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Paroxysmal atrial fibrillation prediction based on HRV analysis and non-dominated sorting genetic algorithm III

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ABSTRACT

This paper presents a method that able to predict the paroxysmal atrial fibrillation (PAF). The method uses shorter heart rate variability (HRV) signals when compared to existing methods, and achieves good prediction accuracy. PAF is a common cardiac arrhythmia that increases the health risk of a patient, and the development of an accurate predictor of the onset of PAF is clinical important because it increases the possibility to electrically stabilize and prevent the onset of atrial arrhythmias with different pacing techniques. We propose a multi-objective optimization algorithm based on the non-dominated sorting genetic algorithm III for optimizing the baseline PAF prediction system, that consists of the stages of pre-processing, HRV feature extraction, and support vector machine (SVM) model. The pre-processing stage comprises of heart rate correction, interpolation, and signal detrending. After that, time-domain, frequency-domain, non-linear HRV features are extracted from the pre-processed data in feature extraction stage. Then, these features are used as input to the SVM for predicting the PAF event. The proposed optimization algorithm is used to optimize the parameters and settings of various HRV feature extraction algorithms, select the best feature subsets, and tune the SVM parameters simultaneously for maximum prediction performance. The proposed method achieves an accuracy rate of 87.7%, which significantly outperforms most of the previous works. This accuracy rate is achieved even with the HRV signal length being reduced from the typical 30 min to just 5 min (a reduction of 83%). Furthermore, another significant result is the sensitivity rate, which is considered more important that other performance metrics in this paper, can be improved with the trade-off of lower specificity.

1. Introduction

Atrial Fibrillation (AF) is the common non-life-threatening cardiac arrhythmia that can lead to stroke, heart failure, and other heart related disease [1,2]. Patients often start with episodes of paroxysmal atrial fibrillation (PAF), which last from seconds to days but it is self-terminating. It also can be treated by medication or electrical shock issued by the Implantable Defibrillator Device (ICD) [3]. However, the PAF can slowly evolve to the chronic AF that cannot return to normal sinus rhythm even with external treatment. Therefore, the development of an accurate predictor of the onset of PAF is clinically important because it increases the possibility to electrically stabilize and prevent the onset of atrial arrhythmias with different pacing techniques [4]. This can lead to decrease in symptoms, and possibly a decrease in atrial remodeling that causes increased susceptibility to future episodes of PAF [3].

Much research have been done for developing a method that can predict the onset of PAF based on electrocardiogram (ECG) signal. The works can be divided into premature atrial complexes (PAC) detection [5–7] and heart rate variability (HRV) analysis [8–13]. Tables 5 and 6 summarizes their methodology and prediction performance. Almost all existing methods, which achieved acceptable prediction accuracies (around 80% and above), employed 30 min signal for feature extraction [8]. Some of them [5,9,10] even could achieve same or above the level of 90%.

Previous works also attempted to use the HRV signal shorter than 15 min for prediction. However, their accuracy rates were lower when compared to the methods that used 30 min signal. For example, Boon et al. [8] proposed a HRV analysis prediction method based on HRV analysis, and they achieved accuracy rate of 79.3% and 68.9% for 15 min and 10 min respectively. Yang and Yin [12] achieved lowest accuracy rate with 57% when they extracted features from 10 min HRV signal based on footprint analysis. With spectral features, Hickey and Heneghan [6] achieved prediction accuracies of 68%, 70%, and 66% for 5, 10 and 30 min of HRV signal respectively.

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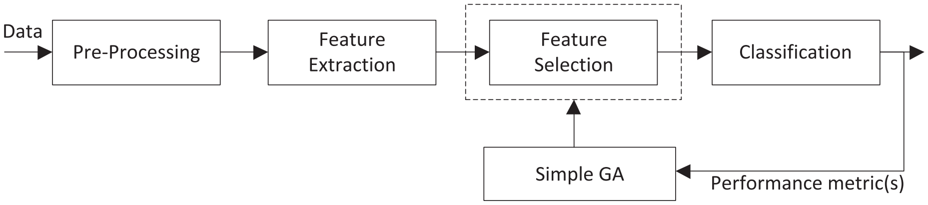

Fig. 1. Block diagram of typical feature selection based on simple GA.

Therefore, this main objective of this paper is to propose a PAF onset prediction method that requires shorter time duration of the HRV signal during the feature extraction, while improving the prediction accuracy level.

2. Optimization method

Multiple features are usually extracted during the HRV analysis. However, using all features does not always give the best classification performance due to the curse of dimensionality [14]. Therefore, feature selection algorithm is usually used to improve the performance. The feature selection is an optimization problem that involves selecting the best combination of features from the original extracted features without transforming them. It can enhance the performance, reduce the number of features, and help the researchers to understand which features are important to the classification model.

Genetic algorithm (GA) is one of the popular methods for feature selection. Fig. 1 shows the block diagram of the typical feature selection model based on simple GA for the existing research based on HRV analysis [8,15–19]. After the features are extracted from the pre-processed data, the simple GA is used to select the feature subset with high classification performance. Based on critical review, there are a few shortcomings for the feature selection model in Fig. 1.

One of the shortcomings is the parameter values and settings in both HRV pre-processing and feature extraction stages are not optimized (tuned) for maximum classification performance. As shown in Fig. 1, before the feature selector is applied, the HRV features must be extracted based on certain pre-defined values and fixed setting of HRV feature extraction algorithms. According to Rashedi et al. [20], to maximize the performance of extracted features, these parameters should be tuned simultaneously with the feature selection process for different application and database. They proposed a heuristic search method called gravitational search algorithm (GSA) to optimize the image recognition system. It simultaneously optimized both the parameters of feature extraction algorithms (wavelet transform and color histogram) and the feature subset, and this improved detection rate of their system. Inspired by their work, this paper intends to propose an optimization algorithm that can simultaneously optimizes the parameters in pre-processing and feature extraction stages, feature subset in feature selection process, and parameters of classification model. Such optimization model is shown in Fig. 2.

Another shortcoming is that the trade-off between the classification sensitivity and specificity rate is not considered. Improving certain amount of sensitivity may need to sacrifice certain degree of specificity, or vice versa [21]. Some medical applications require high sensitivity while other need high specificity [21]. For example, Xie and Minn [22] and Koley and Dey [23] developed the algorithm for detecting the sleep apnea based on ECG signal. They were interested in high sensitivity rate because it reduced the risk of overlooking the apnea events that could pose threats to the patients. In this paper, we are more interested in improving the sensitivity at the expense of acceptable reduction in specificity rate when predicting the PAF onset. Therefore, the trade-off between different prediction performance metrics is considered when developing the optimization algorithm.

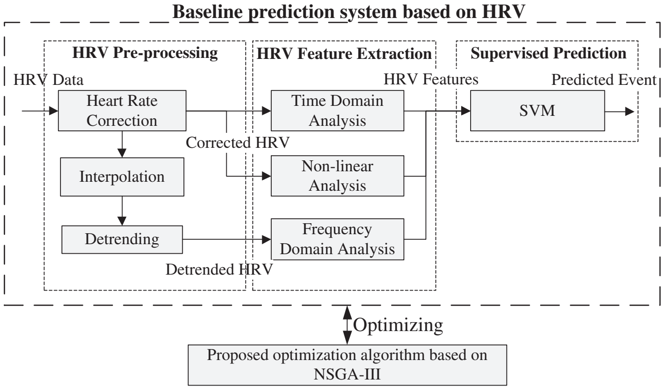

Fig. 2. Overview of the proposed method.

In this paper, optimizing the PAF onset prediction model is a multiple-objective problem. When GA is used for this class of problems, there are two common approaches: weighted sum, and Pareto dominance concept [24]. The former case is used in simple GA, in which multiple objective fitness functions are linearly combined with different weight coefficients into a single composite function. It was employed in previous works [8,18,19] to combine different performance metrics (i.e., sensitivity, specificity, accuracy rate and feature count). There are several drawbacks with this approach [24]. One of them is that the trial and error is required for tuning the weights values in order to obtain a solution with desired performance. Moreover, the simple GA only can return single solution per optimization run. As a result, the GA needs to be run multiple times for obtaining multiple solutions before trade-off among the solutions can be analyzed, which is not convenience for designer. It should be noted that, although the fitness functions in previous works [8,18,19] had multiple metrics, they did not perform the trade-off analysis because their interest was obtaining a single solution with highest accuracy. The drawbacks in the simple GA can be tackled by using the Pareto dominance concept based GA. In this paper, the state-of-the-art Pareto dominance based GA, which is called non-dominated sorting genetic algorithm III (NSGA-III) [25, 26], is adopted for optimization.

Finally, the GA based feature selectors in HRV based previous works [8,15–19] are belong to the type of wrapper method [27] because only the machine learning classifier is used to evaluate the fitness of the chromosome. Wrapper method has a well-known shortcoming: the risk of selecting a subset that is overfitting to the trained supervised classifier [8,27]. In the non-HRV research, the hybrid feature selection based on simple GA [28–30] has been proposed to mitigate this issue to certain degree. The hybrid GA uses the filter method (i.e., statistical test or correlation measure) to evaluate the feature, and only selects the feature that can pass certain evaluation criterion during the formation of feature subset. In the research based on HRV analysis, Boon et al. [8] cascaded