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A Bioelectric Controller for Computer Music Applications

Introduction

This article is a description of a special purpose signal processing computer designed to acquire low-level neuroelectric and myoelectric signals, perform feature extraction on these signals, and then map the desired features to MIDI commands—all in real-time. The computer—called the *Biomuse*—can be used as a "biocontroller" to augment normal musical instrument performance or as a direct nervous system, computer interface for musical composition and performance. Additionally, it could be used for paralyzed and movement impaired individuals as a means to regain the pleasures of music making. The concept of making musical sound from biological phenomena is not new. In fact, one of the earliest references to the idea of transforming a biological feature into musical sound appeared in an essay by the poet Rainer Maria Rilke in 1919 entitled *The Primal Sound.* In this essay, Rilke proposes creating a special stylus that could track the coronal suture of the skull and transduce the wave form into the "primal sound," just as a phonograph needle recreated sound from the wavy imprint in a wax roll. In the poet's words:

> The coronal suture of the skull has—let us assume—a certain similarity to the closely wavy line which the needle of a phonograph engraves on the receiving, rotating cylinder of the apparatus. What if one changed the needle and directed it on its return journey along a tracing which was not derived from the graphic translation of a sound, but existed of itself naturally—well, to put it plainly, along the coronal suture, for example. What would happen? A sound would necessarily result, a series of sounds, music. . . .
>
> Feelings—which? Incredulity, timidity, fear, awe—which of all the feelings here possible prevents me from suggesting a name for the primal sound which would then make its appearance in the world—(Rilke 1978).

Although Rilke did not actually make the necessary apparatus to intone the primal sound, the underlying idea pointed to the prospect of listening directly to nature's forms and signals. The use of electrical signals emanating from nerve and muscle (bioelectric signals) to create music came into being in the late 1960s. Numerous bioelectric musical recordings and performances were produced in the 1960s and 1970s, most of which fall under the general heading of biofeedback experiments. Descriptions of brainwave feedback concepts and performances are available (Eaton 1971; Rosenboom 1976), as well as compositions using heart signals (Teitelbaum 1974), and later myoelectric signal-mediated dance compositions (Gillett, Smith, and Pritchard 1985).

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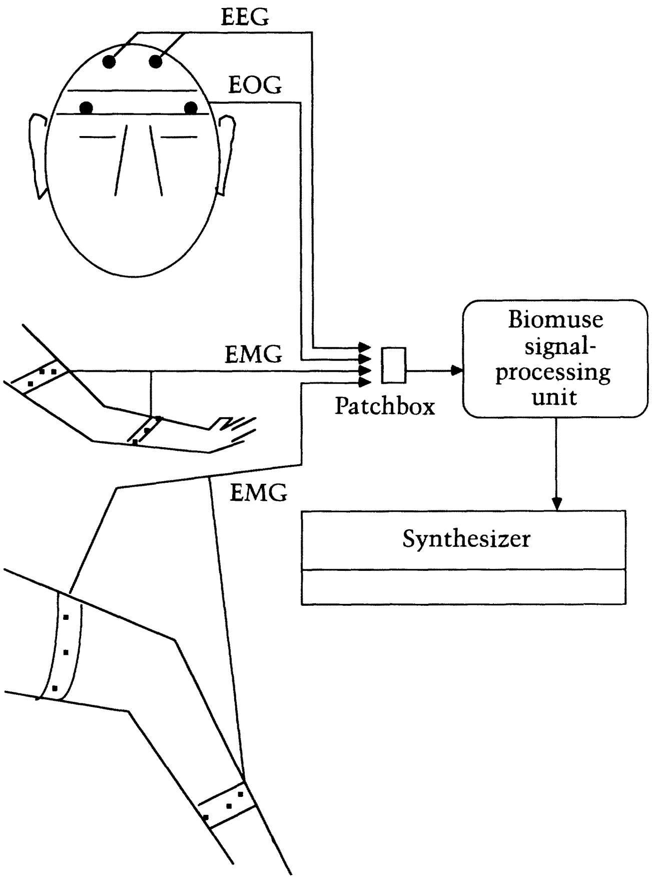
Fig. 1. Schematic representation of the Biomuse electrode configuration showing the relative positions of head, arm, and leg electrode bands. The patchbox is worn on the hip and connects to the Biomuse unit via a flexible cable to afford the user freedom of movement.



There are problems, however, in listening directly to bioelectric signals from the body. The problems arise from detection of the electrical signal at a distance from the actual signal generators. The raw amplified output from a given set of surface electrodes sounds very noisy, so the user requires a means to filter and perform signal analysis on the bioelectric activity in order to focus on aesthetically pleasing components of the signal. Further, some variable form of mapping biological inputs to sound outputs is necessary in order to avoid constantly producing the same sounds. Even in the more sophisticated biofeedback devices of the 1960s and 1970s, the mapping of bioelectric signals to acoustic output was usually set in hardware and difficult to change.

Hardware Description

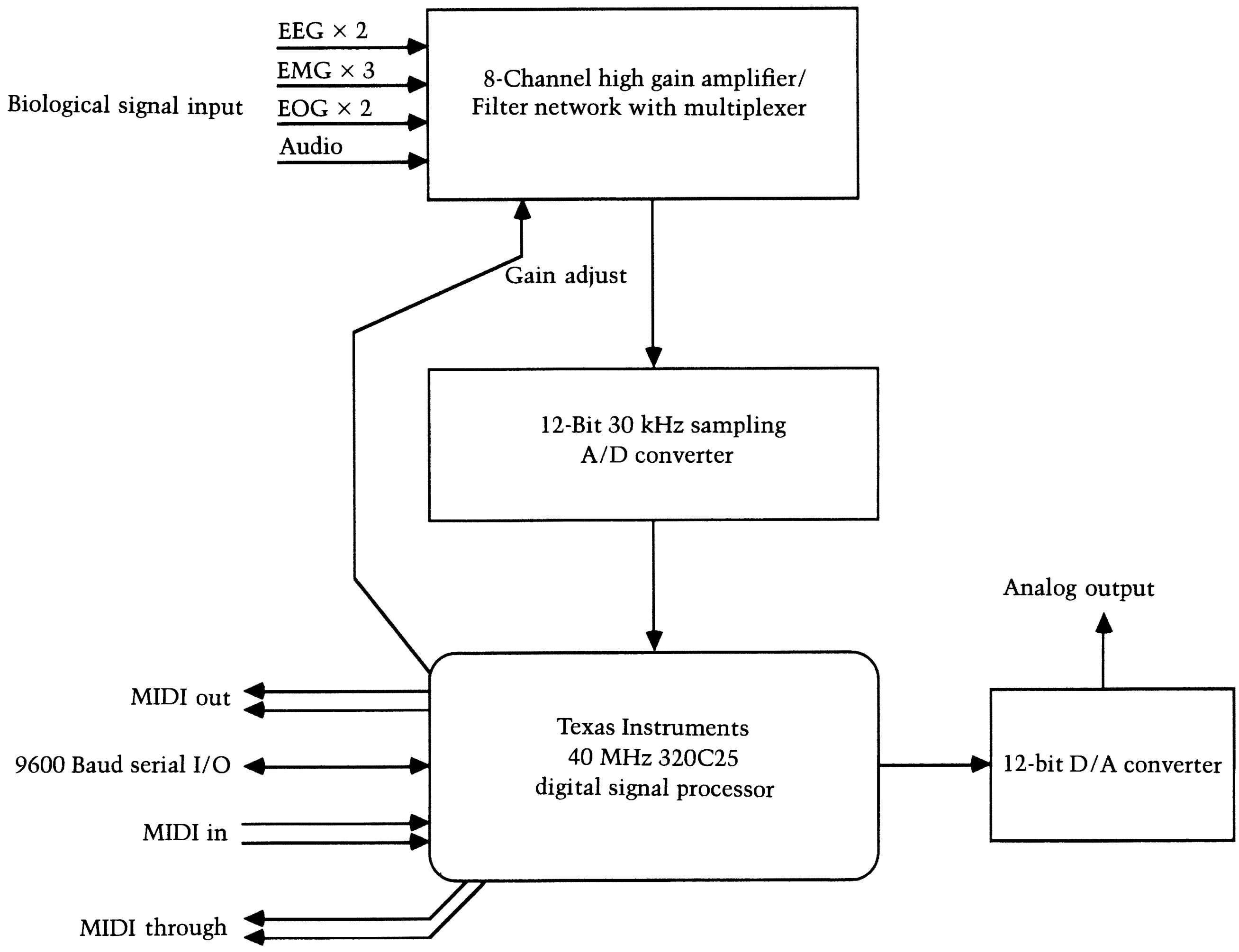
The Biomuse is a complete portable digital signal-processing system designed to provide a real-time interface between the electrical signals of the human body and any computer or MIDI instrument. Figure 1 shows a block diagram of the Biomuse system. There are two separate components of the Biomuse: (1) the bioelectric interface and (2) the signal processing unit.

The Bioelectric Interface

The bioelectric interface consists of several velcro elastic bands, as well as a headband. Each elastic band has three disposable snap electrodes, which are used to sense the electrical signals produced by the muscles lying directly underneath the band. These muscle potentials, or electromyogram (EMG) signals, are sent through a shielded cable to a patchbox that fastens to the user's belt. Each velcro band can be placed around the bicep, forearm, thigh, or elsewhere, enabling any muscle of the body to be a computer or MIDI controller. As many as three EMG channels can be monitored simultaneously.

The headband is used to measure two other important bioelectric signals, brain potentials or electroencephalogram (EEG) signals and eye potentials or electrooculogram (EOG) signals. The headband uses the same disposable snap electrodes as the EMG bands. Unlike the single channel EMG bands, however, the headband consists of a four-channel electrode montage. Two of these channels record EEG signals from the occipital and frontal brain areas, and the other two channels record horizontal and vertical EOG signals. These four signals along with the three EMG signals allow for seven independent (or interacting) real-time computer or MIDI controllers. There is also an eighth input channel for a microphone that can be used separately or in conjunction with the seven "biological interface" channels. The Biomuse interface was specially designed to be used while moving around in electrically noisy environments (such as on stage). Thus the user is not confined to sit in a shielded room and create music in isolation.

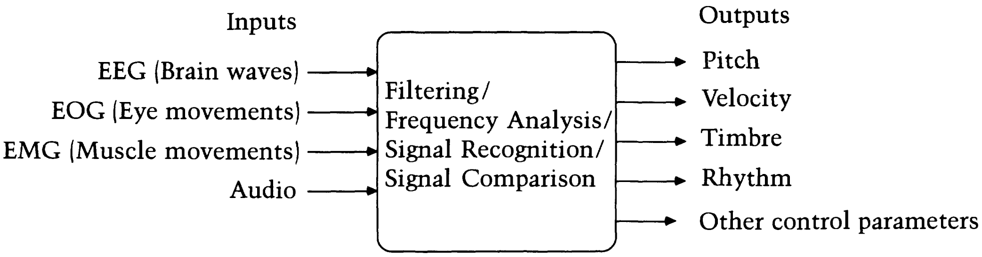
Fig. 2. Block diagram showing the information flow inside the Biomuse signal-processing unit.



The Signal Processing Unit

The seven signals from the patchbox are then sent to the "Bio In" port of the signal processing unit; the microphone has its own connection. These signals are then amplified by as much as 500,000 times, digitized, and processed by a Texas Instruments TMS320C25 special purpose digital signal-processing (DSP) chip, as shown in Fig. 2. The DSP chip simultaneously performs several independent operations. It monitors system status and controls the amount of amplification for each input channel. It analyzes all eight input signals in real-time and also receives and sends information to a host computer over a standard RS-232 serial interface. In addition, it receives and sends MIDI information through two MIDI ports and sends information to a digital-to-analog converter so that the user can display signal information on an oscilloscope or listen to this information as an audio signal. However, the real-time signal analysis of the eight input channels is what consumes must of the processing time of the TMS320C25 and ultimately determines what information is sent to the computer and to the MIDI instruments.

Fig. 3. Signal-processing algorithm input and output mappings.



Software Description

In describing the software for the Biomuse it is important to point out that two different programs are running simultaneously: signal analysis software and personal computer software. The signal analysis software refers to the TMS320C25 assembly code that runs in real-time and is stored in read-only memory (ROM) in the DSP unit. The personal computer software refers to code written for a personal computer that allows the user to communicate with the Biomuse over a serial port.

Signal Analysis Software

The primary purpose of the signal analysis software is to extract information from the incoming biological signals that will be used to control a given MIDI parameter. This process can best be explained with an example. In a recent demonstration of Biomuse at the New Music Seminar in New York City, four biological signal channels were used to control six MIDI parameters to allow the user to play "air violin." The information for the first channel was taken from an EMG band placed around the right bicep. The signal analysis software digitally filtered this signal to extract amplitude information that corresponded directly to slow, sustained muscle tension. This amplitude information was used to generate both MIDI note-on and volume commands. Thus, the right arm became an invisible bow arm (the synthesizer was programmed to play a violin sound). The information from the second channel came from a band placed around the left forearm and was processed identically to the first channel; however, the processed signal amplitude-to-MIDI mapping was more complex. As with a violin player, the left arm controlled pitch (MIDI note number) while the note was struck, but while the note was sustained, the tension in the left arm controlled vibrato. The third channel used information from the horizontal EOG electrodes to control the stereo panning of the violin sound. Thus, if the performer looked left, the sound emanated from the left speaker and as the eyes were swept left to right the sound gradually moved from the left speaker to the right speaker. The fourth channel used spectral information from the occipital EEG electrodes to control a MIDI program change. Fourier analysis was used to extract a 10 Hz component of the EEG, referred to as the "alpha" component. The alpha wave component appears in most people with a lack of visual input or visual imagery. For the demonstration, if an alpha wave was present, the violin sound was switched to a glockenspeil sound. Thus, performers could close their eyes (or just "think black") and cause a MIDI program change.

This example demonstrates the ability of the signal analysis software to map any biological signal to any MIDI parameter. It is the responsibility of the personal computer software to customize this mapping to an individual user's needs. This software is shown as a black box in Fig. 3.

Personal Computer Software

The personal computer software allows the user to type in—and eventually to control graphically—parameters that are sent to the Biomuse. Two of the most important parameters are channel sensitivity and threshold. Adjustment of the sensitivity parameter allows the user to adjust, for example, how much change in muscle tension will cause a single semitone change in pitch (one MIDI note number) or cause a 6 dB change in volume. The threshold parameter might be used to allow the performer to control how much muscle tension is necessary to turn a note on, or how much concentration is necessary to enact a program change. Since every biological signal has unique features, and since some of these features differ from person to person, it is important to be able to adjust the sensitivity of each channel for the individual user.

Another parameter that is just now being implemented is the ability to control bioelectric signal-to-MIDI mappings. For example, the user may want to specify that muscle channel 1 will no longer control note-on but will now control attack velocity. Eventually a graphical interface will allow the user to connect a line from an icon of the human body to a selection of MIDI parameters.

All changes sent from the personal computer to the Biomuse are stored in nonvolatile random access memory, so that there is no need to maintain a connection between the Biomuse and the personal computer. In addition, the Biomuse may be powered by its own internal battery pack, making it a truly portable MIDI controller.

Applications

The most obvious musical application for the Biomuse is in live performance situations to control synthesizers, sequencers, drum machines, or any other MIDI device. For example, a keyboard player could use leg tension to control a sequencer, eye position to control where in the auditorium the keyboard is heard, and relaxation level to cause the keyboard sound to switch from harpsichord to grand piano. It is also possible to choreograph a piece so that dance (or simply on-stage theatrics) is used to interact with the music. The performing musician becomes literally inseparable from the music he or she is creating.

Another area of utilization for the Biomuse is rehabilitation. Victims of paralysis and degenerative nervous system diseases cannot participate in normal daily activities without the aid of prosthetic devices, and much effort has been devoted to developing technology to aid the movement and instinctive functions of these victims. Very little technology is available, however, to serve the aesthetic and recreational needs of the disabled. Psychiatric evaluation of completely paralyzed individuals (those with a cervical spine section) indicates that boredom or "down time" is a serious problem and that these patients need some form of active recreation. The programming of the Biomuse inputs to suit the user's capacities would open a whole new world of creative endeavor for many rehabilitation patients. As described above, the Biomuse can also be used to interact directly with a personal computer for tasks other than music making. Exploiting this would allow the disabled individual to participate in the normal software development work force or any other computer terminal based business. Work is currently underway at the Center of Electronic Music (CEM) in New York to begin making the Biomuse available to various rehabilitation programs. CEM already has an Outreach to the Disabled program in place that makes electronic musical instruments available to the disabled, and the Biomuse will fit naturally into their program.

Conclusion

Although the Biomuse is an easy-to-learn MIDI controller, its flexibility has created many areas of research. In the area of digital signal processing, more complex analysis of the EEG is being examined so that the user can achieve more degrees of control. Research is underway in the area of musical therapy and rehabilitation. In addition, the use of Biomuse in musical composition and live performance will be an area of constant exploration for the creation of new sounds and new ways of controlling them.

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