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Research on Waveform Reconstruction of Imaging Photoplethysmography

摘要

心脏信号对于评估人体的健康和情绪状态非常重要，心率变异性等特征在情绪识别、压力测试中应用广泛，成像光电容积描记（iPPG）信号可以实现远程非接触式的监测，从 iPPG 信号中可以计算心跳间期和 HRV 等特征，具有广大的应用前景。这些特征均依赖于心跳峰值的准确定位。但是目前传统的 iPPG 信号提取方法提取的信号质量较差，容易受到干扰产生非正常峰值，影响心跳间期的计算，本文主要从神经网络处理 iPPG 信号的角度进行研究，提出了一种 IMTransformer 神经网络对 iPPG 信号进行波形重构，该网络对传统 Transformer 网络结构进行了改进，加入 GRU 结构加强信号近端间的联系。同时计算了传统 Transformer 网络和语音增强中使用的 SETransformer 网络的处理结果，将其与已有文献使用的 LSTM 和 PulseGAN 神经网络结果进行对比。对比结果验证了本文提出的 IMTransformer 神经网络的有效性和优越性，该网络可降低心率计算误差、提高 iPPG 波形的信噪比和波形一致性，结果证明了通过 iPPG 计算更可靠的心脏特征如 HRV 特征的可行性，为面部视频在压力检测、情绪分类等领域拓宽应用奠定了基础。

关键词

成像式光电容积描记术、神经网络、心率计算、波形重构

Abstract

Cardiac signals are crucial for assessing human health and emotional states. Features such as heart rate variability (HRV) are widely applied in emotion recognition and stress testing. Imaging photoplethysmography (iPPG) enables remote, non-contact monitoring, from which heartbeat intervals and HRV can be derived, demonstrating broad application prospects. These features rely on accurate detection of heartbeat peaks. However, traditional iPPG signal extraction methods often yield poor-quality signals susceptible to interference-induced artifacts, which compromise heartbeat interval calculations. This study explores neural network-based approaches for iPPG signal processing and proposes an IMTransformer network for waveform reconstruction. The network improves upon the traditional Transformer architecture by incorporating a GRU structure to enhance local temporal dependencies. Comparative experiments evaluate the proposed IMTransformer against conventional Transformers, SE-Transformer (used in speech enhancement), and existing methods (LSTM and PulseGAN) from literature. Results validate the superiority of IMTransformer in reducing heart rate calculation errors, improving signal-to-noise ratio (SNR), and enhancing waveform consistency. This work demonstrates the feasibility of deriving reliable cardiac features (e.g., HRV) from iPPG signals, laying the foundation for expanding the application of facial video analysis in stress detection and emotion classification.

Keywords

Imaging photoplethysmography; IMTransformer; Heart rate calculation; Waveform reconstruction

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