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# Comparative Evaluation of Diffusion-Based ECG Denoising and Hierarchical Kalman Filtering with Online Learned Evolution Priors

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ECG signal denoising is a crucial preprocessing task for accurate downstream cardiac analysis, as ECGs are susceptible to various noise interferences (e.g., baseline wander from respiration, muscle artifacts and electrode motion) that hide meaningful morphological features. This challenge is further amplified in wearable device conditions, where the environment, motion and respiration introduce frequent and diverse noise sources compared to stationary clinical equipment. Approaches like the Hierarchical Kalman Filtering With Online Learned Evolution Priors (HKF) [1] leverage adaptive state-space modelling of heartbeat dynamics to enhance signal quality, outperforming deep-learning methods, such as fully convolutional denoising Auto-Encoders, in tasks involving the noise removal of Additive Gaussian Noise (AGN). Recent diffusion-based generative models like: DMAM-ECG [2], BeatDiff [3] and DeScoD-ECG [4], have demonstrated state-of-the-art (SOTA) performance in denoising ECG signals corrupted by aforementioned noise interfaces. While HKF authors mention the model as an alternative to current deep-learning methods, no detailed comparison under real noise conditions between HKF and SOTA diffusion-based models currently exists. This work presents a comparative analysis of diffusion-based models against HKF under identical training conditions. All models were trained under the same time constraints, tracking the performance of each model every 10 epochs to ensure fair evaluation. Standard error metrics like: Sum of Squared Distances (SSD), Percentage RMS Difference (PRD), Maximum

Absolute Distance (MAD), and Cosine Similarity (Cos Sim), were used to quantify the performance of each model. We evaluated denoising performance on the ECG signals from the MIT-BIH Arrhythmia Database [5], which were synthetically corrupted with three different noise types from the MIT-BIH Noise Stress Test Database [6]: baseline wander (BW), muscle artifact (MA), electrode motion (EM), that appear in clinical settings. Noise power is set randomly at signal-to-noise ratios (SNR) varying from 20% to 200%. We conducted the analysis of performance by stratifying by noise level to quantify the robustness of each model with the increase of noise. In addition, we enforced inter-patient splits, ensuring no subject overlap in the training and testing sets, and the use of different noise segments, to prevent memorization and to evaluate the true generalization of models. Experiments were conducted in matched-noise scenarios, where the model was trained and tested on the same noise type using an unbalanced dataset for training with the test set retaining the global class ratio, while hyperparameters for each of the methods were set based on the provided information in each of their corresponding papers. Our results highlight the superior denoising results achieved by diffusion-based models in comparison to HKF under matched training (epoch/time) constraints, while at the cost of higher inference latency.

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