

摘 要

心律失常是心血管疾病中最常见的一组疾病。临床上心律失常的诊断由专业医生对病人的十二导联心电图（Electrocardiogram, ECG）进行分析推断得出。近些年数字医疗的发展使得心电数据呈现爆炸式增长。同时由于心律失常类型多，病理情况复杂，使得误诊时有发生。因此实现心律失常的自动化、智能化识别成为热点研究方向。

基于机器学习的心律失常自动识别算法严重依赖人工特征的设计，这使得识别过程及结果具有较高的主观性，且无法捕捉到心电图深层次的特征。基于深度学习的心律失常自动识别算法通常专注于单导联心电图的特征提取，继而融合不同导联训练后的特征进行再训练。这种方法在训练初期忽视了不同导联之间的相关联系，导致所提出的模型在部分心律失常类型分类性能低下。在算法不断精进的这段时间里，市面上出现的多种便携式设备也增添了实时记录心电图的功能，这为预防心律失常和提供自动识别创造了条件。受制于电极数量便携式设备无法同时获取完整十二导联 ECG 信号，这为利用十二导联 ECG 进行自动识别的算法造成了障碍。基于以上背景，本文主要进行了如下四项内容研究：

（1）本文提出了一种二维化十二导联 ECG 的方法并进行改进。十二导联 ECG 信号被转化为二维化数据作为深度学习模型的输入，该二维化数据既具备单导联信号在时间上的连续性又具有不同导联信号在空间上的相邻性。

（2）本文提出了一个通用的能够处理二维化数据的深度学习模型 DSE-ResNet。该模型能够在训练初期同时关注导联内部与导联之间的相关联系，实现二维化十二导联 ECG 在时间维度以及空间维度的特征提取。实验过程中引入了正交试验挑选超参数，并利用集成模型提升模型分类性能。

（3）本文对深度学习过程中导联信息的冗余性问题进行分析研究，旨在验证能否以损失小部分识别性能为代价换取兼容多种便携性设备进行高性能心律失常自动识别的可能性。换言之是在验证所有十二导联信息在智能识别过程是否需要全部使用。

（4）本文基于 Flask 框架构建了线上心律失常自动分类平台。用户可自主上传十二导联 ECG 采样文件，平台通过解析文件、加载数据和模型，最终给出识别结果并反馈至用户。

与近几年利用同一数据库的研究进行对比，结果表明本文建立的基于二维化心电图的深度学习模型在所有心律失常分类中取得的平均 $F_1 = 0.817$ ，在部分心律失常类型（例如心房颤动和传导阻滞）的自动识别中取得最高 F_1 分数。针对导

联信号冗余性的研究表明，双极肢体导联和单极加压肢体导联的捆绑在深度学习过程中存在信号冗余。

综上，本文基于二维化十二导联 ECG 信号，使用 DSE-ResNet 模型增强了心律失常分类的精确性，可作为心律失常诊断方向的辅助检测算法。同时本文对导联信息的冗余性进行了研究，验证了深度学习过程中部分导联信息缺失的可能性，为便携式设备减少测量复杂性和增强识别性能提供理论基础。

关键词：十二导联；二维化；深度神经网络；心律失常；导联冗余性

ABSTRACT

Cardiac arrhythmias are the most common group of cardiovascular diseases. The clinical diagnosis of arrhythmia is inferred from the analysis of a patient's 12-lead electrocardiogram (ECG) by a medical professional. Recent advances in digital health care have led to an explosion of ECG data. At the same time, the variety of cardiac arrhythmias and the complexity of the pathology make misdiagnosis a frequent occurrence. Therefore, the realization of automated and intelligent identification of cardiac arrhythmias has become a hot research direction.

The automatic recognition algorithm of cardiac arrhythmia based on machine learning relies heavily on the design of artificial features, which makes the recognition process and results highly subjective, and cannot capture the deep-level features of the ECG. The automatic cardiac arrhythmia recognition algorithm based on deep learning often focuses on the feature extraction of single-lead ECG, and then fuses the trained features of different leads for retraining. This method ignores the correlation between different leads in the early stage of training. This leads to the low performance of the proposed model in classification of some cardiac arrhythmia types. During this period of continuous improvement of the algorithm, various portable devices appearing on the market have also added the function of recording ECG in real time, which creates conditions for preventing cardiac arrhythmia and providing automatic identification. Restricted by the number of electrodes, portable devices cannot simultaneously acquire a complete 12-lead ECG signal, which creates obstacles for the automatic identification algorithm using 12-lead ECG. Based on the above background, this thesis mainly carried out the following four research contents:

(1) This thesis proposes a two-dimensional 12-lead ECG method and improves it. 12-lead ECG signals are transformed into a two-dimensional plane as the input of the deep learning model. The two-dimensional plane has both the temporal continuity of single-lead signals and the spatial adjacency of different lead signals.

(2) This thesis proposes a general deep learning model DSE-ResNet that can handle two-dimensional data. The model can pay attention to the correlation between the leads and the leads at the early stage of training, and realize the feature extraction of the two-dimensional 12-lead ECG in the time dimension and the space dimension. During the experiment, an orthogonal experiment was introduced to select

hyper-parameters, and ensemble learning was used to improve the classification performance of the model.

(3) This thesis analyzes and studies the redundancy of lead information in the process of deep learning, aiming to verify whether it is possible to exchange a variety of portable devices for high-performance automatic cardiac arrhythmia recognition at the cost of a small loss of recognition performance. In other words, it is to verify whether all 12-lead information needs to be fully used in the intelligent identification process.

(4) This thesis builds an online cardiac arrhythmia automatic classification platform based on the Flask framework. Users can independently upload 12-lead ECG sampling files, and the platform will analyze the files, load data and models, and finally give the recognition results and give feedback to users.

Compared with studies using the same database in recent years, the results show that the two-dimensional ECG-based deep learning model established in this thesis has achieved average $F_1 = 0.817$ in all cardiac arrhythmia classifications, and in some cardiac arrhythmia types (such as atrial fibrillation and Highest score in automatic identification of conduction block). Research on lead signal redundancy has shown that bundling of bipolar and unipolar pressurized limb leads can be redundant during deep learning.

In summary, based on the two-dimensional 12-lead ECG signal, this thesis uses the DSE-ResNet model to enhance the accuracy of cardiac arrhythmia classification, which can be used as an auxiliary detection algorithm in the direction of cardiac arrhythmia diagnosis. At the same time, this thesis studies the redundancy of lead information, verifies the possibility of missing some lead information in the process of deep learning, and provides a theoretical basis for portable devices to reduce measurement complexity and enhance recognition performance.

Keywords: 12-lead, Two-dimensional, DNN, Cardiac Arrhythmia, Lead Redundancy