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An integrated index for detection of Sudden Cardiac Death using Discrete Wavelet Transform and nonlinear features

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ABSTRACT

Early prediction of person at risk of Sudden Cardiac Death (SCD) with or without the onset of Ventricular Tachycardia (VT) or Ventricular Fibrillation (VF) still remains a continuing challenge to clinicians. In this work, we have presented a novel integrated index for prediction of SCD with a high level of accuracy by using electrocardiogram (ECG) signals. To achieve this, nonlinear features (Fractal Dimension (FD), Hurst's exponent (H), Detrended Fluctuation Analysis (DFA), Approximate Entropy (ApproxEnt), Sample Entropy (SampEnt), and Correlation Dimension (CD)) are first extracted from the second level Discrete Wavelet Transform (DWT) decomposed ECG signal. The extracted nonlinear features are ranked using *t*-value and then, a combination of highly ranked features are used in the formulation and employment of an integrated Sudden Cardiac Death Index (SCDI). This calculated novel SCDI can be used to accurately predict SCD (four minutes before the occurrence) by using just one numerical value four minutes before the SCD episode. Also, the nonlinear features are fed to the following classifiers: Decision Tree (DT), k-Nearest Neighbour (KNN), and Support Vector Machine (SVM). The combination of DWT and nonlinear analysis of ECG signals is able to predict SCD with an accuracy of 92.11% (KNN), 98.68% (SVM), 93.42% (KNN) and 92.11% (SVM) for first, second, third and fourth minutes before the occurrence of SCD, respectively. The proposed SCDI will constitute a valuable tool for the medical professionals to enable them in SCD prediction.

1. Introduction

Sudden Cardiac Death (SCD) is an unexpected and sudden death of a person from known or unknown underlying cardiac causes within a short period of time (<1 h) after the onset of symptoms [46,9,66]. SCD is an alarming cardiac event that can significantly strip off a person's life within several minutes [11]. In spite of decline in death from cardiac disease in the industrialised world for the last two decades [26,52,53,13], approximately 20% of all sudden and unexpected deaths are still reported to occur, most frequently caused by Ventricular Fibrillation (VF) or asystole [56]. It is estimated that the death caused by SCD alone is 10 times higher than the deaths by traffic accidents in the EU, and USA combined and 250,000–300,000 lives annually in the USA alone [39,56]. It accounts for more than 50% of all deaths from cardiovascular diseases and more than 12% of all natural or sudden death worldwide [67,58,2,47,15]. However, precise worldwide figures are currently not available due to the lack of emergency medical facilities in most regions [10]. These alarming statistics emphasize the importance of this societal challenge and the need for attempts to improve SCD risk prediction methods.

The process of death in almost 84% of SCD patients is ventricular tachyarrhythmias (including VF and Ventricular Tachycardia (VT)) and 16% is due to bradyarrhythmia [63]. These arrhythmias often lead to Sudden Cardiac Arrest (SCA), which renders the heart unable to pump out the blood effectively. Then, unattended SCA leads to SCD. There are numerous other risk factors identified for SCD, such as Coronary Artery Diseases (CAD), Valvular Diseases (VD), previous Myocardial Infarction (MI), and genetic factors [66]. Research worldwide has focused on this severe health problem with the goal of developing an efficient way of predicting

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the risk of SCD using invasive and non-invasive techniques [1,59,35,28,30,50]. Studies show that the QT interval/dispersion and Heart Rate Variability (HRV, namely the RR interval in an ECG signal) from the ECG recordings are the most prominent electrophysiological indicators for SCD risk assessment [43,29]. However, QT interval measurement is complex and there are reported negative results of its prognostic ability [64]. HRV signal analysis has proved to be a strong and accurate mortality predictor after MI [48]. HRV is decreased in a person with higher risk of ventricular arrhythmia and SCD [37]. VanHoogenhuyze et al. [68] used Standard Deviation (SD) of the mean sinus R–R intervals (SDANN) and mean of SD from HRV signals. The study claims that the value of HRV is lower in SCD patients compared to normal young subjects.

Even though linear methods are used for HRV analysis, information/ability to predict SCD is lacking in such techniques [63,14]. Recently, researchers have used nonlinear methods of HRV analysis to predict SCD from HRV signals, as these methods provide more information compared to the linear methods [36]. Huikuri et al. [27] described the nature of ECG signals by means of a non-linear short-term fractal scaling exponent α_1 (DFA α_1), as a useful independent risk predicting factor for SCD in 446 survivors of acute myocardial infarction with a depressed left ventricular function ejection fraction $\leqslant$35%. The study claims DFA α_1 can identify the worse cumulative (arrhythmic and non-arrhythmic cardiac deaths) survival during 1200 days of follow-up, as compared with a Standard Deviation of Normal-Normal (SDNN) and very low-frequency spectral component ($p < 0.001$). In a study by [45], the short-term fractal scaling properties of the heart rate were found to indicate increased risk of SCD in a random population of elderly subjects. Furthermore, James et al. [34] developed a novel non-linear algorithm, which used the time-dependent Point Correlation Dimension (PD2i) that was derived from HRV. They reported 100% specificity and 85% sensitivity in detecting VF/VT ($p < 0.01$).

In comparison with the above studies which focus on the HRV signal analysis, our present work proposes a novel algorithm which directly uses ECG signal to predict SCD risk. In our work, features are extracted by applying nonlinear analysis methods (Fractal Dimension (FD), Hurst's exponent (H), Detrended Fluctuation Analysis (DFA), Correlation Dimension (CD), Approximate Entropy (ApproxEnt), Sample Entropy (SampEnt)) on two level DWT decomposed ECG signals of normal subjects and subjects prone to SCD. The informative features are selected from the extracted features by using a ranking process, and then used in Classifiers like Decision Tree (DT), k-Nearest Neighbour (KNN), and Support Vector Machine (SVM) for classification.

This whole process is applied to individual components of the ECG signals (at consecutive intervals of 1 min) i.e. first interval before SCD (first one min before SCD), second interval before SCD (2 min before SCD), third interval before SCD (3 min before SCD) and fourth interval before SCD (4 min before SCD). The accuracy of predicting if the subject is susceptible to SCD or not is calculated for each of the above mentioned time intervals. Fig. 1 shows the block diagram of the proposed method for SCD ECG signal classification. Furthermore, a novel Sudden Cardiac Death Index (SCDI) is then presented through a judicious combination of the non-linear features.

2. Materials and methods

2.1. Data acquisition

The data required for the proposed method was obtained from the open access MIT-BIH SCD Holter database and the Normal

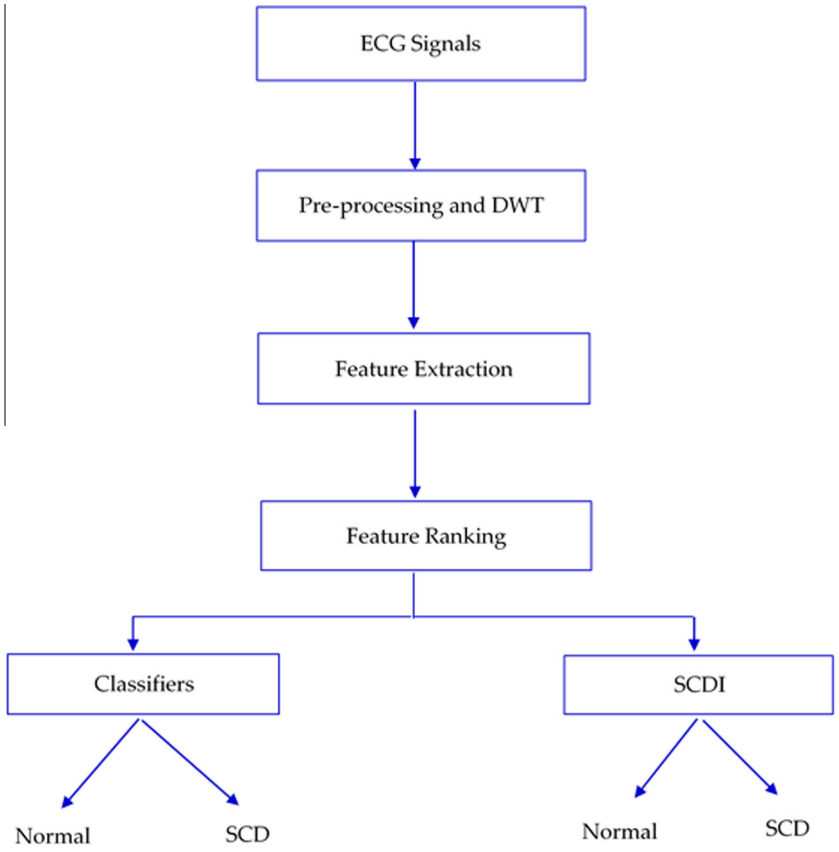

Fig. 1. Block diagram of the proposed methodology for SCD ECG signal classification.