Closed-loop control for microscale robotic neural interfaces

Sindhu Anand, Swathy Sampath Kumar and Jit Muthuswamy, *Senior Member, IEEE*

ADVANCES in implantable MEMS technology has made possible adaptive micro-robotic implants that can track and record from single neurons in the brain. The micro-robots can execute precise micro-scale movements using electro-thermal actuators [1, 2] that can now potentially enable us to maintain the microelectrode in close proximity to targeted single neurons in the brain for reliable, consistently high quality neural recordings in long-term experiments.

A closed loop control algorithm is proposed here for optimizing the signal-to-noise ratio (SNR) of multi-unit neural recordings by carefully adapting the position of the implanted microelectrode. Conventional tracking modalities need to overcome significant challenges due to the time-varying mechanical properties of the brain tissue-electrode interface. The following issues pose significant challenges in defining an effective control strategy: a) the complex non-linear stress response of brain tissue to a step displacement of microelectrode due to its hyper-elastic, viscoelastic properties b) non-stationarities in the neural signal caused by mechanical and physiological events in the interface and c) the lack of visual feedback of microelectrode position in brain tissue.

When the electrode moves by a step displacement, the real distance between the electrode and a neuron in the surrounding tissue evolves as a function of time and reaches steady state (with a *relaxation time constant*). If the tissue relaxation effects are not taken into account, the neuron of interest can become a moving target. Hence, the control algorithm proposed here estimates and compensates for this tissue relaxation time using empirical models of the constitutive properties of the brain tissue and that are validated with experimental measurements of force-displacement curves in brain tissue. The following stress relaxation model was used to fit the experimental data and estimate the relaxation time constants [3].

$$\frac{1}{\sigma^{m-1}} = \frac{1}{\sigma_O^{m-1}}[1+(m-1)\frac{t}{\lambda}]$$

where, σ is stress, σ_o is initial stress, m is the steady state creep rate exponent of the viscoelastic material and λ is the characteristic relaxation time of the material. The key feature of our proposed approach is our goal to achieve *quasi-static stress states*, where stresses at the brain-tissue interface are maintained at constant levels as the microelectrode is moved. Experimental analysis showed that the most optimal movement strategy to achieve quasi static stress levels involved an inchworm type movement where a forward motion of 30 μm is realized by a forward movement of 60 μm immediately followed by a backward movement of 30 μm within a span of 1 min.

The closed loop control algorithm has two phases: a) *Search phase* employs a bisection linear search algorithm for seeking neural recordings of interest b) *Optimize phase* where a gradient search algorithm maximizes the SNR once desired target neural recording has been achieved. The step size and inter-movement interval for microelectrode movement in these phases is derived from the above empirical model. Results of testing this optimal microelectrode movement strategy in a closed-loop micro-robotic control paradigm in short term rodent experiments will be presented. Results validated that it was possible to achieve a consistent SNR above 11 dB (which is the threshold above which spikes can be distinguished from the background noise) throughout the duration of the experiment using the bisection linear search algorithm alone (operating without the "optimize" phase). Over six-hour duration of continuous multi-unit recording, 12 interventional movements of 30 μm were made to the microelectrode to restore the SNR when it decreased below 11 dB.

References

[1] S. Anand, J. Sutanto, M. Baker, M. Okandan and J. Muthuswamy, "Electrothermal Microactuators With Peg Drive Improve Performance for Brain Implant Applications," *IEEE/ASME J. Microelectromech. Syst.*, vol. 21(5), pp. 1172-1186, Oct 2012.

[2] J. Muthuswamy, S. Anand, A. Sridharan, "Adaptive movable neural interfaces for monitoring single neurons in the brain," *Frontiers in Neuroscience*, vol. 5, article 94, Sep 2011.

[3] X. Xu, J. Hou, "A stress relaxation model based on viscoelastic solids based on the steady state creep equation," Mech. Time-Depend. Mater., vol. 15, pp. 29-29, Sep 2011.

This work was supported by the National Institutes of Health under Grants R01NS055312 and R01NS055312-S1.

S. Anand, S. Sampath Kumar, and J. Muthuswamy are with the School of Biological and Health Systems Engineering, Arizona State University, Tempe, AZ 85287-9709 USA (e-mail: jit@asu.edu).