

Self-Supervised Learning for ECG Representation Using Physiology-Informed Wavelet Transforms

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Deep learning for electrocardiogram (ECG) analysis typically requires large expert annotated datasets, which are costly and time-consuming to create. Self-supervised learning (SSL) provides an alternative by learning generalizable representations directly from unlabeled data.

However, many existing SSL methods rely on augmentations inspired by computer vision or natural language processing that do not fully exploit the physiological characteristics of ECG signals. In this work, we introduce a wavelet-based SSL framework designed to incorporate physiological structure into ECG representation learning by using two time-frequency views of each signal, generated using continuous wavelet transforms with the magnitude of a standard Morlet wavelet and the phase of a custom wavelet derived from a unipolar electrogram model of ventricular repolarization. These representations are used within a Bootstrap Your Own Latent (BYOL) architecture with a TimeSformer encoder to learn invariant embeddings.

The pretrained encoder is evaluated on the task of T-wave delineation using signals from the LUDB dataset. A regression head is finetuned to predict T-start, T-peak and T-end from the learned embeddings. The proposed method achieves state-of-the-art sensitivity compared with existing supervised approaches, reaching 99.96%, 99.96% and 99.92% for T-start, T-peak and T-end respectively, within the tolerance window suggested by AAMI.

Moreover, strong performance is maintained when fine-tuning with only 20% of labeled data, highlighting the advantage of the learned representations. Furthermore, UMAP visualizations confirm that the embeddings organise signals by morphological cluster, suggesting that wavelet-based SSL can effectively capture ECG morphology and enable robust downstream analysis with limited annotations.

