

Computer–Aided Diagnosis of Cardiac Arrhythmias

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INTRODUCTION

In this chapter, the field of computer-aided diagnosis of cardiac arrhythmias is reviewed, methodologies are presented, and current trends are discussed. Cardiac arrhythmia is one of the leading causes of death in many countries worldwide. According to the World Health Organization, cardiovascular diseases are the cause of death of millions of people around the globe each year. The large variety and multifaceted nature of cardiac arrhythmias, combined with a wide range of treatments and outcomes, and complex relationships with other diseases, have made diagnosis and optimal treatment of cardiovascular diseases difficult for all but experienced cardiologists. Computer-aided diagnosis of medical diseases is one of the most important research fields in biomedical engineering. Several computer-aided approaches have been presented for automated detection and/or classification of cardiac arrhythmias. In what follows, we present methods reported in the literature in the last two decades that address: (i) the type of the diagnosis, that is, the expected result, (ii) the medical point of view, that is, the medical information and knowledge that is employed in order to reach the diagnosis, and (iii) the computer science point of view, that is, the data analysis techniques that are employed in order to reach the diagnosis.

BACKGROUND

Arrhythmia can be defined as either an irregular single heartbeat (arrhythmic beat), or as an irregular group of heartbeats (arrhythmic episode). Arrhythmias can affect the heart rate causing irregular rhythms, such as slow or fast heartbeat. Arrhythmias can take place in a healthy heart and be of minimal consequence (e.g., respiratory sinus arrhythmia), but they may also indicate a serious problem that may lead to stroke or sudden cardiac death (Sandoe &

Sigurd, 1991). Ventricular arrhythmias may be categorized broadly as premature ventricular contractions (PVCs) and ventricular tachyarrhythmias, the latter including ventricular tachycardia (VT) and ventricular fibrillation (VF). Atrial fibrillation (AF) is the most prevalent arrhythmia in the western world, affecting 6% of the individuals over age 65 and 10% of those over age 80.

REVIEW OF THE PROPOSED METHODS

There are several aspects that can be addressed in order to review the proposed methods for computer-aided diagnosis of cardiac arrhythmias. The type of the diagnosis is the most important since cardiac arrhythmia is a very complex problem, having several different characteristics that need to be considered before reaching a safe diagnosis. Also, the electrocardiogram (ECG) analysis that is employed for this purpose is another important aspect. Finally, the data analysis and classification algorithms that are used define the accuracy and robustness of each approach.

Type of Diagnosis

Concerning the type of the diagnosis, two main approaches have been followed in the literature: (i) arrhythmic episode classification, where the techniques focus on the total episode and not on a single beat, and (ii) beat-by-beat classification, in which each beat is classified into one of several different classes related to arrhythmic behavior. Arrhythmic episode classification was performed in most of the methods proposed early in the literature, addressing mainly the discrimination of one or more of ventricular tachycardia (VT), ventricular fibrillation (VF), and atria fibrillation (AF) from normal sinus rhythm (NSR). More recent approaches mainly focus on beat-by-beat classification. In each case, a much larger

number of different types of cardiac arrhythmic beats are considered. A combination of these two different approaches has been proposed by Tsipouras (Tsipouras, Fotiadis, & Sideris, 2005), where beat-by-beat classification was initially performed and the generated annotation sequence was used in order to detect and classify several types of arrhythmic episodes.

Medical Data and Knowledge

In what concerns medical information, the main examination that leads to cardiac arrhythmia diagnosis is the ECG recording; thus, the majority of the methods proposed in the literature are based on its analysis. In the early studies, the ECG waveform was directly used for the analysis from it. However, more recent approaches are based on ECG feature extraction. In this case, features are mainly on the time and frequency domains in the early studies, while more complex time-frequency (TF) and chaos analysis are employed in the more recent studies, trying to access the nonstationary dynamic nature of the signal. Related to morphological features, QRS detection is the easiest to apply and the most accurate ECG processing method and thus, the most commonly used in the literature: almost all proposed methods include QRS detection in some stage of their analysis. Several other morphological features, inspired from the physiology of the ECG signal, have been employed in the proposed studies. However, the detection and measurement of all morphological features is seriously affected by the presence of noise, with the R peak being the least distorted. The identification of the importance of the heart rate variability has led to the development of methods based solely on the RR-interval signal and features that are extracted from it, for cardiac arrhythmia assessment.

Medical knowledge has been used in most of the proposed methods, mainly defining the features that carry sufficient information to be used for the classification. Rule-based medical knowledge has been employed in limited studies; instead mainly data-driven approaches have been developed. Thus, medical knowledge have also been employed for the generation of the annotation of the datasets, since data-driven approaches require an initial annotated dataset in order to be trained. In Tsipouras (Tsipouras, Voglis, & Fotiadis, 2007), a hybrid technique has been proposed in which both knowledge-based rules and training based on annotated data have been integrated into a single fuzzy model.

Data Analysis and Classification Algorithms

The general scheme that dominates the proposed methods for arrhythmia diagnosis is a two-stage approach: feature extraction from the ECG and classification based on these

features. For the feature extraction stage, time and frequency analysis techniques have been gradually replaced by TF and chaos analysis. TF distributions and wavelet transform (WT) are commonly employed to measure the signal's energy distribution over the TF plane. In addition, combination between features originated from two or more different domains, has become a common practice. However, the major shift has emerged in the classification stage: the initial threshold-based techniques and crisp logic rules have been replaced with complex machine-learning techniques and fuzzy models. Most of the proposed approaches are based on several variations of artificial neural networks (ANNs) for the final classification and, in addition, hybrid approaches employing several ANNs and combining their outcomes have also been widely used. Support vector machines (SVMs) have also been incorporated, while fuzzy logic has been employed, either as part of the classification mechanism or for the definition of the fuzzy classifiers.

PROPOSED APPROACHES FOR COMPUTER-AIDED DIAGNOSIS OF CARDIAC ARRHYTHMIAS

Several researchers have addressed the issue of automated computer-based detection and classification of cardiac rhythms. We present methods that are considered in the literature as the most cited in the field. Thakor et al. (Thakor, Zhu, & Pan, 1990) proposed a sequential hypothesis testing (SHT) algorithm for the detection of VT and VF. The detection is based on the evolution of a binary signal, generated using a threshold crossing interval (TCI) technique. The algorithm was tested in a database consisting of 170 ECG recordings (half from each category) having 8-sec length, and the results indicate that the detection was 94.12% for VT and 82.35% for VF after 4 sec, while the results increase to 100% for both arrhythmic types after 7 sec. An improvement of this approach was proposed by Thakor et al. (Thakor, Natarajan, & Tomaselli, 1994), named multiway SHT algorithm. In this case, three types of rhythm are considered, VT, supraventricular tachycardia (SVT), and NSR. The algorithm is evaluated in a dataset including 28, 31, and 43 segments for each type of rhythm and its accuracy is 98% after 1.6-, 5-, and 3.6-sec evolution time of the episode for VT, SVT, and NSR, respectively. Chen et al. (Chen, Clarkson, & Fan, 1996) applied the SHT algorithm, on the malignant arrhythmia subset of the MIT-BIH database (MITADB), resulting in much lower results. Thus, they have proposed a modification for this technique, employing dubbed blanking variability as basis for discrimination. Testing both the initial SHT technique and their modified approach to a subset of the database (30 episodes of VF and 70 episodes of VT), the classification accuracy improved from 84% to 95%. A similar approach

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