RESEARCH TRIANGLE INSTITUTE

Third Quarterly Progress Report

March 27 through June 26, 1984

NIH Contract N01-NS-2356

Speech Processors for Auditory Prostheses

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Introduction

The purpose of this project is to design and evaluate speech processors for multichannel auditory prostheses. Ideally, the processors will extract (or preserve) from speech those parameters that are essential for intelligibility and then appropriately encode these parameters for electrical stimulation of the auditory nerve on a sector-by-sector basis. Work in this quarter was directed at (1) completing the construction and beginning the checkout of a hardware interface between the Eclipse computer and patient electrodes, for use in tests to be conducted at the University of California at San Francisco (UCSF); (2) completing the first versions of the software for our computer-based simulator of multichannel speech processors, for use in the same tests; (3) obtaining and installing hardware and software components for our computer system at Research Triangle Institute (RTI), with the aim of making the computer system at RTI fully compatible with the one at UCSF; and (4) further development of our integrated field-neuron model of electrical stimulation by intracochlear electrodes. In this report we will briefly describe these efforts and outline our plans for the next quarter.

Hardware Interface

A preliminary description of the RTI interface for communication between the Eclipse computer and patient electrodes was presented in Appendix 1 of the last quarterly report for this project. Several design changes have been made since this description was written, including the addition of conditioning circuitry for reliable transmission of digital data between the computer room and the test site (the test site is several rooms away from the computer room and both locations are in noisy electrical environments); modification of the output driver circuit, in which the "charge filter" is eliminated and the linearity of output is improved; addition of an isolated AC power supply, to eliminate the need for frequent surveillance and replacement of batteries; modification of the logic decoder circuitry, to allow communications not only with the Eclipse but with a variety of other computers; and improvement of the artifact-suppression circuit for monitoring electrode impedances and intracochlear evoked responses. Although the hardware interface is now a more powerful and useful instrument than originally envisioned, these changes did require considerable effort to implement. At present, six of the seven boards in the interface have been constructed and are being populated with chips for a full functional checkout. Development of the controlling software for the unit is proceeding in a parallel effort. Our target date for completion of both the hardware and software is August 20. The unit will then be transported to UCSF for final installation, functional testing and extensive saftey evaluation.

Computer-Based Simulator

A preliminary set of notes on software development for our computer-based simulator of speech processors for multichannel auditory prostheses was presented in Appendix 2 of the last quarterly report for this project. A large effort was mounted in the present quarter to complete the first working versions of all programs in this computer-based simulator. These programs include the following:

CPEXEC — executive program for managing communications between and execution of other programs in the set of simulation programs;

DESIGN — program for design of a signal-processing system, in which the user specifies the function and topology of each block in a network of blocks;

MODIFY — program to modify signal-processing systems previously defined by program DESIGN;

PREPARE — program that transforms the files generated by program DESIGN into files that are used by program EXECUTE;

EXECUTE — program that executes the simulation of signal-processing systems on a "once-per-clock-tick" basis

SHOWNTELL — program for display of outputs generated by EXECUTE, either as graphs on the computer console or as acoustic signals produced over the D/A converter;

SAMPLE — program to sample speech and other data with the A/D converter, and to store these data on the disk in contiguous files with identifying headers;

ASNELEC — program to assign electrode channels to receive data from the outputs of EXECUTE, and to transform these data into the format for control of and communication with the hardware interface between the Eclipse and electrodes;

TEST — program to send data out to the electrodes from the files generated by program ASNELEC, to monitor and log patient responses to stimuli, to automate impedance measurements, and to verify that the proper electrode-selection plug is in place for the present test and patient.

At present, we have a working version of all programs except for ASNELEC and TEST. Some software has been written for these last two programs, but this code cannot be tested until the hardware interface is completed and until the Data Control Unit (DCU) and comminications chassis are installed in our computer system at RTI. As will be mentioned in the next section, we just received these pieces of equipment and installation at this time is incomplete.

Performance of the remaining programs in the set is most encouraging. We have evaluated the DESIGN, PREPARE and EXECUTE programs by specifying and then simulating a four-channel vocoder system that emulates one version of the present UCSF speech processor for multichannel auditory prostheses. The entire system could be specified in about fifteen minutes, and the time required for simulation of the system was comparable to the time required for simulation in a "benchmark" program that implemented the system with straight-line code. In contrast to the quick specification of the network using program DESIGN, preparation and debugging of the benchmark program required a full day of programming effort. Thus, our purpose for writing the programs listed above is clearly met in that we now have a tool for rapid and practical emulation of different speech processors for tests with single subjects. Because we plan to incorporate many improvements in the present set of programs during the next quarter, a full description of the RTI computer-based simulator of speech processors for multichannel auditory prostheses is deferred for now but will appear in our next quarterly report.

Hardware and Software for the RTI Computer System

Another activity of this quarter was to obtain and install hardware and software components for our computer system at RTI so that the RTI system would be completely compatible with the system at UCSF. This turned out to be a large undertaking. The hardware and software components included (1) a communications chassis; (2) a digital control unit (DCU 200); (3) an additional 128 kword memory board; (4) a programmable interval timer board; and (5) the Data General AOS operating system. The hardware components (1-4) have just been received from various suppliers, and are now being installed and tested. We have had the AOS operating system running for approximately two months. During this period we have become facile with its use and have converted most of our signal-processing programs originally developed under the RDOS operating system into programs that will execute under AOS.

Integrated Field-Neuron Model

The final major thrust of this quarter was further development of our integrated field-neuron model of electrical stimulation by intracochlear electrodes. As described in detail in the last quarterly report for this project, one component of the model calculates the electrical field patterns surrounding neural elements within the cochlea. This calculation provides estimates of the potential gradients along the course of axons for given geometries and types of electrodes, and for given stimulus waveforms. A finite-element technique is used for simulation of the electric field patterns and present work is focused on a two-dimensional model of a mid-modiolar cross section.

The other major component in the integrated field-neuron model is a Frankenhauser-Huxley description of events at the target neurons. Effort in this quarter was directed at writing and testing the software for this component of the integrated model. In the following paragraphs we will briefly indicate our strategies and objectives for determining the patterns of neural discharge that result from intracochlear electrical stimulation.

First, the results from the finite-element computation for a single neuron may be described by the equivalent electrical circuit shown in Figure 1. Re1 and Re2 are the series DC resistances of the electrodes 1 and 2, respectively. Ce1 and Ce2 are the electrode/tissue interface capacitances. Resistive dividers formed by the combination of Rax and Rbx (x ranges from 1 to N) are distributed along the course of the axon. The ratios of Rax to Rbx are adjusted to produce the node voltages (V1 to VN), as calculated by the finite-element model. Cs is the electrode cable shunt capacitance. The current driver is described as a Norton equivalent circuit whose parameters may be changed to represent the transcutaneous rf link or the high-voltage compliance current sources used with the percutaneous cable. Observation of

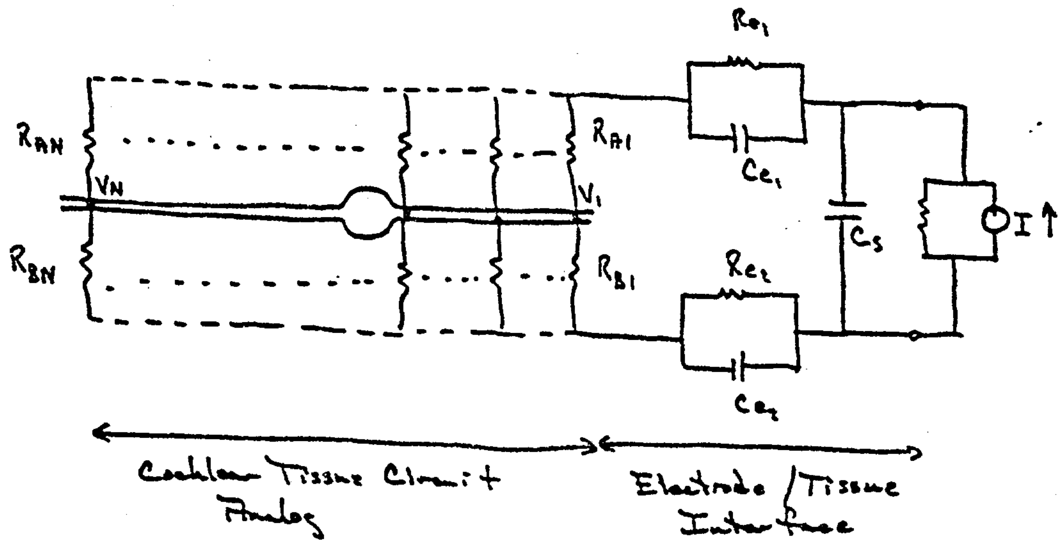


Figure 1.

Equivalent circuit of field calculation results.

the model demonstrates (1) that the absolute magnitude of the potentials along the course of the neuron is a direct function of the magnitude of the stimulus current and (2) that the relative ratios of the potentials along the neuron are a function of the physical geometry and resistive characteristics of the electrodes and surrounding tissue.

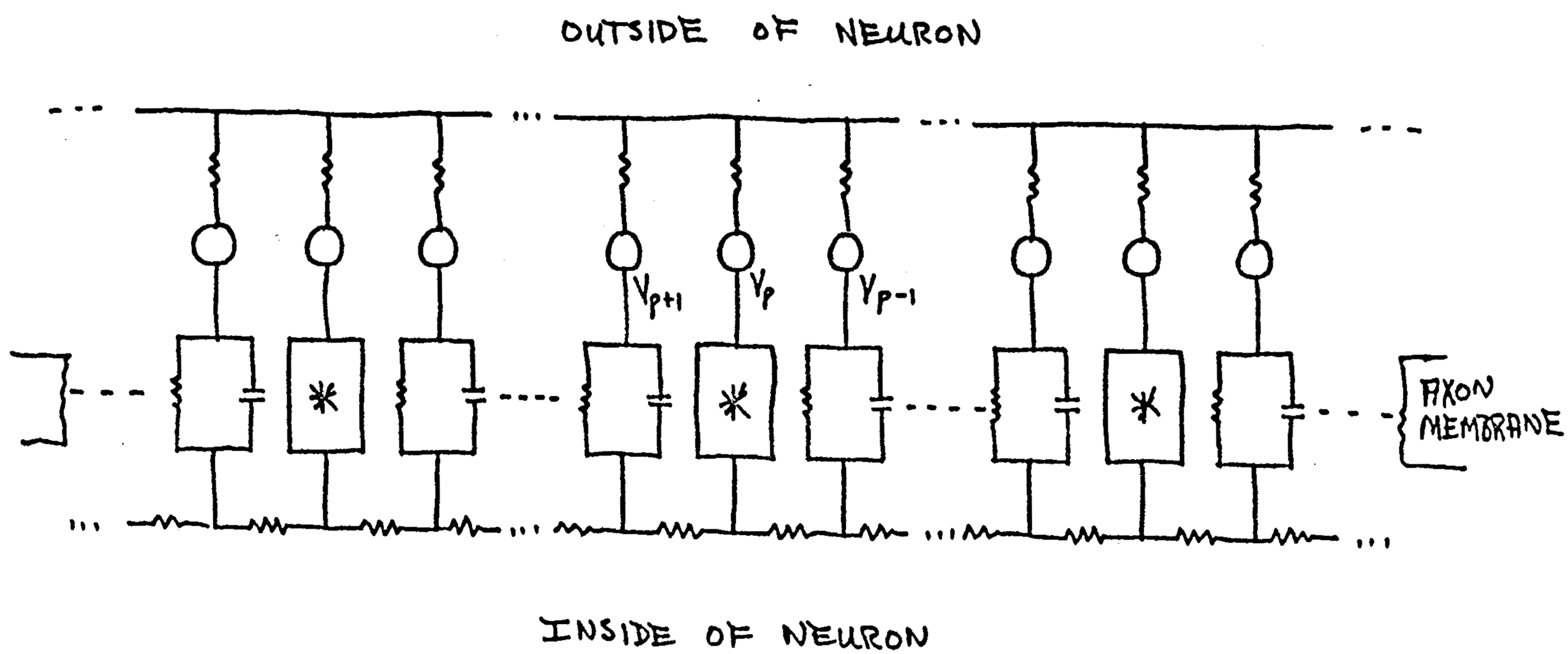
The motivating interest in the integrated model is in predicting and studying the discharge characteristics of the neurons themselves. Consequently, the next step of modeling is the calculation of neural responses to stimuli delivered by implanted electrodes. This moves the modeling problem into the time domain and therefore links the modeling work directly to the issues of speech-encoding strategies and the specification of stimulus current waveforms. It is here that the modeling approach may prove most valuable by providing insight into the factor controlling the temporal features of electrically-induced neural firing.

Temporal modeling is accomplished by feeding the calculated voltages along the neuron into a lumped-element model of a myelinated neuron. This approach is described schematically in Figure 2. A modification of McNeal's (1976) axon model of resistively-linked, Frankenhauser-Huxley nodes is used. The modified model accounts for the myelinated axon cable properties, which largely determine the conduction velocities of propagated action potentials.

Presently, an expanded, lumped-element model similar to that indicated in Figure 2 has been implemented on the Eclipse. Nine active nodes of Ranvier are included, each separated by ten myelin segments. The calculations involve the solution of a system of simultaneous, nonlinear node equations. The program for implementing these calculations is complex and not yet completely free of bugs. Once all bugs are identified and corrected, emphasis on further development of the program will be to increase the speed of computation by building "intelligence" into the integration and loop iteration algorithms. Several studies involving electrical stimulation of single fibers have been indentified for initial verification of the neural model. We hope to present results of these and other studies conducted with the integrated field-neuron model in the next quarterly report.

Plans for the Next Quarter

The most important activity planned for the next quarter is to begin patient testing at UCSF. Unfortunately, we were unable to begin testing during the last quarter because of technical problems with the percutaneous link of the patient implanted in mid March and because many of the tools we wanted to use in the tests were still undergoing development. Another patient will be implanted at UCSF in the near future, and we will be fully prepared for tests with this patient. Our present plan is to visit the UCSF team during the week of August 20 to (1) install and test the hardware interface for communication between the Eclipse and patient electrodes; (2) review the lists of experimental objectives that have been prepared by the UCSF and RTI teams, to decide on the set of experiments that will have priority for tests with this next patient; (3) install and test the software of our computer-based simulator of speech processors for multichannel auditory prostheses; (4) instruct the UCSF team on the function and use of the hardware interface and computer-based simulator; and (5) receive instruction on the details of psychophysical testing procedures at UCSF.



* indicates Frankenhauser/Huxley nonlinear membrane model describing voltage-dependent behavior of the neuron to electrical stimulation.

Figure 2. Neuron Model

Successful completion of these activities should provide a firm foundation for tests with the next patient, which hopefully will be well underway during the upcoming quarter.

In addition to the work just outlined (to prepare for tests at UCSF), we will continue to develop our software for simulation of speech processors and for the integrated field-neuron model. The directions we will take for these efforts have been indicated in previous sections of this report.