Biological Information Interface Technology

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Abstract

We are studying biological information interfaces to enable people to interact with information via enhanced senses and limbs. In this article, we discuss the future possibilities of this interface technology and introduce our current research on the measurement, analysis, and application of biological signals in nerves and muscles. We are starting to use such biological signals as control signals for input operations.

1. Importance of biological information interfaces

As communications technology has advanced there has been a parallel increase in the types of information being exchanged. Interface technology plays an important role in ensuring that all types of information can be communicated smoothly and efficiently.

Against that backdrop, we have placed importance on research into communication processes inside the human body and—based on the concept of using our bodies more naturally—are developing technology for interfacing with biological information, the information behind the body's electrical signals. With that goal in mind, we are conducting research into user interfaces (biological information interfaces) that utilize biological information more aggressively. Biological information interfaces will manipulate all sorts of information and devices as if the information were human knowledge and the devices were the hands or feet of a human being. We aim to enhance not only the five human senses, but also a person's knowledge and the effective range and ability of his/her limbs by having biological information interfaces extend a human's internal communication abilities beyond the body to the outside world. This approach will also lead to human-centered communication and computing (HC^3) [1], making biological information interfaces an important technology.

2. Research approach

There are various types of biological information. We have been focusing on the phenomena that occur when information is processed and transmitted inside the body, such as those recorded by electromyogram (EMG), electroencephalogram (EEG), magnetoencephalogram (MEG). Although the ideal way of measuring human intention, emotion, or action would be by measuring brain activity, the human brain is so complex and processes such great volumes of information that it is difficult at present to isolate and extract from the brain only one particular type of information.

In contrast to those in the central nervous system such as the brain and the spinal cord, functions in the peripheral nervous system, such as muscle and neuron functions, are specialized and much easier to observe and measure. They perform only uncomplicated information processing. In our studies, therefore, we decided to launch an analysis of biological information measured in the peripheral nervous system, while keeping in mind that we are preparing for a more serious study of the brain in the future.

The study of selected functions in the peripheral nervous system will still enable us to apply the results

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and move further ahead in our overall research. When vocal sound is generated, for example, there is movement in the articulatory and vocal organs. We can measure that movement and use the results in speech recognition applications. It is also possible to create a virtual keyboard that recognizes the slight movements of fingers as if they were typing on a keypad. Or by quantitatively measuring the activity occurring inside neurons we believe it will be possible to quantify a user's feelings.

3. Muscle activity and measurement

Motor neurons carry impulses from the brain that reach individual muscle cells and cause muscle fibers to contract with electrical pulses. The electrical discharges are recorded as EMG. Since EMG is correlated with the force generated by a muscle, it is possible to measure the signals and thus grasp the details of muscle activities. One example of a device that recognizes muscle activities is a myoelectric prosthetic hand that recognizes intended finger movements from the EMG signals it monitors in the arm.

EMG signals are measured by attaching electrodes to the surface of the skin. This method is efficient because the electrodes are attached to the skin and do not invade the body. Also, measuring EMG is much simpler than measuring activities inside neurons or inside the brain. For those reasons, EMG measurement offers a high likelihood of success for use as a biological information interface.

4. Neural activity and measurement

Figure 1 shows the structure of a typical neuron. It consists of a cell body with dendrites branching out from it, and usually a single axon. Nerve cells form a network by establishing connections between the ends of the axon of one cell and the dendrites of another cell - these connections are called synapses. Nerve cells receive information from other nerve cells via these synapses in the form of electrical signals. The cell assimilates this received information and enters an exited state due to this stimulus. This stimulus propagates along the axon as an electrical signal, and is transmitted to other nerve cells via the synapses. Synapses can be either excitatory or inhibitory, depending on whether they promote or inhibit the activity of the nerve cell. The electrical signal that propagates along an axon is called an action potential or nerve impulse. It travels at a speed of 100 m/s or more [2].

When directly measuring the action potential traveling along neurons it is important to use a non-invasive technique to avoid damaging either the living tissue surrounding the neurons or the network they are part of. One such technique is an ultra-sensitive magnetic flux sensor known as a superconducting quantum interference device (SQUID) for measuring biomagnetic field. Use of this technique has resulted in substantial progress being made in recent years in the research of brain functions and neuron activity [3], [4]. A SQUID element consists of a superconducting ring with a Josephson junction that can convert feeble magnetic field fluctuations into voltages with extremely high sensitivity. A SQUID flux sensor consists of a SQUID element, a sensor coil that senses the magnetic field to be measured, an input coil that guides the sensed magnetic field to the SQUID element, and a feedback/modulation coil. Biomagnetic field measurements made using a SQUID magnetometer have three main characteristics: i) magnetic fields generated by nerve activity can be measured even though they are over a billion times weaker than the earth's magnetic field, ii) measurements with very high temporal resolution are possible even at kilohertz-order sampling rates, and iii) analysis of magnetic data makes it possible to infer the position of electrical currents and analyze the action potential with millimeter precision.

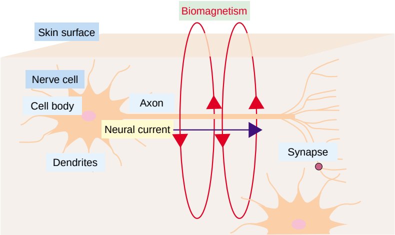

Fig. 1. Structure of nerve cells and the generation of biomagnetism.

5. Interface research using EMG

The recognition of movement tied to muscle activity is a most important factor in any consideration of user interfaces utilizing EMG. We have pursued this research while realizing that muscle movements related to speech generation are especially important for communication. Since such muscle movements are observed by measuring EMG, it is actually possible to recognize speech by observing the activities of the articulatory and vocal organs for utterance operation whether with or without voiced speech. This will lead voiceless communication, a new communication style. Because this voiceless speech recognition does not require audio signals, it can be applied in noisy environments, used as a speech support tool for persons with impaired hearing or speech, or used in extremely quiet environments, such as in libraries.

Figure 2 shows an overview of the voiceless speech recognition process. EMG is measured from the muscles around the mouth that contribute the most to speech generation. Speech patterns are recognized from these signals, and the results can be output as text or synthesized speech. We are currently able to recognize the five Japanese vowels without generating voice with 90 percent accuracy by using EMG measured from three locations on the face [5].

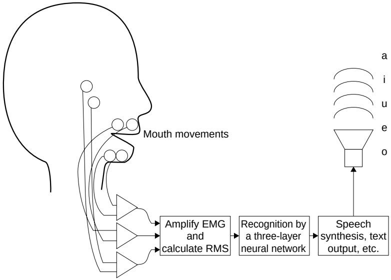

Fig. 2. Voiceless speech recognition.

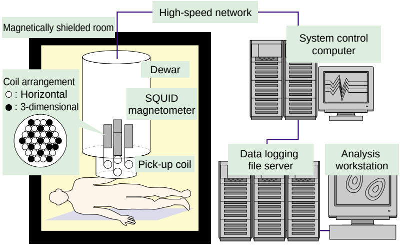

Fig. 3. SQUID biomagnetism measuring system for peripheral nerves.

6. Biomagnetic interface research

Biomagnetic interface research aims at utilizing the SQUID system to directly measure externally, without invading the body, the action potentials that flow along neurons in the form of biological signals. In the first stage of research we sought to clarify the body's information processing function and the neural information that flows in the peripheral nervous system. In 2002, we designed, introduced, and began using the first SQUID biomagnetic measuring system, a world-class system for working with the peripheral nervous system. In doing so we were able to complete the preparations needed for measuring and analyzing biomagnetism. Figure 3 shows an outline of the SQUID biomagnetism measuring system and Fig. 4 is a photograph showing its external appearance. As a system for measuring events in the peripheral nervous system, it consists of the world's most advanced 71-channel planar SQUID magnetometer, a high-performance, large-scale magnetically shielded room approximately 22 m^2 in area with a magnetic shielding factor of over 90 dB (10 Hz), and a computer workstation for controlling the system. In implementing our research, we recognized three important system requirements: i) high spatial resolution, ii) high temporal resolution, and iii) three-dimensional vector measurement of magnetic fields.

To achieve spatial resolution, we paid careful attention to the diameter of the sensor coil so that sufficient spatial resolution could be achieved when measuring the peripheral nerve magnetic field.

Outstanding temporal resolution is essential, because the transmission of neural signals reaches speeds of 100 m/s in humans. To adequately track signals being transmitted at such high speeds, the SQUID system supports high-speed sampling at 100 kHz.

Three-dimensional vector measurements, required for precise measurement of magnetic fields, are accomplished by allocating two extra channels with sensor coils orthogonal to the planar sensor, making a total of three channels. This configuration permits precise measurements, including simultaneous measurements of three-dimensional magnetic fields. As a result, the SQUID magnetometer performs peripheral nerve measurements with the world's highest number of channels. Our biomagnetism measurement system can therefore satisfy all possible conditions currently required for peripheral nerve measurements. We also wrote software to analyze biomagnetic data derived from measurements using this system. Figure 5 shows a time-series waveform display derived from using actual measurement data and Fig. 6 is an example of a magnetic field contour plot.

As an experiment in the early stages of our research, we measured the magnetic fields induced by the median nerve in the upper arm when we stimulated it with external electrical signals. We applied a slight electrical stimulus to the test subject's wrist and then measured the resultant upward signals propagating along the median nerve in the upper arm toward the shoulder. Figure 5 shows a time-series waveform display produced using typical biomagnetic data that we measured and analyzed. Figure 6 shows a magnetic field contour plot based on an analysis of measured data. In the center of this figure are four large concentric circular patterns, corresponding to the current quadrupoles being observed. The two blue patterns represent magnetic field sources; the two yellow patterns represent magnetic field sinks. In Fig. 6, the left side corresponds to the wrist and the right side the shoulder. By analyzing the temporal variation of the magnetic field contour plot we were able to observe how the concentric patterns at the magnetic field sources and sinks travelled from left to right. Doing so enabled us to visualize the propagation of the action potentials along the median nerve.

Fig. 4. External appearance of the SQUID biomagnetic measuring system (seen from the entrance to the magnetically shielded room, the middle cylindrical object is the dewar).

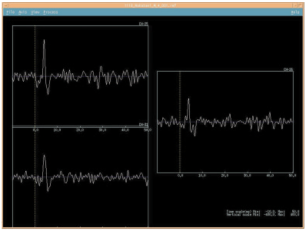

Fig. 5. Biomagnetic analysis software (time-series waveform display).

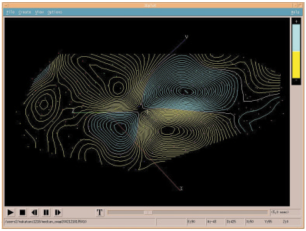

Fig. 6. Biomagnetic analysis software (magnetic field contour plot).

7. Future research

The SQUID biomagnetism measuring system that we designed and introduced is performing at the world's highest level in terms of measuring peripheral nerve activities. The present stage of our research can be regarded as the first step for creating a new user interface that utilizes biological information such as EMG and biomagnetism measured using the SQUID system. We will continue this research with the aims of creating HC^3 and developing biological information interfaces for extending the use of internal biological signals in the human body to use outside the body.

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