A Resonant Model of the Action Potential in Cardiac Cells

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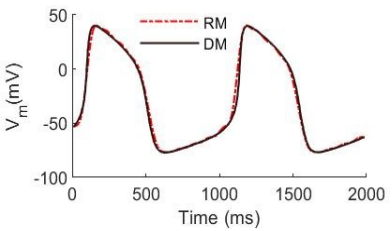
Aims: The mathematical models of the bioelectric activity in the cardiac conduction system can be used to study the impact of drugs, conduct hypothetical experiments, and for closed-loop validation of cardiac devices. These applications demand real-time performance. To meet the goal of real-time simulations, we have developed a high-fidelity mathematical model of cardiac cells. These models, called as Resonant Model (RM), are based on truncated Fourier Series and are adaptable for parallel execution.

Methods: The RM consists of a waveshape generator, state controller and coefficient memory. A set of sinusoidal oscillators constituted a waveshape generator (WG) and reproduced AP waveshape of a cell. Coefficients for WG were obtained using an iterative Levenberg-Marquardt algorithm by fitting to waveshape generated by the detailed electrophysiology (DEP) cell models. A state controller was designed with the help of a stateflow® to incorporate dynamic properties by responding to an external stimulus. To validate the model, results were compared with experimental and DEP model data.

Results: The RM consisting of 10 Fourier harmonics reproduced the AP morphology of detailed human atrioventricular node (AVN) cell model with the Pearson correlation coefficient (PCC) of 0.9882. In addition to capturing autorhythmic cell's bioelectric behaviour, AP generated by human atrial RM exhibited spike and dome morphology. This morphology was similar to experimentally recorded spike-and-dome APs of cardiac myocytes. The AP duration at 90% repolarization (APD90) obtained with the RM during 1Hz stimulation was 302ms. This was very close to 297ms duration obtained from detailed electrophysiology model.



AP waveform simulated in human AVN cell electrophysiology model (DM) (black solid) and RM (red dashed).

Conclusion: The RM capture the bioelectric activity of human atrial and human AVN with quantitative accuracy. The close to ideal values of PCC, suggests that the RM methodology is viable for capturing morphology of a variety of cardiac cells. This model development methodology can be easily extended to other biological periodic or quasi-periodic processes.