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Firing rate control of a neuron using a linear Proportional-Integral (PI) controller

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Controlling the firing rate of a neuron is useful for experiments where you would like to see how a small perturbation to the neuron deviates it from its normal period. This is used to characterize phase response curves (PRCs). PRCs can be used to predict how networks of neurons will synchronize, which help in understanding dynamical diseases as epilepsy.

In PRC experiments, it is necessary first to apply a constant current in order to make the neuron to fire at a desired constant frequency and then series of short perturbations are applied to find the causal relationship between the timing of the perturbation and the change in the natural period of the neuron. Cells that spike regularly are preferred for this experiment because they tend to keep a constant interspike interval (ISI) at a given constant current. However, even when constant current is applied there are small variations in the ISI that obscure or confound the change of the period caused by the perturbations. These variations can be broken into two types, jitter, which characterizes the rapid changes in interspike intervals from spike to spike, and drift, which characterizes the slow changes in firing rate of the neuron over the time scales in which we measure the phase response curves, on the order of minutes.

We designed a linear Proportional-Integral (PI) controller to remove the slow drift and maintain the neuron at a desired firing rate by controlling the current applied to the neuron. We measured the change in ISI in response to steps of constant current. A discrete first order model was fit to the measured response. Then, the proportional and integral coefficients were estimated using a z-domain analysis to obtain critical damping of the neuron's response. When the controller is on, the histogram of ISI is centered at the set value and also is narrower than using constant current, which implies variance reduction.

The PI controller was then tested first on a model neuron and then and then implemented in a dynamic clamp and tested on pyramidal neurons from hippocampal rat slices. Furthermore, we implemented an autotuning algorithm that will estimate the coefficients on line. The program runs on Real Time eXperiment Interface (RTXI), which is a real-time Linux based software system for hard real-time data acquisition and control applications. The RTXI PI control module we have made will be available to the community trough the rtxi website.

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