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A survey on ECG analysis

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ABSTRACT

The electrocardiogram (ECG) signal basically corresponds to the electrical activity of the heart. In the literature, the ECG signal has been analyzed and utilized for various purposes, such as measuring the heart rate, examining the rhythm of heartbeats, diagnosing heart abnormalities, emotion recognition and biometric identification. ECG analysis (depending on the type of the analysis) can contain several steps, such as preprocessing, feature extraction, feature selection, feature transformation and classification. Performing each step is crucial for the sake of the related analysis. In addition, the employed success measures and appropriate constitution of the ECG signal database play important roles in the analysis as well. In this work, the literature on ECG analysis, mostly from the last decade, is comprehensively reviewed based on all of the major aspects mentioned above. Each step in ECG analysis is briefly described, and the related studies are provided.

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1. Introduction

An electrocardiogram (ECG) is simply a recording of the electrical activity generated by the heart [1]. Sample ECG signals associated with a common cardiac cycle are illustrated in Fig. 1 [2,3]. The ECG is an effective non-invasive tool for various biomedical applications such as measuring the heart rate, examining the rhythm of heartbeats, diagnosing heart abnormalities, emotion recognition and biometric identification.

One of the major fields in which ECG analysis is required is the diagnosis of cardiovascular diseases. As reported by the World Health Organization, cardiovascular diseases are the main reason for deaths worldwide. Among the cardiovascular diseases, cardiac arrhythmias are the most common, and as a result, their precise classification has been of great interest in biomedical studies [4]. One of the most effective tools for identifying arrhythmias is ECG signal exploration [5]. The investigation of individual ECG beat characteristic shapes, morphological features, and spectral possessions can provide meaningfully correlated clinical information for the automatic recognition of an ECG pattern. However, automated classification of ECG beats is a difficult problem because the morphological and temporal features of the ECG signals include noteworthy dissimilarities for different patients under different physical circumstances [6]. The main problem for diagnosing heart diseases with ECGs is that an ECG signal can vary for each person, and sometimes different patients have separate ECG morphologies for the same disease. Moreover, two different diseases could have approximately the same properties on an ECG signal. These problems cause some difficulties for the problem of heart disease diagnosis [5,7,8]. To detect abnormalities of the heartbeat, the electrical signal of each heartbeat must be analyzed. Therefore, the process of analyzing long-term ECG records, especially for bedside monitoring or wearable online health care monitoring, can be very troublesome for a person, and it is very time-consuming. Furthermore, some personal errors can occur throughout an ECG analysis due to fatigue, [9] and the interpretation of the signal requires deep knowledge [10]. Therefore, computer-assisted methods that provide automatic ECG analysis are utilized.

The use of ECG analysis in fields other than the diagnosis of cardiovascular diseases has also increased substantially. Many researchers have used ECG signals for emotion recognition, especially for stress level detection in addition to many other signals such as the electroencephalogram, skin temperature, blood pressure, electromyogram, heart rate variability, cortisol levels, and thermal imaging features. Researchers measure ECG signals at different critical moments (stress situations), such as during an oral exam, after a holiday for students, in office environments for office workers, and during a driving task for drivers. The results of these studies reveal that ECG features are useful at distinguishing the characteristics between different mental workloads and stress levels as well [1].

In addition, ECGs are also being used in the field of biometric identification. In biometric recognition, physiological characteristics, such as face, fingerprints, hand geometry, DNA and iris, as well as behavioral characteristics, such as voice, gait, signature and keystroke dynamics, are used for identifying an individual. The biometric systems provide security and restricted access to protected areas [11]. The mentioned characteristics and the features to be used for this purpose must meet the criteria of universality, uniqueness, permanence and robustness to attacks [3,11,12]. Because ECG has features that are unique to an individual, it is being used increasingly by many researchers in this area.

As seen in the examples above, an ECG signal is analyzed and utilized for various purposes and applications. Depending on the application, the analysis contains several steps, such as preprocessing, feature extraction, feature selection, feature transformation and classification. Additionally, the employed success measures and appropriate constitution of the ECG databases play crucial roles