

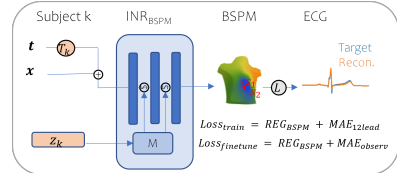
Generalized Implicit 12-Lead ECG Reconstruction

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Aims: MR-compatible ECG sensors are essential for cardiac monitoring but produce signals that differ from the diagnostic standard 12-lead ECG. We propose two reference-free methods for 12-lead ECG reconstruction that eliminate the need for outside-MR reference ECGs for subject-specific calibration: a generalized implicit neural representation (INR) network and a linear matrix solution using Laplacian smoothness regularization (baseline).

Methods: The proposed INR, a multi-layer perceptron with sine activations and scale-and-shift modulation layers, learns a mapping from atlas torso surface locations, trainable temporal encodings, and subject-specific latent vectors to dense body surface potential maps (BSPM), from which arbitrary leads can be reconstructed. During training, the model is optimized to accurately reconstruct 12-lead ECGs while encouraging smooth body surface maps. At test time, new subject-specific latent vectors are tuned to reconstruct observed leads (in our



The proposed INR network.

using a frozen INR model, with or without low-rank adaptation. The model was trained on healthy samples from the PTB-XL+ training set (N=8151, 12-lead ECG) and evaluated on healthy samples from the PTB-XL+ test set (N=914, 12-lead ECG) as well as in-house data (N=7, 12-lead ECG and 12 bipolar MR sensor leads, acquired outside the MR environment).

Results: The INR model outperformed the linear solution, achieving cross-correlation (CC) scores of 0.9, 0.95, and 0.80 (vs. 0.87, 0.87, and 0.79) for the three datasets. Further improvements are needed to enhance MR sensor reconstructions, particularly for the limb leads. Future work will focus on personalized torso models, advanced electrode localization, and evaluating model performance under magnetohydrodynamic distortions.

12-lead ECG reconstruction CC results ([chest leads only]).

Dataset “Observed” leads	PTB-XL+ test (III, V1, V5)	In-house (III, V1, V5)	In-house MR sensor leads
Matrix-solution	0.87 [0.88]	0.87 [0.89]	0.79 [0.85]
Proposed INR	0.90 [0.87]	0.94 [0.94]	0.80 [0.87]