WIENER KERNEL CHARACTERIZATION OF THE ELECTRICAL PROPERTIES OF NERVE AXONS

B.L. Bardakjian, D. Kundur, and W.N. Wright
Institute of Biomedical Engineering and Department of Electrical and Computer Engineering
University of Toronto, Toronto, Ontario, Canada M5S 1A4.

ABSTRACT

The response of a system to Gaussian White Noise (GWN) stimulus allows the estimation of the Wiener kernels which characterize the general input-output relationship of the system [1]. This study deals with the effects of changes in the system parameters on the Wiener kernels of a nerve axon model.

INTRODUCTION

The nonlinear models used to characterize physiological systems are categorized as parametric or nonparametric [1]. Parametric models describe how the system performs its function by explicitly using system parameters. On the other hand, nonparametric models describe the input-output relationship using a functional expansion which is comprised of mathematical kernels. Each term in the expansion is associated with a kernel of a certain order. In general, parametric models are easier to interpret than nonparametric models, but they usually involve many assumptions about the system and their parameters are difficult to measure experimentally. On the other hand, nonparametric functional expansions are more difficult to interpret but they are easier to measure experimentally. Therefore, combining the two approaches improves both prediction and interpretation of the nonlinear model. This is accomplished by varying the parameters of a parametric model and associating such variations with changes in the kernel shapes of the nonparametric model.

The objective of this study is to determine whether the zeroth, first, and second order Wiener kernels of the nonparametric model give insight into the state of the ionic channels of a nerve axon. The Hodgkin-Huxley (HH) equations [2] are used to represent the parametric model of a squid axon. The transmembrane voltage response to a GWN stimulus is used to estimate the zeroth, first and second order Wiener kernels of the nonparametric model.

METHODS

The response of the the HH model to GWN stimuli was determined numerically by solving the nonlinear ordinary differential equations describing the HH model [2], using the LSODE computer package [3]. The zeroth, first and second order Wiener kernels were estimated using *Korenberg's Fast Orthogonal Algorithm* [4].

The applied GWN stimuli (10000 samples with a sampling interval of 1 ms) were band limited (500 Hz) with zero mean and power level of 6.27 pW/cm^2. The HH model had the following parameters: a) The *Nernst potentials* for sodium, potassium and leakage were 115, -12 and 10.6 mV, respectively. b) The specific conductances for sodium, potassium and leakage were 120, 36 and 0.3 mS/cm^2, respectively. c) The specific membrane capacitance was 1 $\mu F/cm^2$.

The Wiener kernels were estimated when a) the ionic channels were not blocked, b) only the sodium channel was blocked, and c) only the potassium channel was blocked. Their sensitivity to the GWN power level was also investigated.

RESULTS AND DISCUSSION

1) The zeroth order Wiener kernel was approximately equal to zero and did not change significantly when the sodium channel was blocked, whereas it increased by a factor of 224 when the potassium channel was blocked. Thus, a large value of the zeroth order kernel indicates that the potassium channel is blocked.
2) The magnitude of the first order Wiener kernel changed when the power level of the GWN was

0-7803-1377-1/93 $3.00 ©1993 IEEE

changed and the ionic channels were not blocked. It started to increase after the threshold of action potential firing was reached, then it started to decrease when the frequency of the action potentials did not change significantly in response to increases in the GWN power levels. Thus, a sudden increase in the magnitude of the first order kernel indicates that the cell has reached the threshold for firing, whereas a sudden decrease in the magnitude indicates that the cell has reached a state of saturation due to refractoriness.

3) The second order Wiener kernel had a large positive peak when the ionic channels were not blocked but when the sodium channel was blocked it had a negative peak (Figure 1). Thus, a main negative peak in the second order Wiener kernel indicates that the sodium channel is blocked.

In conclusion, the zeroth, first and second order Wiener kernels can indicate excitability, refractoriness, and the state of ionic channels in a nerve axon.

ACKNOWLEDGMENTS

This work was supported by the Natural Science and Engineering Research Council of Canada.

REFERENCES

[1] P.Z. Marmarelis and V.Z. Marmarelis, *Analysis of physiological systems: The white noise approach.* New York: Plenum, 1978.

[2] A.L. Hodgkin and A.F. Huxley, "A quantitative description of membrane current and its application to conduction and excitation in nerves", *J. Physiol.*, vol. 117, pp. 500-544, 1952.

[3] A. C. Hindmarsh, "Odepack, a systematized collection of ode solvers" in *Scientific Computing*, R.S. Stepleman et al., North-Holland, Amsterdam, pp. 55-64, 1983.

[4] M.J. Korenberg, "Identifying nonlinear difference equation and functional expansion representations: The fast orthogonal algorithm". *Ann. Biomed. Eng.*, vol. 16, pp. 123-142, 1988.

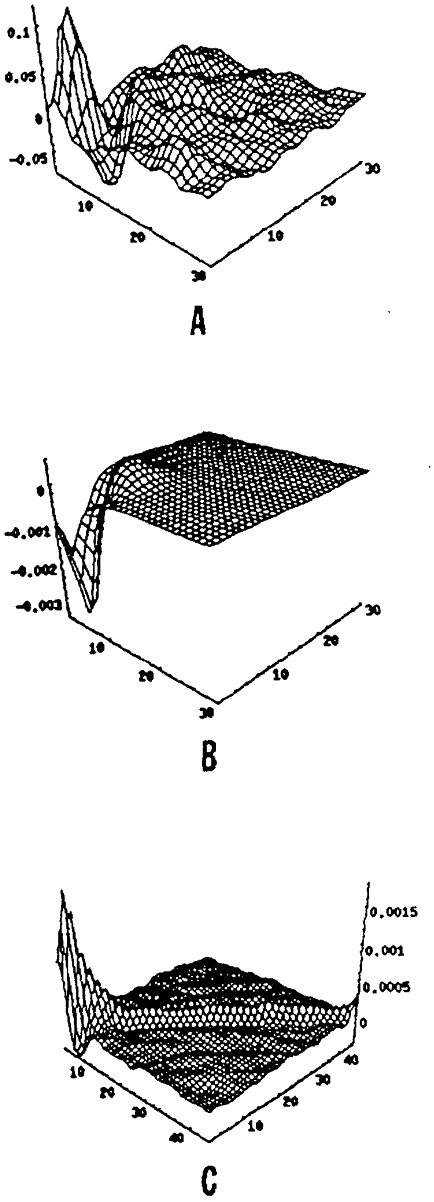

Figure 1: Second order Wiener kernels when a) ionic channels are not blocked, b) only sodium channel is blocked, and c) only potassium channel is blocked.