heart Failure, and Healthy; then Hybrid Classifier will combine the outputs from these methods in order to improve classification accuracy and to create a more robust system against new data. Lastly we evaluate the performance of the feature identification system by using accuracy and other statistical measures assisting us in determining how well each Category Classifier has identified cardiac abnormalities.

V. SYSTEM DESIGN

Using machine learning techniques with automated detection of cardiac abnormalities through ECG signals.The architecture of the system revolves around several sequential stages that include; ECG data acquisition, ECG data preprocessing & feature extraction/selection, Feature/Signal Normalization, Hybrid Classification, and finally prediction of ECG Heart Disease Diagnosis. With such an organized workflow of components & processes, accurate & reliable analysis of ECG signals will be provided in a timely manner for diagnostic purposes.

In the first stage, ECG signals are sourced from publicly shared datasets available on sites like PhysioNet. These datasets provide recordings that contain annotated descriptions of many different types of cardiac medical conditions including Sleep Apnea, Atrial Fibrillation (AF), Heart Failure (HF) and normal rhythm. While the ECG signals are considered 'raw' they will also likely contain noise that isn't part of the heart rhythms/ECG waveforms (such as baseline wander, various movements by patients being recorded during data acquisition, and powerline interference).

A variety of advanced technologies are used to pre-process the signals to remove any noise (e.g. wavelet based denoising, Baseline Correction). The result of pre-processing enhances the quality of the ECG signals while still maintaining important characteristics of the waveforms. Additionally normalization is also done to the signals so that the amplitudes and durations of ECG signals are equal before continuing with the analysis.

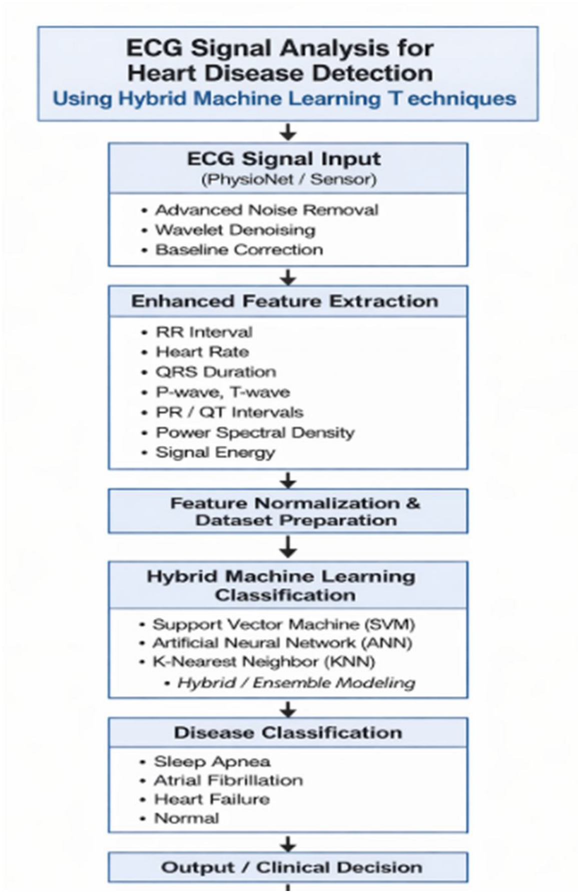

Fig.1 Enhanced ECG-based cardiac disease detection system using hybrid machine learning classifiers and combined time-frequency domain feature extraction.

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After preprocessing, features need to be extracted in order to get time-based and frequency-based features. Features that are extracted from time include: RR interval, Heart rate, QRS complex (Width of R peaks.), Duration of P waves and T waves, PR/QT intervals, and several statistical measurements such as Mean and RMS. Features extracted from the frequency domain include; Power Spectral Density (PSD) and Signal Energy to capture the small to large variations in ECG signals over time. Those features collectively provide a detailed dataset about the heart's activity that will ultimately help improve classification performance.

Once the features have been extracted, the next step is to normalize the features in order to scale them down into a common range. This will help lessened the amount of bias introduced due to differences in magnitudes among the separate features. The final step is to create training and testing sets from the original dataset to determine how well the algorithm identified new records with no prior experience.

Finally, the output stage provides classification results indicating whether the ECG signal corresponds to Sleep Apnea, Atrial Fibrillation, Heart Failure, or Normal Condition. Accuracy is one of the metrics used for evaluating a system's performance. This automated system aids clinicians by providing fast, reliable, and data-based diagnostics support for effective decision-making.

VI. RESULT

The accuracy of the machine learning methods in studying ECG signals and detecting heart disease abnormalities is proved with the help of the results obtained with the developed ECG heart disease detection system. The system is developed in Python and an amalgamation of signal processing and machine learning classification to identify the Heart diseases sleeping Apnea, Atrial Fibrillation and Heart Failure. The hybrid model which is created in this project is a combination of various classification algorithms which are used to enhance the accuracy of the prediction.

First, the hybrid machine learning model was trained on the ECG datasets that have been acquired in the PhysioNet database. The training was done by deriving meaningful aspects about ECG signals and then training them to machine learning classifiers. The performance of the training process was carried out in Python IDLE environment. The hybrid classification model was trained successfully and after the training, it became feasible to reach high accuracy of 98.2 and this implies the system can classify ECG signals into various heart disease categories with high accuracy.

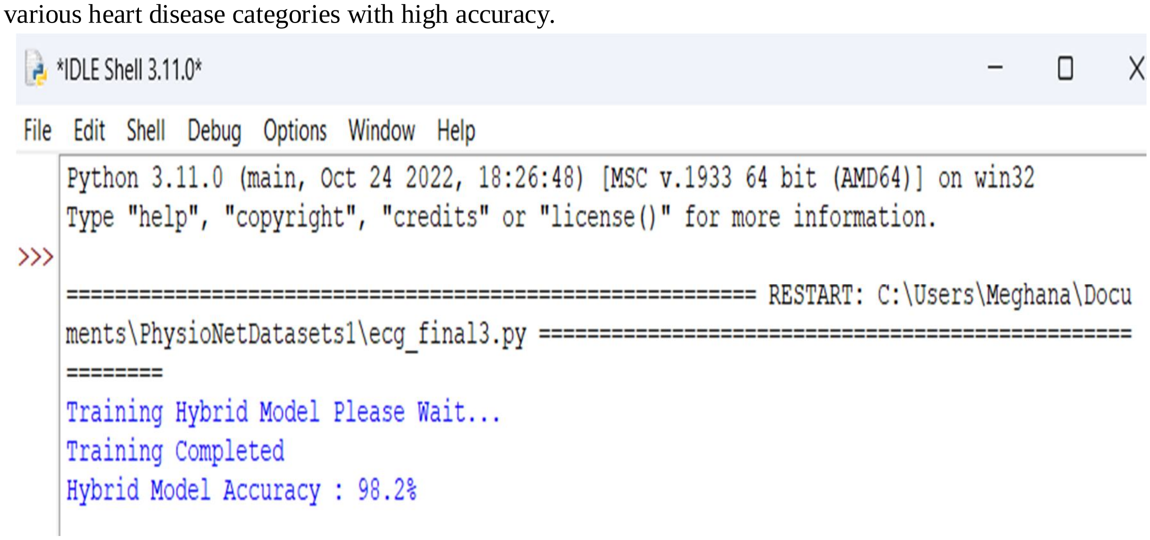

Fig.2 The Hybrid Machine learning model training result.

The figure above indicates the level of training output of the hybrid model which was run in the Python IDLE environment. The console output is a confirmation that the training process was completed successfully and the hybrid classifier was able to attain 98.2 percentage accuracy. This high accuracy indicates that a combination of machine learning algorithms is effective in the classification of ECG signals.

Once the model is trained, ECG signal acquisition and visualization is carried out by the system. The signal of ECG provided by the dataset is plotted in graphical format in order to see the nature of the waveforms. ECG waveform has significant parts that include the P wave, QRS complex, and T wave that indicate the various phases of a cardiac cycle.

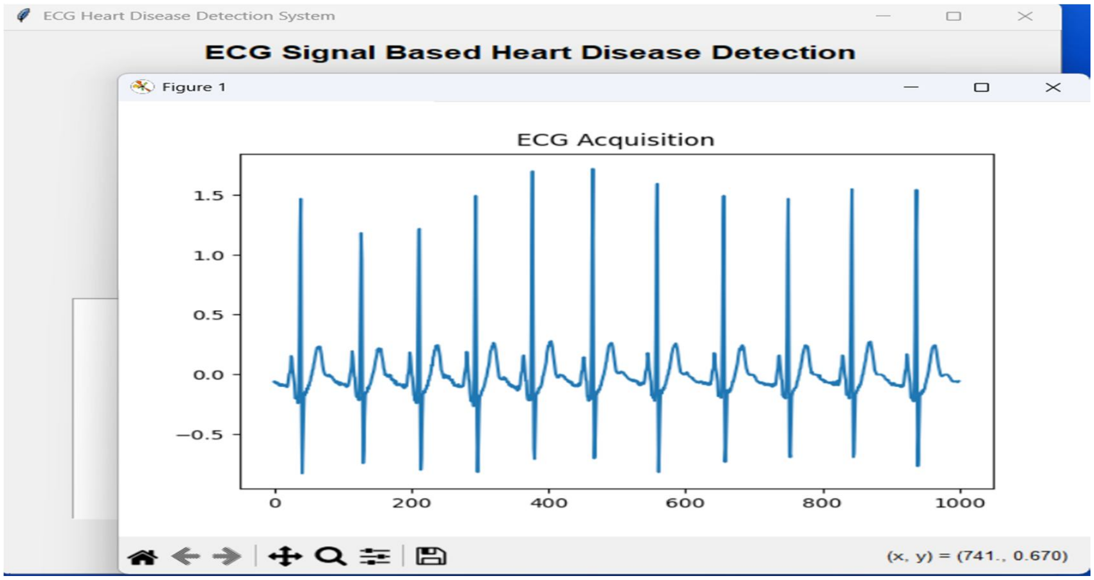

Fig 3.ECG Signal-acquisition and Visualization

The waveform of ECG signal, as displayed in the figure, is a demonstration of the electrical activity of the heart with time. The peaks in the waveform are the QRS complexes that are significant because they indicate depolarization of the ventricles. ECG signal visualization is used to confirm that the dataset is good to the eyes before proceeding with processing.

The second step of the system is preprocessing of ECG signals. Noise and other undesirable disturbances like baseline wander, power-line interference, and muscle artifacts have to be removed by preprocessing. There is a filtering of the signal that is intended to clean it and enhance the quality in order to extract the features.

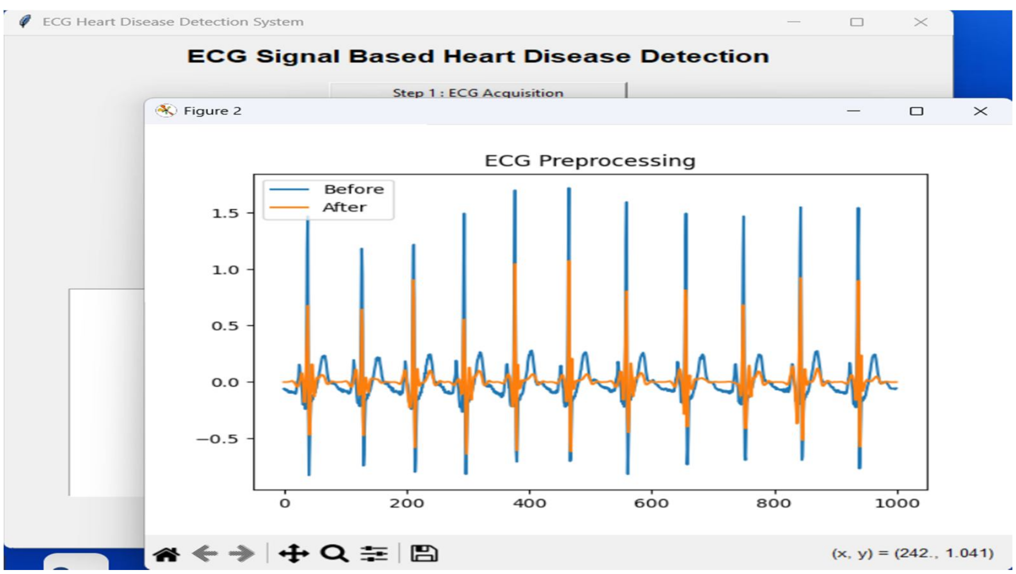

Fig.4 Preprocessing of ECG Signal (Prior to and after Filters)

The figure above compares preprocessing and post-processing ECG signal. The blue signal is the raw ECG signal and the orange signal is the filtered signal after noise has been removed. Preprocessing stage enhances the signal clarity and enables the system to obtain the accurate features of ECG waveform.

When the preprocessing is done the system identifies some significant statistical and physiological features in the ECG signal. Such characteristics are mean value, standard deviation, variance, root mean square (RMS) and energy, peak count, RR interval statistics, heart rate, and power spectral density (PSD) values. These are the extracted features that are the characteristics of the cardiac activity and they are inputted in the machine learning classifiers.

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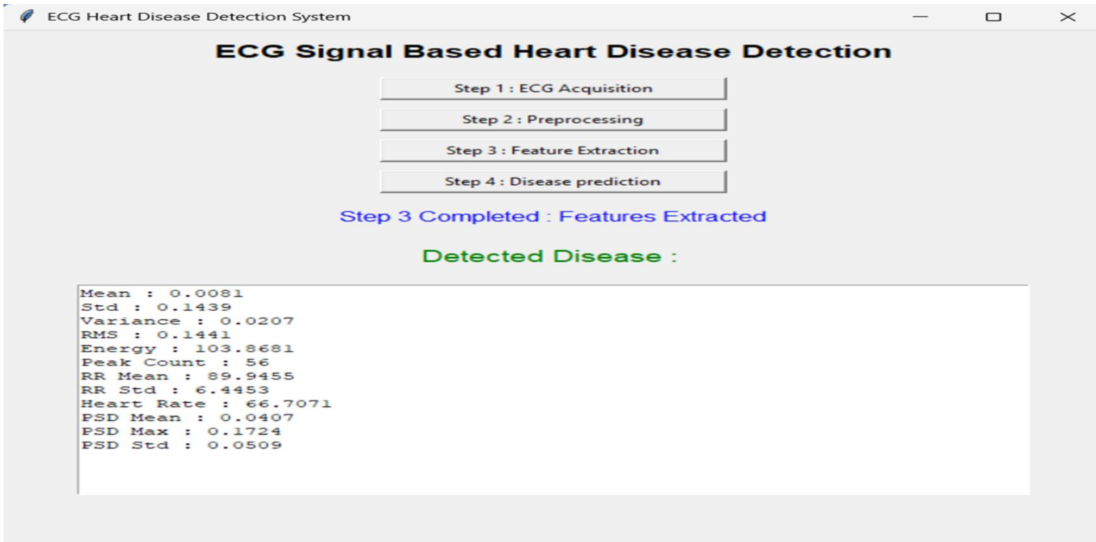

Fig 5. Features extracted ECG Signal

The results obtained after feature extraction provided in the figure indicate different calculated values of the ECG signal. They are parameters that give valuable data on the heart activity and the machine learning models use it to categorize the ECG signal into various disease kinds. Lastly, the classification step forecasts the heart disease depending on the features that have been extracted. The trained hybrid machine learning model compares the features of the input and finds out the related heart condition. The system has a graphic user interface that displays the end classification result.

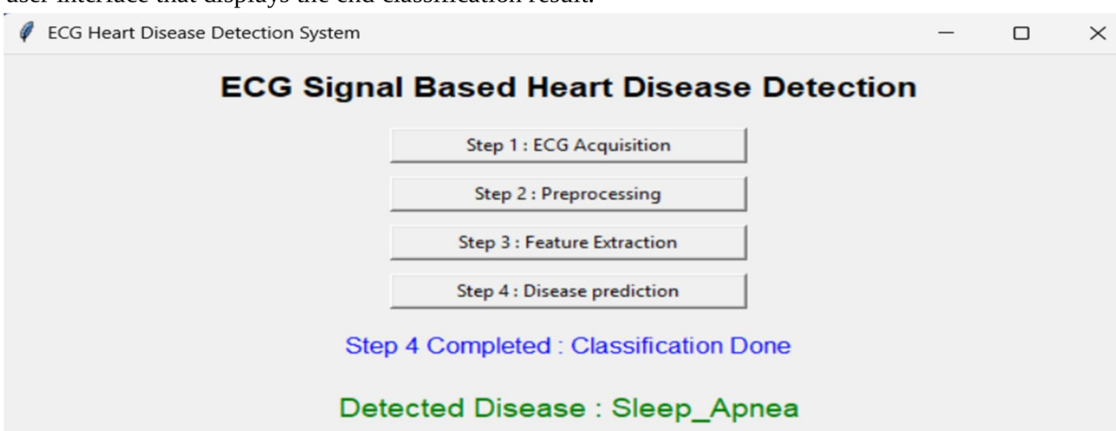

Fig 6. The final disease classification result

The result of classification in the figure has indicated that the system was able to identify the disease in the figure Sleep Apnea. This proves that the proposed ECG signal analysis system can potentially detect cardiac abnormalities with the help of machine learning.
In general, the findings prove that the hybrid ECG classification system suggested can analyze the ECG signals successfully and identify the heart diseases. The good precision of the hybrid model implies that the combination of machine learning algorithms with the use of signal processing techniques can be used as an effective method of heart disease diagnosis using automated methods. The created system can help healthcare practitioners to diagnose cardiac issues more effectively and can also be combined with wearable monitoring devices to be used to monitor health in real-time.

VII. FUTURE SCOPE

ECG-based heart disease detection has great potential in modern health care, particularly given the growing demand for early detection and ongoing monitoring of patients due to the advancement of wearable medical devices, such as smart watches, fitness trackers, and portable ECG monitors. ECG signal analysis can now be done in real time at the point of care and be integrated into a person's daily life through continuous monitoring of their heart, with immediate alerts to the user when an abnormality occurs;

thereby allowing for the prevention of the potential progression of these abnormalities into serious medical conditions. Advanced ECG signal processing methods such as wavelet-based denoising and adaptive filtering techniques will improve ECG signal characteristics. Also incorporating advanced methods of feature extraction (e.g., deep learning based feature extraction of cardiac events) will increase the ability to identify subtle differences in ECG waveform patterns that might be indicative of early-stage heart disease. Incorporating larger and more diverse ECG datasets into model training would improve the robustness of the ECG detection model across diverse patient populations. Integrating IoT will also enhance ECG detection systems by enabling them to exchange information with other connected devices. In addition, through the development of hybrid models through machine learning and using new and developing techniques in artificial intelligence (AI), there is a possibility of increasing the efficiency and accuracy of classification systems. The continual advancement of artificial intelligence (AI), wearable and remote healthcare systems, and ECG-based diagnostic solutions will play a crucial role in preventive healthcare and the development of smart medical systems.

VIII. CONCLUSION

Using ECG signal analysis as a reliable and effective method for locating heart disease electrically by the electrical activity of the heart is well-known. The analysis of ECG signals not only gives information concerning the physiological characteristics of an individual's heart but also enables the identification of problems associated with Sleep Apnea, Atrial Fibrillation, and Congestive Heart Failure. An integration of both Signal Processing Techniques and Machine Learning Techniques allows for more accurate and efficient ECG-based diagnosis. Signal Preprocessing Techniques (e.g., Noise Reduction Techniques) and Wavelet based Denoising Techniques improve the quality of the signal; whereas, Feature Extraction Techniques (time domain characteristics (TD), frequency domain characteristics (FD)) allow for a better analysis because they provide detailed characteristics of ECG Signals. Machine Learning Algorithms (e.g., Artificial Neural Networks (ANN), Support Vector Machine (SVM), K-Nearest Neighbor (KNN)) enable the automated classification of cardiac-related conditions based on characteristics of the cardiac signal. Hybrid Classification Approaches enable improved system performance through using the best features from the combination of the Classification Algorithms and reducing the number of misclassifications. The automated heart disease detection system is a fast, accurate, and reliable method to help healthcare providers make clinical decisions. Automated heart disease detection systems will aid healthcare providers in the early diagnosis and improvement of patient care. As technology advances, ECG-based diagnostic systems will increase in efficiency, availability, and overall use in today's healthcare system.

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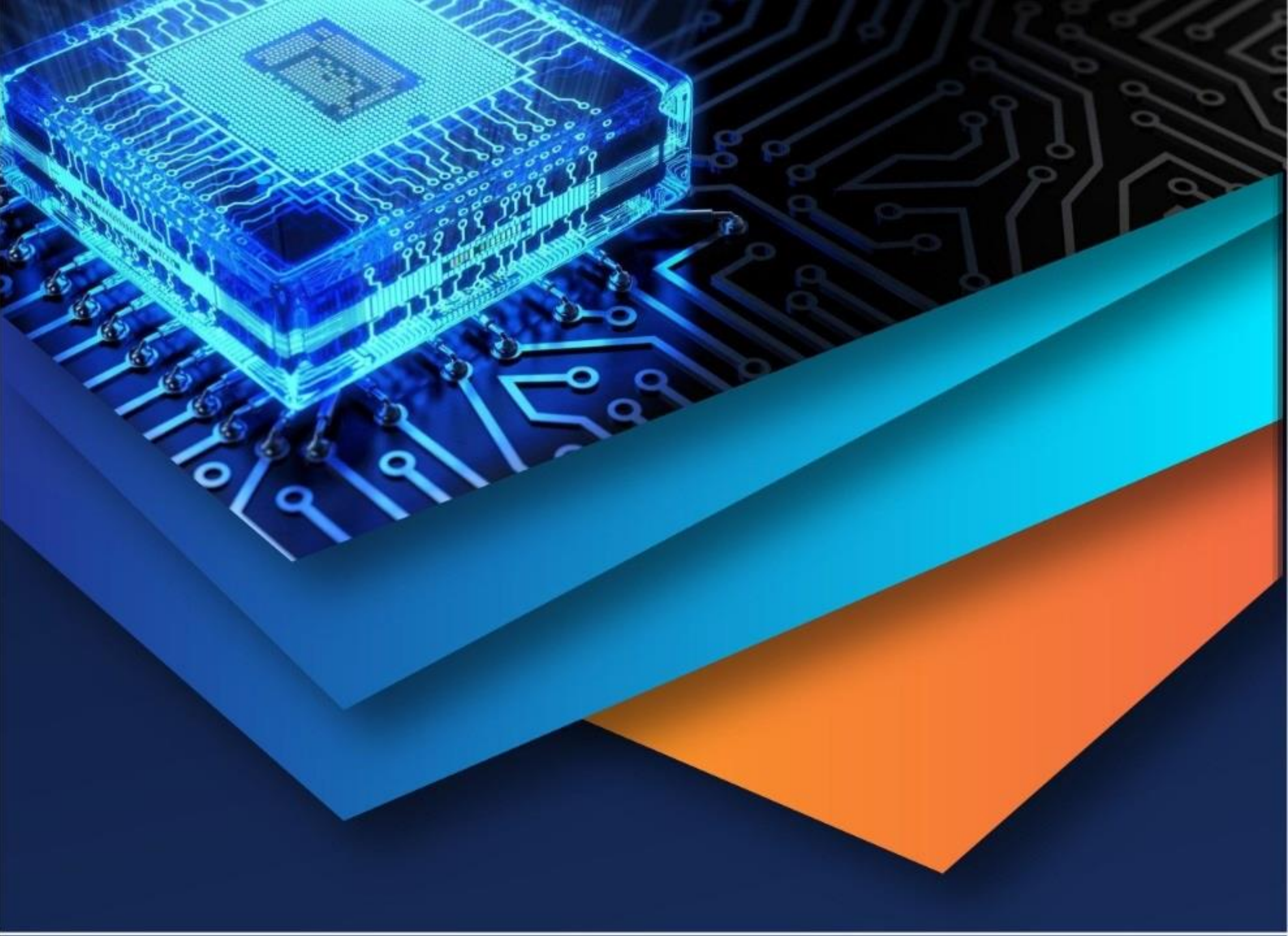

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