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ECG Signal Analysis for Heart Disease Detection

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Abstract: One of the predominant causes of deaths around the globe is heart disease, and thus, this illness should be detected at an early stage in order to be treated and prevented. The electrocardiogram (ECG) signals allow an electrical activity of the heart to be tracked without any invasion and cardiac abnormalities to be detected. Conventional ECG-based diagnostics systems identify the heart conditions through signal processing and machine learning processes. These systems extract ECG characteristics like RR interval, heart rate, QRS complex, and the characteristics of the waveforms among others of the recorded signals and analyze them. They usually use classification techniques such as Artificial Neural Networks (ANN), K-Nearest Neighbor (KNN) and Support Vector Machine (SVM) to recognize cardiac diseases such as Sleep Apnea, Atrial Fibrillation (AF) and Heart Failure (HF). Signal processing methods, such as filter and feature multiplication, are also employed in order to remove noise and enhance signal quality. The current methods of ECG analysis help medical practitioners in identifying heart anomalies and aid in coming up with clinical decisions in diagnosing the heart.
Keywords: Electrocardiogram, cardiac disease detection, machine learning, healthcare system.

I. INTRODUCTION

Heart disease is a disease that causes the death of many people in the world and it needs early diagnosis in order to be treated effectively. The ECG signals are extensively utilized to track the heart electrical activity and detect any defect in cardiac functioning. ECG is a non-invasive and accurate method of analyzing the heart conditions by physicians. The conventional medical frameworks of healthcare include the examination of ECG to identify irregular heart rate and other cardiac issues by hand through medical specialists. Manual analysis of ECG signals however can be time consuming and in some instances susceptible to human error particularly when large amount of patient data has to be analyzed. Noise, motion artifact and power-line interference can also tend to influence the ECG signals which complicates the interpretation. In the quest to enhance the diagnosis process, scholars have investigated the various signal processing approaches and machine learning algorithms in ECG classification. The current systems are mostly based on the mining of simple time-domain features like heart rate, RR intervals and QRS duration. The classification algorithms such as Artificial Neural Networks (ANN), K-Nearest Neighbor (KNN), and Support Vector Machine (SVM) are then applied to these features to identify various cardiac conditions including Sleep Apnea, Atrial Fibrillation and Heart Failure.The key contributions of the work were development of an automated ECG signal analysis system that is able to detect the presence of several cardiac conditions through machine learning methods. The system combines preprocessing of signals, feature extraction and classification techniques to enhance reliability in the interpretation of ECG. Moreover, the relative analysis of various classifiers can be used to gain an idea of their usefulness in the detection of cardiac abnormalities using ECG signals.

II. LITERATURE SURVEY

To explain the formation of ECG-based heart disease detection systems, it should be noted that previous studies in the field of ECG signal analysis, signal processing, and machine learning methods in cardiac diagnosis. The analysis of electrocardiogram (ECG) has long been a subject of many years of research since it is a reliable and non-invasive technique of observing electrical activity of the heart. It was found that significant elements of the ECG waveform like the P-wave, QRS complex and T-wave carry useful information that indicates heart activity. The changes in these waveforms may denote severe disorders like arrhythmia, atrial fibrillation, heart failure and sleep apnea. First, cardiologists manually interpreted ECG signals thus consuming a lot of time and skill. As the field of digital signal processing improved, the automated ECG analysis systems started to appear to allow the medical professionals to diagnose heart diseases more effectively. With time, numerous pieces of research have been conducted on the application of machine learning algorithms to classify ECG signals. Electrocardiogram Research like the one by Potter and Sims (Early Detection of Cardiac Diseases by Electrocardiogram by Artificial Intelligence Techniques) has shown that algorithms like Artificial Neural Networks (ANN) and K-Nearest Neighbor (KNN) and Support Vector Machine (SVM) can be used to analyze ECG signals and identify cardiac abnormalities.

These methods utilize extracted ECG characteristics which include heart rate, RR interval, mean values and waveform characteristics to determine patterns in association with various heart diseases. Besides classification techniques, scholars have also concentrated on the enhancement of signal preprocessing techniques to increase the quality of the ECG signal. The power-line interference and muscle movement artifact and baseline drift tend to introduce noise in the ECG recordings. Thus, each of the filtering techniques, wavelet transforms, and statistical methods of feature extraction is often used to eliminate the noise and emphasize valuable features of ECG signals.

The use of publicly available ECG databases including PhysioNet of ECG recordings annotated with various cardiac conditions is another important topic in the literature. The datasets are popular in machine learning model training and testing as well as in the performance comparison of different classification algorithms. Through standardized datasets, researchers can compare the effectiveness of various methods of ECG analysis and enhance the accuracy of the diagnosis. In general, existing research demonstrates that machine learning can be successfully used to detect heart diseases in combination with ECG signal processing. Despite the fact that currently, there are systems that aid clinical diagnosis, ongoing studies are being conducted to increase the feature extraction processes, advance noise reducing systems, and create more precise and trustworthy ECG based heart disease detection systems.

III. PROBLEM STATEMENT

Heart disease has remained one of the primary causes of death in most countries globally and therefore early and correct diagnosis cannot be overemphasized. ECG signals are popular to study heart activity and identify cardiac functional deviations. Yet, the current traditional healthcare systems often have the ECG analysis manually performed by medical specialists. This may be lengthy and even subject to errors of human beings particularly when physicians are required to review huge volumes of patient information. The other problem is that ECG signals are usually exposed to noise, baseline drift ECG and other signal disturbances that complicate the interpretation. Minor changes in the patterns of ECG waveforms might be a sign of severe heart conditions, which is not always easily observed using standard techniques. When the patient population and medical data volume grow, it is no longer effective to use the manual analysis of ECGs and postpone the diagnosis. This is why more sophisticated systems are required to be able to study ECG signals effectively and help medical workers to detect the heart diseases with greater accuracy and faster.

IV. PROPOSED METHODOLOGY

This project involves the analysis of ECG signals based on signal processing and machine learning algorithms to identify various heart diseases. To begin with, ECG data is gathered and filtered out to eliminate undesired noise and signal artifacts. The quality of the ECG signals is enhanced by the use of preprocessing methods, including filtering and wavelet denoising. Following the preprocessing, the signals are extracted and sent into important ECG characteristics, including R-peaks, RR intervals, heart rate, QRS complex, P-wave, T-wave duration, PR/QT intervals.

The ECG data worked with in this case were obtained using the PhysioNet database that is publicly available and contains annotated ECG signals of patients with various cardiac conditions. The data set has the records of the Sleep Apnea, the Atrial Fibrillation (AF), the Heart Failure (HF), and the standard heart rates. The sampled ECG signals were separated into training and testing sets and the classification performance of the proposed system was assessed. About 70 percent of the data was utilized to train the machine learning models whereas the other 30 percent was utilized to test and verify the machine learning models.

After the acquisition of the corresponding features, the machine learning algorithms of Artificial Neural Networks (ANN), K-Nearest Neighbor (KNN), and Support Vector Machine (SVM) are deployed to classify ECG signals into various cardiac conditions of Sleep Apnea, Atrial Fibrillation (AF), Heart Failure (HF), and Normal. The extracted features are analyzed using these algorithms and patterns that are related to various heart diseases are identified. Lastly, the results of classification are also determined by the performance measures like accuracy to help identify the system effectiveness in identifying abnormalities that can be detected in the heart.

V. SYSTEM DESIGN

The current system will be aimed at automated cardiac abnormalities detection on the basis of Electrocardiogram (ECG) signals and machine learning. The general architecture will be made of consecutive steps such as ECG data acquisition, preprocessing, feature extraction, feature normalization, classification, and prediction of the disease. The workflow of the system allows proper processing of ECG signals to be diagnosed correctly. Primarily, ECG signals are acquired based on a generalized database like PhysioNet or sensor-recorded signals.

Raw ECG signals have different kinds of noise such as baseline wander, motion artifact and power-line interference. Hence signal preprocessing is done in order to improve the quality of signal. This step involves noise reduction, baseline mending and normalization to give uniformity of signal height and length.

Preprocessing phase is used to maintain the minimum distortion that is not relevant before feature extraction. Significant features of ECG signals are then extracted after preprocessing. The system mainly aims at extraction of time-domain features so as to capture the behavior of the heart appropriately. Characteristics like mean value, standard deviation, root mean square (RMS), heart rate, and RR interval, Signal energy are calculated. The calculation of heart rate is done in regards to RR interval using the relation: HeartRate=60/RRInterval. These are used to capture statistical and physiological parameters of ECG waveform and as input parameters to classification.

After the extraction of the features, feature normalization is done to make the values fall into a similar range. This enhances the work of classifiers and avoids bias, due to the different magnitudes of features. The processed data is then segregated into a set of training and testing data in which the capability of the system to generalize is tested. In order to be classified, they use conventional machine learning algorithms. The Support Vector Machine (SVM), Artificial Neural Network (ANN), and K-Nearest Neighbor (KNN) are some of the models that are used in the existing system. The extracted features are used to train each of the classifiers to identify normal and abnormal cardiac conditions. SVM model builds the best hyperplane that can be used to distinguish between classes, ANN learns nonlinear decision boundaries by use of hidden layers and KNN classifies the similarity between two classes, basing on distance measures.

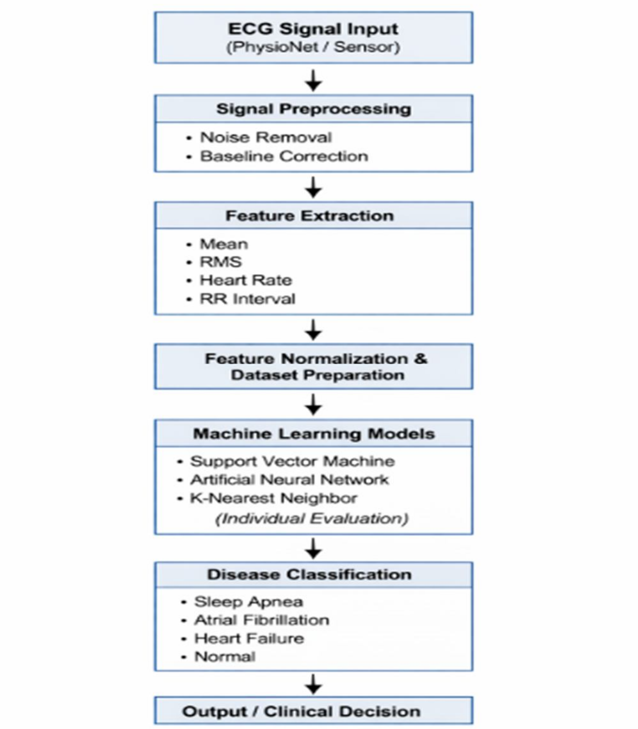

Fig.1 Existing ECG-based cardiac disease detection system using time-domain feature extraction and conventional machine learning classifiers (SVM, ANN, and KNN).

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The output stage gives an output of the disease classification that gives the results in terms of Sleep Apnea, Atrial Fibrillation, Heart Failure or normal rhythm. System effectiveness is evaluated by performance metrics such as accuracy.

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The last prediction helps the clinicians in the decision-making process, as it offers an automated diagnostic help. The system architecture in general provides a structured ECG analysis with the preprocessing, feature engineering, and classical machine learning classification to provide a reliable cardiac disease detection.

VI. RESULT

To assess the work of the current ECG-based cardiac disease detection system, experiments were done with the help of regular ECG data sets that included the recordings of normal and abnormal heart conditions including Atrial Fibrillation, Sleep Apnea, and Heart Failure. Preprocessing steps such as noise filtering, normalization and time-domain features extraction were applied to the ECG signals to obtain uniform input to use in classification.

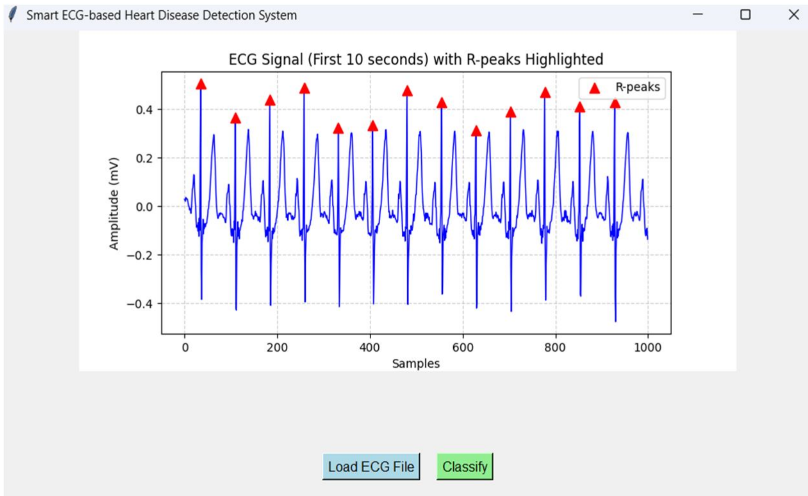

Fig.2 ECG Signal with Detected R-Peaks

Various machine learning classifiers such as Support Vector machine (SVM), Artificial Neural Network (ANN) and K-Nearest Neighbor (KNN) were highly tested on both training and testing data sets. The SVM classifier was the most successful in the classification with a score of about 97%, and ANN with a score of about 95%. In comparison, the accuracy of the KNN classifier was approximately 92% with relatively low performance of the classifier at different values of k. These findings show that time-domain statistical features are effective to differentiate normal and abnormal cardiac conditions.
In order to assess the performance of the classifiers even further, some other evaluation measures like precision, recall, and F1-score were also computed with the classification accuracy. Precision shows the rate of how perceptions of positive cases were accurately measured as a percentage of all that are predicted to be positive and recall represents the capability of the model to perceive actual positive cases that are actually present. F1-score is a harmonic mean of precision and recall, which gives the balanced possibility of the model work.

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
KNN	90.4	89.1	88.7	88.9
SVM	96.8	96.2	95.8	96.0
ANN	94.7	94.0	93.5	93.7

Fig 3. Machine learning model performance comparison

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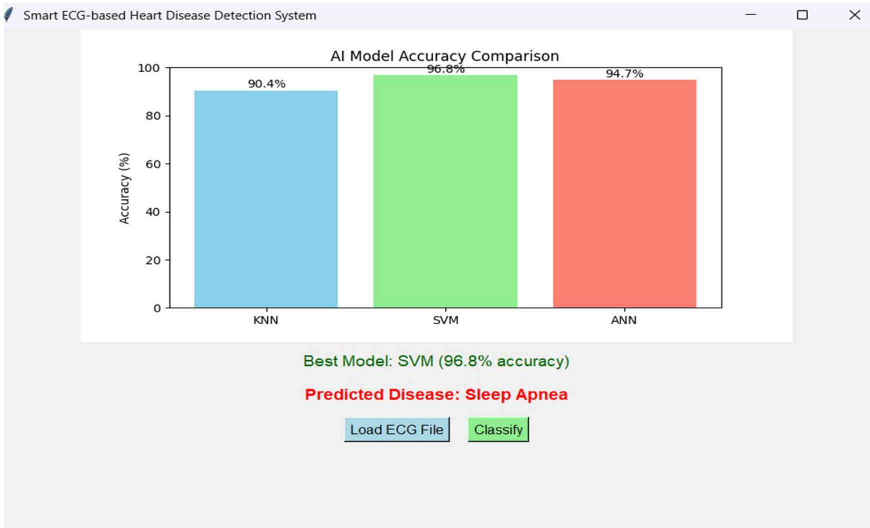

Fig.4 ML Model Accuracy Comparison of ANN, KNN, SVM and Prediction of Disease

The analysis of the confusion matrix showed that the SVM model was able to have better separation in classes and fewer false positives and false negatives. The SVM model was found to be very reliable in classifying data as performance measurements like precision, recall and F1-score were noted to be above 95%.

The results of the experiment verify the effectiveness of classical machine learning models and in particular SVM in the detection of cardiac disease using extracted statistical features based on ECG. The system has good generalization ability and can be used as a decision-support system to carry out automated cardiac analysis in the clinical setting.

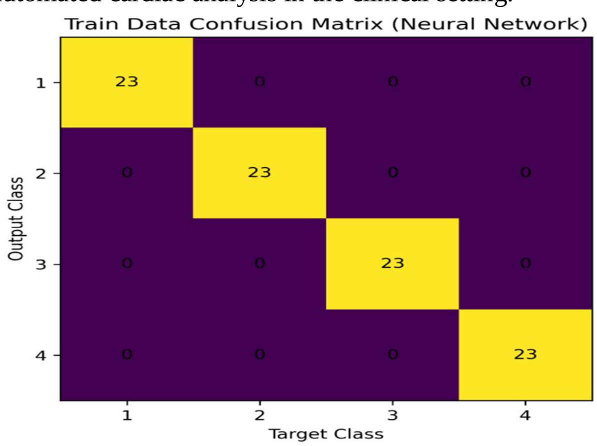

Fig.4 Train data confusion matrix of the neural network classifier

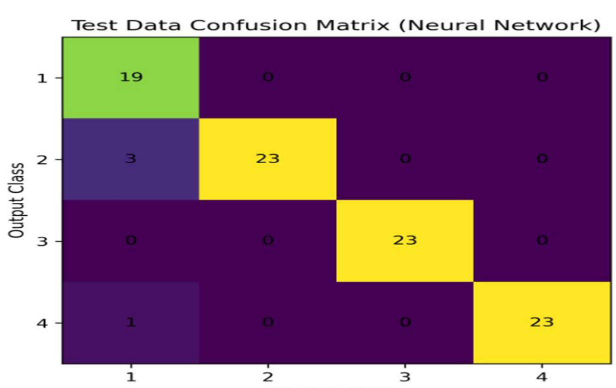

Fig.5 Train data confusion matrix of the neural network classifier

VII. FUTURE SCOPE

The ECG-based heart disease detection systems have a great potential in the contemporary medical field, particularly since the need to diagnose patients early and monitor them constantly are on the increase. As more and more wearable medical devices and portable health monitoring systems are made available, ECG signal analysis can find its way into the smart healthcare technologies of smartwatches, fitness trackers, and portable ECG monitors that can record heart data in real time and notify users of any abnormalities before they turn into serious medical conditions. The accuracy and reliability of ECG-based diagnostic systems could be further improved using improvements in signal processing methods and machine learning algorithms, whereas advanced feature extraction techniques can be used to identify subtle differences in ECG waveforms that can reflect the early signs of heart disease. Moreover, larger and more varied ECG data can be used to better train the model and make systems more resilient to various patient conditions. The other potential direction is to combine ECG monitoring technology with Internet of Things (IoT) tools and cloud-based health systems, which would enable remote patient monitoring by healthcare professionals to diagnose patients faster and provide the necessary medical treatment in time. As the technology of artificial assistance, wearable devices, and remote health monitoring advances, ECG-based heart disease can be significant in enhancing preventative care and augmenting smarter medical systems in the future.

VIII. CONCLUSION

The ECG signal analysis system is one of the effective methods of heart diseases detection based on the analysis of electrical activity of the heart. ECG signals have useful data regarding heart activity and the examination of these signals aids medical workers to determine abnormalities associated with different heart disorders. The current systems assist in diagnosing heart diseases like Sleep Apnea, Atrial Fibrillation and Heart Failure as important ECG features like heart rate, RR interval and waveform characteristics are extracted. Older ECG analysis techniques along with the use of machine learning including Artificial Neural Network (ANN), K-Nearest Neighbor (KNN), and Support Vector Machine (SVM) have demonstrated benefits in detecting cardiac abnormalities and automate the analysis process as a way of assisting physicians in detecting heart diseases more expeditiously. Signal preprocessing methods also enhance the quality of the ECG signal by eliminating noise and enhancing significant features of the waveforms to analyze correctly. Even though currently available ECG analysis systems are meaningful sources of diagnostic assistance, there are still several ways to advance the field of signal processing and machine learning algorithms to achieve better accuracy and reliability. As research and technological achievements continue, the ECG-based diagnostic systems can be more efficient and widespread, thus aiding the healthcare professional to provide a better care of the patient and making it possible to diagnose the diseases of the heart earlier.

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