Convolutional Neural Networks to Track Rotors from Simulated Voltage Maps During Atrial Fibrillation

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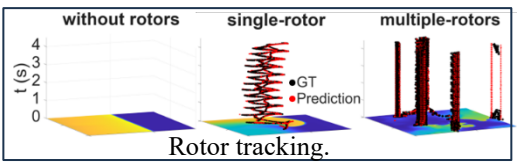
Motivation: Rotor-tip detection during atrial fibrillation (AF) using phase analysis typically requires offline processing and computation of intermediate maps before identifying phase-singularity points (PSPs), limiting its applicability in real-time scenarios. Convolutional neural networks (CNN)-based methods enable direct rotor-tip detection from transmembrane potential (Vm) data, eliminating the need for intermediate calculations and allowing real-time implementation.

Objective: Development of a CNN-based methodology for tracking rotors from Vm maps during AF.



Rotor tracking.

Methods: The dataset consisted of 30,000 simulated Vm maps (80% train, 10% validation, 10% test), evenly distributed across three categories (one-third each): without rotors, with a single-rotor, and with multiple-rotors. Ground-truth (GT) tip locations were obtained through PSPs detection. GT heatmaps were generated by centering a Gaussian (sigma=2) at each tip location. A CNN (U-Net) featuring a 3-layer encoder-decoder structure, followed by a regression layer, was used to predict the heatmaps using a weighted root mean squared error (RMSE) loss function. The peaks of the Gaussians in the GT and predicted heatmaps were identified as rotor tips. Performance on the test set was evaluated using the percentage of false-positive (FP) and false-negative (FN) detections, as well as mean RMSE, structural similarity index measure (SSIM) and localization error (LE).

Rotors	RMSE (↓)	SSIM (↑)	LE (mm)	FP (%)	FN (%)
Without	0.00	0.99	0.00	0.00	0.00
Single	0.02	0.98	1.47	0.20	0.20
Multiple	0.03	0.97	1.71	12.50	19.90
All	0.02	0.98	1.19	9.68	13.96

Results: The predicted heatmaps achieved a mean RMSE of 0.02, an SSIM of 0.98 and a LE of 1.19 mm. The rates of FP and FN detections were 9.68% and 13.96%, respectively. Performance across categories showed worse results for multiple-rotor cases, mainly due to a higher number of false detections (FP and FN). For true detections, the LE was like that of the single-rotor category (1.71 vs 1.47 mm). No tips were detected in the absence of rotors.

Conclusions: CNN-based approaches provide an efficient and accurate framework for rotor-tip detection directly from Vm maps, representing a promising tool for real-time cardiac electrophysiology analysis.