Finite Element-Based Space-Time Total Variation Regularization of the Inverse Problem in ECGI

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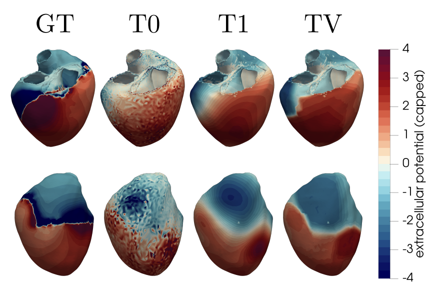
Introduction. The non-invasive reconstruction of cardiac electrical potentials has huge potential to shorten clinical intervention times and improve patient outcomes. However, due to the ill-posedness of the inverse problem of electrocardiography, an accurate and robust reconstruction remains challenging. Inspired by the wave-like behavior of action potential, we propose a novel regularization approach, based on a joint spatio-temporal total variation (TV) regularization in a finite element setting.

Methods. For smooth functions, the total variation regularization penalizes the derivatives of the electrical activity on the heart in the L^1-norm allowing for sharp transitions. The proposed method enables anisotropic smoothing in spatial and temporal directions. Reconstructions are computed by an iterative first-order primal-dual method. We simulate a ground truth activation with 100 timesteps utilizing a pseudo-bidomain model on a 3D rabbit model with 32 body surface potential measurements. The regularization method is compared to widespread zero- and first-order Tikhonov (T0/T1) regularization in a finite element setting by L^2-error, relative error, and correlation coefficient.

Results. The penalization of the spatial gradient in first-order Tikhonov outperforms the sparsity-enforcing zero-order Tikhonov regularization in all evaluation errors. Our proposed total variation regularization improves reconstructions of the electrical activity and outperforms state-of-the-art regularization methods for all error variants. The largest improvement of 1.67% is gained to a correlation coefficient of 0.642 with respect to the next best of T1.



Simulated epicardial potential (GT) and different reconstructions.

Conclusion. Promoting sharp interfaces with total variation instead of Tikhonov regularization benefits reconstructions. Additionally, combining space and time penalization enhances the spatio-temporal structure of the electrical activity on the heart.