



**A SLIDING WINDOW REGULARIZATION APPROACH IN
ELECTROCARDIOGRAPHIC IMAGING**

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Introduction: Cardiac arrhythmias are a prevalent form of cardiac disease caused by erratic electrical signals in the heart [1]. These and other forms of heart disease can lead to erratic electrical signals due to changes in the electrical properties of the cardiac tissue. While a 12-lead electrocardiogram (ECG) can often diagnose heart abnormalities, a more precise location of the diseased tissue is often required for treatment [2-3]. Electrocardiographic imaging (ECGI) can enhance the ability of the ECG to locate these problematic tissue regions in a noninvasive fashion. ECGI requires a geometric model of the patient's heart and torso, knowledge of their electrical properties, and electrocardiographic recordings from the torso surface. With this information, ECGI allows for the reconstruction of the electrical signals on the heart surface. However, ECGI is known to be an ill-posed problem, meaning that small changes in the inputs have an unbounded effect on the computed solution [4]. To counter the ill-posed nature of the problem, there are techniques called regularization, which constrain our solution to realistic values. Regularization can be applied instantaneously, to each time point in the reconstructed electrical signal, or globally, over the entire time of the reconstructed electrical signal. Applying regularization to each individual time point can lead to solutions that are choppy as the regularization value can change dramatically from time instant to time instant. Global regularization causes the solution to be overly smoothed in some regions and under-smoothed in others, as the regularization value is the same across all time points [4]. Thus, we propose a middle ground between these two regularization techniques: a sliding window regularization, where we regularize the solution in a sequence of small time windows. We hypothesized that this sliding window technique will lead to more accurate solutions that strike a balance between continuity and regularization.

Methods: Our sliding window technique regularized about a 39 ms window at each time point in the signal. The window size of 39 ms was chosen to match the time it takes the ventricles (the larger 2 chambers in the heart) to contract. We reconstructed the electrical signals from 10 premature ventricular contractions (a type of arrhythmia). These beats were obtained experimentally, where the electrical activity from the torso and heart surfaces were recorded. We compared the inverse solutions from instantaneous, sliding window, and global regularization techniques to the ground truth heart surface potentials using three statistical metrics: root mean squared error (RMSE), spatial correlation (SC), and temporal correlation (TC). The RMSE measures how well the amplitude of our inverse solution matches the ground truth. SC measures how well the spatial patterns of inverse solutions match the ground truth. Finally, TC measures how well the time signals match between the inverse solutions and the ground truth potentials.

Results: Figure 1 shows the three statistical metrics for the instantaneous, sliding window, and global regularization. The RMSE was similar for all three regularization techniques, with a

median of 0.56. The SC showed a decrease from instantaneous (median of 0.79) to the sliding window (median 0.77) to global regularization (median 0.74). The opposite trend was seen in the temporal correlation, with instantaneous regularization having the lowest median TC of 0.887, sliding window regularization in the middle with a median TC of 0.896, and global regularization the highest with a median TC of 0.904.

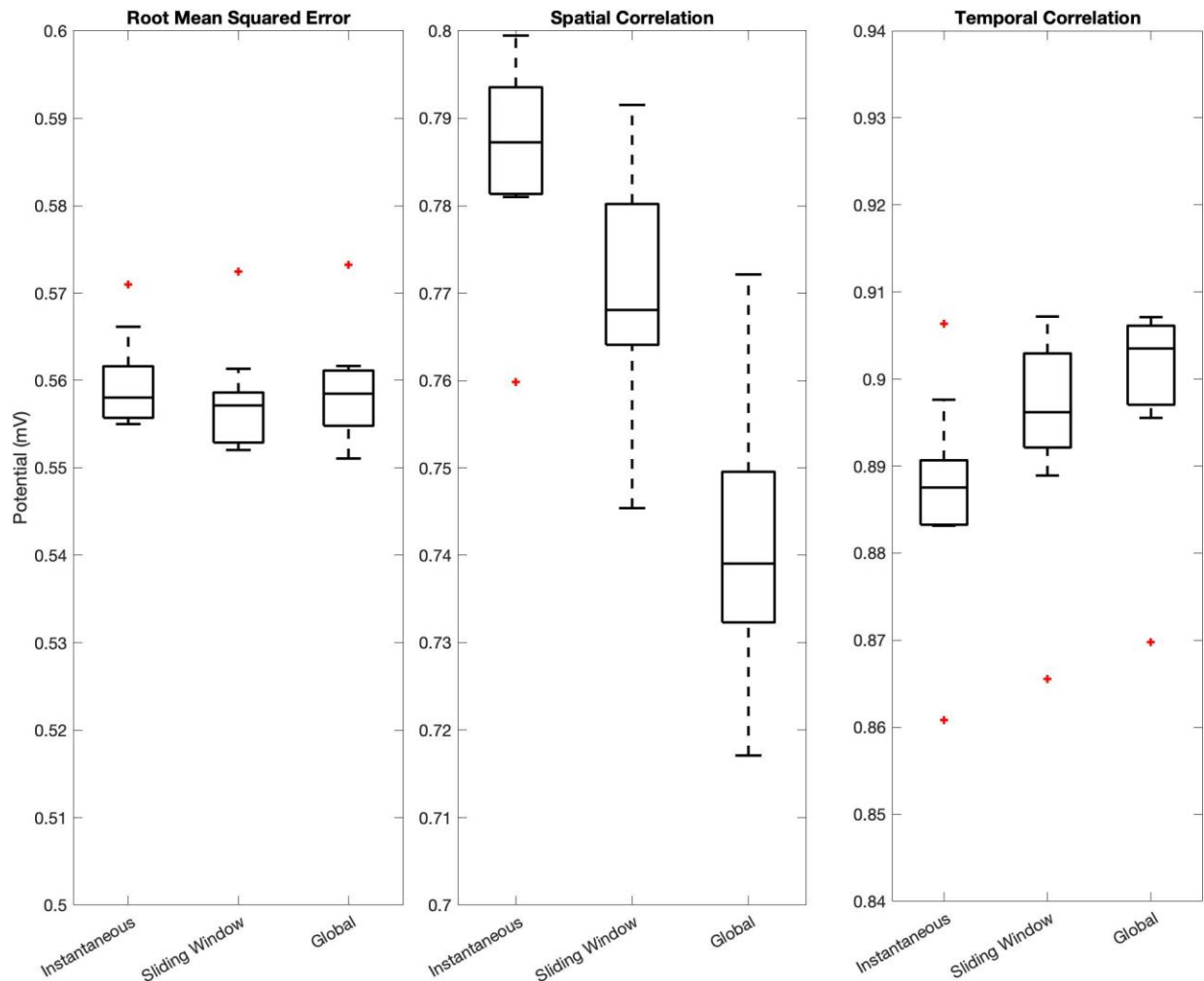


Figure 1. Comparison of Statistical Metrics. Box plots show the RMSE (left) , SC (middle) , and TC (right). Each compared instantaneous (left column), sliding window (middle column), and global regularization (right column). Outliers are marked by a red plus sign (+).

Discussion: Our sliding window regularization created solutions whose spatial and temporal correlations fell between those of the instantaneous and global regularizations, while maintaining a similar RMSE (Fig. 1). Our results indicate that the sliding window regularization can be used to achieve a middle ground between instantaneous and global regularization, with solutions that maintain a balance between continuity and regularization. The main limitation in our study was the small sample size and application to only one kind of arrhythmia. Future work will focus on applying our regularization technique to the reconstruction of other arrhythmias such as atrial fibrillation, which is a particularly challenging form of arrhythmia to reconstruct in a noninvasive fashion. Building this understanding of cardiac arrhythmias through the use of ECGI will allow us to provide individualized care for patients and improve outcomes.

References

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