EDEN: A Deep Generative Emulator for Realistic Residual Noise Synthesis in Body Surface Potential Mapping

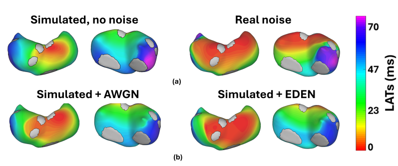
Sabrina Strazzeri Muñiz[1,2], Andrea Cano Cabañero[1,2], Marta Martínez Pérez[2], Ismael Hernández-Romero[1,2], María S. Guillem Sánchez[1,2], Rubén Molero[1,2]

[1] COR Group, ITACA Institute, Universitat Politècnica de València, Valencia, Spain
[2] Corify Care SL, Madrid, Spain

The accuracy of Electrocardiographic Imaging (ECGI) is limited by the inverse problem's ill-posed nature, making it highly sensitive to residual noise from myogenic activity and electrode instability. While previous research addressed single-lead synthesis, realistic multi-lead residual noise generation for Body Surface Potential Mapping (BSPM) remains largely unexplored.

This study introduces EDEN (Electrocardiographic Deep Emulator of Noise), a Generative Adversarial Network (GAN) that learns the underlying patterns of real-world data to generate highly realistic synthetic samples. Noise was isolated from 373 clinical recordings using Principal Component Analysis (PCA). To maintain spatial information by considering the geometry of the patient's torso, signals were projected onto Laplace-Beltrami (LB) eigenfunctions. To ensure training stability and avoid issues such as mode collapse, a Wasserstein GAN with Gradient Penalty (WGAN-GP) was implemented to synthesize the LB coefficients. Performance was evaluated using Cosine Similarity (S_C) and Wasserstein Distance (d_p).

EDEN successfully replicated clinical noise characteristics, achieving an S_C of 0.57 ± 0.11 and a d_p of 2.61 ± 1.40, significantly outperforming Gaussian baselines (S_C: 0.09 ± 0.02, d_p: 121.08 ± 2.10). Qualitative validation via Local Activation Time (LAT) maps confirmed that EDEN emulates realistic clinical distortions, whereas standard models produce unrealistic uniform blurring. This framework represents a relevant advancement in synthesis algorithms, providing a robust tool for validating ECGI solvers and training machine learning models without the privacy constraints associated with clinical data.



LAT maps reconstructed from simulated P-waves (a) without noise and with real noise, and (b) corrupted with AWGN and EDEN noise at 3 dB SNR.