Abnormal Rhythm Detection from Single-lead ECG

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Cardiac arrhythmias affect millions of individuals worldwide and can lead to severe complications such as stroke or heart failure. Due to their transient nature, they can be difficult to diagnose with ambulatory electrocardiogram monitors. A system for long-term arrhythmia monitoring is proposed. It measures single-lead electrocardiogram and tri-axis acceleration signals. This system is composed of a beat detector to extract interbeat intervals and a classifier to detect arrhythmias.

Millions of individuals suffer from cardiac arrhythmias (CAs). While most CAs are not directly life-threatening, they can lead to severe complications. Atrial fibrillation, the most common CA, affects between 2% and 4% of the adult population and is associated with substantial morbidity and mortality. In addition, ventricular arrhythmias are the cause of approximately 80% of sudden cardiac deaths. CAs may cause symptoms such as palpitations, shortness of breath, or fainting. However, symptoms are not necessarily present, and many patients are asymptomatic which prevent an early detection.

A 12-lead electrocardiogram (ECG) reviewed by a cardiologist is the gold standard to diagnose CAs. However, it is not applicable for long-term monitoring and thus might miss transient CAs. Consequently, long-term monitoring is usually performed with a Holter. A common drawback is the necessity to manually review Holter recordings of 24 hours or even several days, which is expensive and time-consuming. Usually, automatic systems are used to tag parts that most likely include CAs to be reviewed by a specialist. Such a system to detect CAs from a single-lead ECG and tri-axis acceleration signals recorded by a sensor that can be worn over long periods of time is proposed. It combines a detector to extract interbeat intervals (IBIs) and a recurrent neural network to classify CAs. This system performs CA detection with the following steps:

- Beat detection from ECG
- Extraction of IBI windows of 30 seconds
- Exclude IBI windows with motion based on acceleration
- IBI outlier detection
- Abnormal rhythm classification

Abnormal rhythm classification is performed with a recurrent neural network composed of two layers: a gated recurrent unit layer that takes sequences of IBIs as input and a sigmoid layer to output the probability of abnormal rhythm. The classification step yields a prediction for each IBI window from one of the following classes: abnormal, normal, tachycardia, or undecidable. The undecidable class is used to indicate that a reliable decision is not possible due to poor ECG signal quality.

The system was evaluated on two datasets collected with the Bodyguard 3 device (Firstbeat Technologies, Jyväskylä, Finland) shown in Figure 1. The first dataset was collected at Hôpital Pourtalès, Neuchâtel, Switzerland, from patients with suspected CA during 24-hours monitoring. The second dataset was collected at KNF-Laboratoriot Oy, Helsinki, Finland from sleep apnea patients during overnight respiratory polygraphy. These two datasets include the following rhythms: atrial bigeminy, atrial fibrillation, normal sinus rhythm, second degree heart block, sinoatrial block, sinus bradycardia, supraventricular tachyarrhythmia, ventricular bigeminy, and ventricular tachycardia.

Figure 1: Bodyguard 3 device by Firstbeat Technologies.

After excluding IBI windows with motion, multiple reference annotations, and undecidable predictions, 49,610 IBI windows of 30 seconds were used to compute performance metrics. The global accuracy was 96.7% and the metrics per class are reported in Table 1.

Table 1: Performance metrics for each class (TPR: true positive rate, TNR: true negative rate, PPV: positive predictive value, NPV: negative predictive value, F1 score: model accuracy).

Class	Abnormal	Normal	Tachycardia
Accuracy	98.8%	96.7%	97.9%
TPR	82.0%	97.3%	N/A
TNR	99.4%	82.0%	97.9%
PPV	85.4%	99.3%	0.0%
NPV	99.3%	54.5%	100.0%
F1 score	83.7%	98.3%	0.0%

The NPV for normal rhythm is quite low indicating too many false negatives for this class, and the TPR and PPV for abnormal rhythm are under 0.9 showing that there is still room for improvement. Nonetheless, the proposed system [1] provides a robust solution to process daily life data, automatically rejecting low quality ECG, and detecting abnormal rhythm with a global accuracy above 95%. Performance can be further improved by combining successive IBI windows.

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[1] J. Van Zaen, *et al*., "Abnormal rhythm detection from a single-lead ECG via a recurrent neural network," Computing in Cardiology (2023).