University of Florida
Increasing medical understanding through signal processing

For more than 14 years, Jose Principe, an associate professor of electrical engineering at the University of Florida, has explored biomedical engineering and signal processing. He is particularly interested in research involving the analysis of electroencephalograms (EEGs)Đtracings that show changes in electrical potential caused by brain activity.

Working with 14 graduate students in a lab of networked NeXT computers, Principe developed several interrelated projects that explore the uses of digital signal processing to medicine. To work toward their goals, Principe and his students rely primarily on *Mathematica* and the NeXT digital signal processing (DSP) chip. Principe says, "The *Mathematica* environment is excellent for prototyping and it offers good plotting facilities. And, of course, I place a high priority on the DSP. Biomedical signals (signals of physiological origin) are concentrated at low frequency, and you can do a lot of processing with the DSPĐeven real-time processing. Along with the NeXT user interface, this combination is what I've always wanted in a computer."

Principe adds, "Computers were developed to work with textĐas substitutes for typewritersĐbut that's not the correct paradigm for biomedical engineering, which lives with images and signals. To make the computer work optimally for us, we needed to develop tools to function like a text editor, but for graphics and signals instead of for letters and words."

Principe used a NeXT computer to build that tool. The Signal Editor is a software package created for NeXT computers by Principe and graduate student Haan-go Choi, used to visualize all types of electrical signalĐfrom EEGs to machine tool data to audio waves (music). Principe says, "With the Signal Editor, the computer becomes a scope, or, actually, more like a microscope, because the computer offers very accurate time and amplitude measurements of signals."

Working with the Signal Editor, a user can import a previously collected signal file, zoom in on specific portions, and measure amplitude/duration and slope. According to Principe, "The Signal Editor has display capability, but there's more. It's structured so that we can create our own signal processing functions and then visualize graphically the results of the processing on the computer screen. For instance, you can apply various digital filters with different parameters and compare the results of the filtering. So it offers an efficient way of visually comparing signal processing algorithms."

A practical medical application using this general-purpose tool relies on the Signal Editor and *Mathematica* to pinpoint the focus of epilepsy in the brain. The idea is to place a two-dimensional grid of electrodes on the exposed cerebral cortex of epileptics before brain surgery. The Signal Editor computes a spatial map of the brain's electrical field. Working with *Mathematica,* it is possible to animate a graphic representation and look for special features, that might indicate the region of epileptic focus. When removing the affected brain tissue, this will provide neuorosurgeons with the ability to plan their incisions more precisely.

Principe says, "My idea is to have this device in the operating room and to work closely with the neurosurgeon, providing a visual indication of the most probable focus of epileptic activity. Of course, it cannot be done in real time yet, but that is a goal of the project. We're still developing the algorithm and validating the method, but with the power of the DSP chip, we will be able to do real time."

The "Cortical Mouse": a new computer interface

Another project in Principe's lab uses samples of brain waves. Principe explains, "The Cortical Mouse project had two motives. One was to research new ways of communication between people and computers. But what really attracted me to this project was to help quadriplegics communicate with computers."

To explore these areas, Principe and graduate student Sina Eatemadi chose to look at event-related potentials (ERPs)Ðtransient waveforms produced by brain structures in response to external stimulus. According to Principe, "It is known that ERPs contain information about the intention of the subject and in response to stimulus from the environment. The problem with ERPs is that they are transient signals of small amplitude, and in the large background noise of the ongoing brain activity they are hard to quantify."

Conventional methods of detection use mathematical averaging techniques, but these were inadequate for Principe's purposes because he wanted real-time response. In addition, simple quantification is not enough: he needed to extract reliable parameters from the ERPs. That, according to Principe, is where neural netwroks come in.

To detect ERPs and obtain information from them, Principe and Eatemadi use a neural network they developed in assembly language and implemented in the NeXT DSP chip. The subject's brain waves are sampled using an Ariel digital microphone, and then sent to the DSP chip, where the neural network is trained to recognize patterns in the ERP responses for each individual subject. The DSP processes the electrical signals and forwards them to the NeXT computer as directional cursor commands.

Principe explains, "The information encoded in ERPs is not very specific. With the present technology, we can't discriminate between actions that the subject wants to do and what he thinks. So, presently, the interface works as a dialog initiated by the computer. The quadriplegic sits in front of the computer, which has a menu-driven screen. To initiate a specified action, the subject must move the cursor to the appropriate command. So the first thing to do is control the motion of the cursor."

To do this, the computer presents the words *up, down, left,* and *right* in sequence on the screen. Every time a word is flashed, the subject is instructed to think "yes" or no. Principe points out that the process of controlling on-screen cursor movements in this experiment is a highly structured and slow communications protocol. It is in no way simply a matter of "controlling the computer with brain waves.

"What we are currently doing is very structured and difficult to extend," he says. "But it has elements that may be highly effective for specific applications. After all, yes/no information can be extremely powerful in terms of communication. It all depends on the question, right?"

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