

Fractal Control and Optimization of Pacemakers: A Cyber-Physical Approach



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Cyber-physical systems (CPS) represent the information technology quest of the 21-st century for a better, cleaner, safer life which integrates computation, communication, and control with physical processes. Physical processes are predominantly non-stationary and require time dependent models for modeling and understanding their behavior. In contrast, in most current computing platforms, their workloads and design methodologies lack proper models for the time component and mostly assume stationary (i.e., time independent) behavior.

In this project, starting from the complex characteristics of CPS workloads, we present a novel statistical physics inspired model which is used to define a new optimal control problem that not only accounts for the observed self-similarity and non-stationarity properties of the CPS workload, but also allows for accurate predictions on CPS dynamical trajectories during the optimization process. More precisely, by taking the fractal characteristics exhibited by human heart rate activity (see Fig. 1), we construct a novel optimal control approach which seeks to regulate the heart rate while having a minimum impact on the control signals and thus on the biological tissue surrounding the artificial pacemaker. As shown in Fig. 2, designing fractal optimal controllers by solving nonlinear optimization problems offers a much more efficient solution than relying on memoryless and linear models proposed previously.

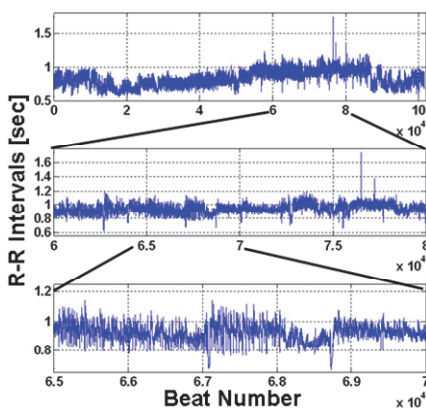


Fig. 1: R-R intervals collected via electrocardiogram recording of data from a healthy subject exhibit self-similarity.

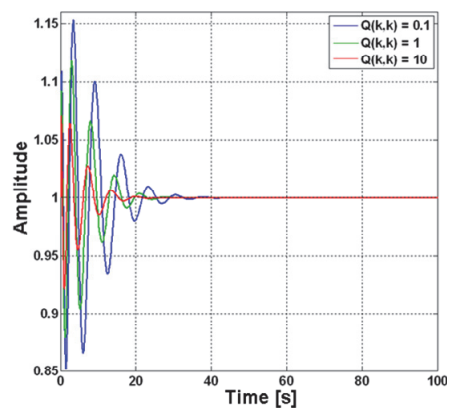


Fig 2: Step responses of the closed loop pacemaker system under the fractional optimal controller for different cost values.