Abstract

Cardiovascular diseases (CVDs) continue to be a leading cause of death globally, necessitating advanced methodologies for the early detection and classification of cardiac abnormalities. Among these, cardiac arrhythmia (ARR), characterized by the irregular electrical activity of the heart, is a major cause of cardiac mortality. To address the issue mentioned above, this thesis proposes innovative approaches using electrocardiograph (ECG) signals that leverage fragment (a segment or portion of ECG recording) and beat (a single ECG cycle) level classification frameworks in single and multi-label scenarios to accurately identify cardiac anomalies. This work explores diverse multi-class classification systems to identify ARR and associated disorders.

Studies suggest that atrial arrhythmias and congestive heart failure (CHF) are closely related, with one aggravating the other. This leads to the first contribution of the thesis, where machine learning techniques are employed to develop a robust model capable of discriminating complex patterns associated with ARR and CHF. The proposed approach involves hand-crafted features and transfer learning embeddings to classify ARR, CHF, and normal sinus rhythm at the fragment level. This work focuses on investigating the interaction between ARR and CHF, acknowledging their simultaneous presence and mutual impact on each other. This comorbidity serves as motivation for early detection of the diseases, potentially halting the progression from one to another. The initial investigation dealt with linear and nonlinear hand-crafted features and self-extracted transfer learning embeddings taken independently, followed by their fusion to combine information from both approaches. With considerable improvement in results, our proposed model also effectively addresses the subject-specific classification issue of state-of-the-art methods.

Further investigation into the literature shows that ARR consists of various sub-categories, some of which are life-threatening, emphasizing the significance of prompt diagnosis and intervention. Hence, the second contribution includes subclassifying ARR by employing a novel time-frequency technique, wavelet scattering transform (WST), at the fragment level. Experimentation shows that WST, which exhibits translation-invariant and deformation-stable representation, was found to be beneficial to categorizing the closely related subclasses of ARR. WST outperforms existing techniques and the proposed framework generalizes well on a different database. Also, the WST offers a deeper understanding of ECG patterns related to ARR compared to standard convolutional neural networks.

Following the subclass classification of ARR at the fragment level, we extended our study into beat-level subclass classification of ARR, a method widely employed in ARR beat categorization. Inspired by WST and its architectural resemblance to convolutional neural networks (CNN), the next contribution targets the beat-level classification of ARR using a WST-inspired CNN framework. Individual experiments and analyses are conducted for WST and CNN models to gain insights into their efficacy in ECG beat detection in intra and inter-patient paradigms. The interpretability of the models is also analyzed for different ARR beats.

Finally, we also consider realistic scenarios where real-time ECG recordings often have multiple correlated classes in a single fragment. To get a practical perspective on the diagnosis of correlated diseases, the next contribution considers multi-label ARR fragments. Motivated by the performance of hand-crafted features and time-frequency representation of the first contribution, the same is used to classify multi-label ARR fragments employing a standard Label Powerset multi-label classification framework. This framework preserves the correlation between diseases and offers valuable insights into the features relevant to disease detection.

Overall, this thesis highlights the importance of analyzing handcrafted features in different aspects of classifying ECG signals. Despite the notable advancements in neural network architectures, our findings indicate that it is crucial to thoroughly investigate manually crafted features to obtain relevant information from the ECG characteristics. By conducting such explorations, this research contributes to the continuous advancements in cardiac health monitoring and diagnosis, providing experts with a precise tool to identify and manage various cardiac irregularities, particularly those linked to ARR.

Keywords: Electrocardiograph, Cardiac arrhythmia, Congestive heart failure, Hand-crafted features, Single-label, Multi-label, Transfer learning, Wavelet scattering transform, Convolutional neural network.