MIAMI UNIVERSITY

ECE – 526

Bio-Medical Signal Analysis

Report on

ECG Development and Application

By

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1 Abstract

The heart is a complex muscular organ that is responsible for the transportation of oxygenated blood to various organs and tissues. The action of depolarization and repolarization causes electrical activity in the heart which can be detected with an electrocardiogram (ECG). ECG is a representation of voltage vs time which is obtained using standard twelve leads. Several empirical, thresholding, machine learning, and deep learning (DL) methods are being implemented on ECG signals for early detection and classification of the anomaly of patient heart. Several DL methods such as convolution neural networks (CNN), recurrent neural network based long short-term memory (RNN-LSTM) have shown promising results for automated diagnosis of cardiac diseases. ECG is useful for the diagnosis of a wide variety of heart diseases. Thus, an ECG signal dataset which is classified using techniques like ML and DL can provide a robust heart disease diagnosis system.

2 Background

2.1 Heart

The heart is a muscular organ that is equivalent to the size of a fist and is located on the slight left side of the human rib cage. It is responsible for the transmission of blood to and from various parts of the human body. To be precise, it collects deoxygenated blood, passes it to the lungs where the lungs diffuse oxygen onto the blood, and transports this oxygenated blood to several organs and parts of the body through links of arteries and capillaries. Cardiac cells make up the cardiac muscle and are responsible for the electrical activity within the heart. On resting state, they are electrically polarized and are negatively charged with respect to the outside environment. The electrical polarity within the cardiac cell is maintained by the membrane pump by ensuring the proper distribution of ions (potassium, sodium, chloride, and calcium). These cells can move in and out of the cell membrane through special channels. [1]

2.1.1 Depolarization and Repolarization

The cardiac cell can lose negative charge spontaneously due to cells known as pacemaker cells or through electrical impulses generated by the positive ions crossing the cell membrane. This is known as depolarization and it propagates from cell to cell producing waves across the entire heart. After depolarization, the repolarization is completed by reversing the flow of ions by the membrane pumps. This process of depolarization and repolarization passes through the sinoatrial (SA) node to the atrium and the atrioventricular (AV) node, finally down the bundle of His to the Purkinje fibers and all around the left ventricle. This pattern of the electrical activity of the heart gives the ECG recordings. [1]

2.2 Electrocardiogram (ECG)

ECG is a recording of the electrical activity of the heart and can be vital for providing information to diagnose the cardiac condition of a patient. ECG is recorded using the electrodes placed in specific positions in the chest and limb. These electrodes can detect small electrical changes of the signal and plot them in a voltage vs time graph which is then generally read by trained health experts to diagnose the patient. Preceding ECG, Dr. Williem Einthoven demonstrated five different deflections with help of a capillary electrometer. He further improved to develop a successful string galvanometer with remarkably high sensitivity. This device was used for producing the electrocardiograph results [2]. Einthoven's mathematical report of the Einthoven triangle was widely used later for ECG moving forward. In the 1960's, automated cardiac health detection using ECG signals became widely popular. The invention of Holter that was portable and could transfer data to the hospital has become another advancement in the field of ECG [3]. The portable microcomputers capable of monitoring arrhythmia connected to the Holter was developed in 1983. This could monitor the heart condition of the high-risk patient for long durations. The algorithms developed by Pan and Thompkins that has high accuracy QRS detection and became the state-of-the-art technology for arrhythmia monitoring. [4] [5]

2.2.1 ECG wave and complex

The morphological study of the wave obtained from the ECG can be interpreted by medical professionals to assess the patient's health. A general ECG curve is labeled using PQRST. P wave, QRS complex, and T wave denote the atrial depolarization, depolarization of ventricles, and rapid polarization of contractile cells, respectively. U wave is the positive wave seen after the T wave and is only seen occasionally. The segments between these individual waves denote the intervals before the onset of the next wave. PR segment shows impulse conduction from the AV node and serves as a reference line of the ECG reading. QRS duration provides the time intervals from the start to the end of the QRS complex. ST-segment is altered in many conditions so it is of prime interest. [6]

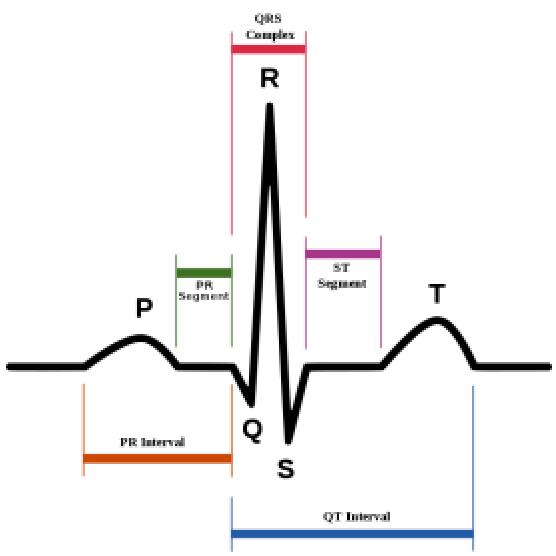

Figure 1 ECG of normal heart (sinus rhythm)

A standard ECG today uses a twelve-lead system for recording the readings. Six out of the ten electrodes are placed in the chest scattered around the sternum and the remaining four are placed in the four limbs (extremity) [7]. Several processing techniques are employed on these signals for feature detection and classification. In the present context, ECG signal processing consists of signal acquisition, preprocessing, feature extraction, and classification. The signal is acquired through several means, but the availability of several open-access databases has allowed for the development of a model without the need for data acquisition. In the preprocessing, several artifacts on the signal including baseline wander, interference, and random noises are removed. This signal is then usually features of the signal are selected, these are typically done either in the time domain, in the frequency domain by wavelet transformation, or in both. The defined features obtained can then be used to classify based on the need of the model. [5]

The classification can be based on empirical methods like using spectral features, frequency domain features, maximum entropy based on autoregressive models, etc., adaptive thresholding model (definite logical rules), machine learning (ML), and deep learning (DL). ML and DL have been widely used in various fields of data classification, including the classification of biomedical signals. Several techniques like correlation analysis and multivariate regression are used in the ML technique to find the pattern on the data and can be used to classify from new information. Support vector machine (SVM) is a type of supervised machine learning technique that has also been used in ECG classification. [5]

Similarly, deep learning-based convolution neural network (CNN), recurrent neural network (RNN) has also seen recent growth in biomedical signal analysis. Compared to other ML-based algorithms, deep learning axioms can extract features so it requires less time for feature engineering. CNN relies on a combined convolution, pooling, and feedforward neural network layer for the modeling. CNN is preferably used for image-based classification which is why ECG graphs are used while using CNN for classification. Long short-term memory (LSTM) is a type of RNN that can handle raw time sequence-based data. [5]

ECG is non-invasive and is one of the best tools for cardiac diagnostics. It has a widespread application for cardiac anomaly detection like – arrhythmia, myocardium infraction, mitral regurgitation, mitral valve prolapse, pulmonary stenosis. Arrhythmia refers to an irregular pattern of heartbeat and can be detected using ECG as it provides timing and duration for the electrical phase of the heartbeat. Myocardial infarction (heart attack) is caused by the blockage of blood flow to the heart muscles and can be diagnosed based on the ST-segment elevation seen in ECG. Mitral valve regurgitation happens when the mitral valve of the heart does not close properly. Although it is non-specific it changes the P wave of the ECG signals. Whereas pulmonary stenosis is the narrowing of the pulmonary valve and severe cases can be detected in ECG reading. Similarly, hypertrophy (thickening of the left ventricle of the heart) can also be diagnosed with ECG. [8] [9] [10] [11]

3 Potential project for ECG

Diagnostic of arrhythmia using CNN is an interesting topic towards the research of ECG using recently developed classification techniques. The dataset containing the ECG signal can be preprocessed to remove noise and interference. This cleaned dataset can be presented to create an image datastore. The datastore is then used to train a model created from pretrained model like ResNet, AlexNet, GoogLeNet. Then, this final trained model should be able to diagnose a new ECG signal.

4 Conclusion

It is very crucial to be prescient about cardiac anomalies to avoid possible mishaps relating to the heart. The ECG provides graphical representation about the current state of the heart which helps diagnose these anomalies early on. Cardiac diseases such as arrhythmia, myocardium infraction, mitral regurgitation, mitral valve prolapse, pulmonary stenosis can be detected and classified without a medical expert via various machine learning and deep learning techniques.

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