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Developing a Multimedia Interface for Electrical Biosignal Interpretation

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Abstract

In the last ten years, a great deal of interest has been generated around the practice of using plants' electrical signals to create sound or music. In order to render biosignals capable of producing sound electronically, some kind of interface is necessary that converts a plant's natural electrical signals into data that a computer can understand. Existing commercial interfaces cost at minimum $300[1,2]. Worse yet, two popular off-the-shelf interfaces conform their output signals to stereotypical human notions of what a plant might "sound like".

In this project we fabricated a simple but high-performance interface for less than $5 in parts. The interface sends electrical biodata to MAX/MSP, a powerful industry-standard software application ubiquitous among music composers, video artists and an enormous community of creative designers for decades. The minimally altered biosignals can then be harnessed to generate sound, video, light or movement.

While many have approached this growing field cautiously, a great deal of misinformation has taken root in certain communities, sometimes attributing human qualities to plants. By using a simple, low-cost and minimally intrusive interface, we hope to provide a way to dispel unfortunate fictions, without demeaning the impressive abilities of plants to sense their environment and respond to stimuli. Our interface provides a means towards fostering more conscientious inter-species collaborations.

[1] Damanhur "Music of the Plants," one off the shelf device that conforms its outputs and costs over $400. https://www.musicoftheplants.com/?ref=dhen
[2] Plantwave costs $300 and also conforms outputs. https://www.plantwave.com

Our presentation includes technical hardware specifications, circuit diagrams, and several MAX/MSP patches that produce musical notes or trigger pre-recorded sound samples in response to plants' idiosyncratic electrical signals.

Electrical Signaling in Plants

The scientific community has been aware of electrical signals in plants since 1873 when Burdon-Sanderson discovered them while stimulating a *Dionaea*[3] leaf, making it known that electrical signals are not exclusive to animals (495-6). It is currently agreed upon that two different types of these signals exist: action potential[4] (AP) and variation potential[5] (VP) (Fromm and Lauter 249). Since plants do not possess cells such as neurons that are specially designed to transmit electrical signals, this exchange happens with the passing of ions through the phylum and xylem tubes, or stems, of the plants. These signals occur because of processes within the plant which can trigger growth, movement, and gene expression.

Measuring these signals can be carried out in several ways, either from the roots of the plants on the stems and leaves. Recording these signals directly from the roots can be somewhat invasive and possibly harmful to the plant, so using the leaves for a signal source is less invasive and therefore more desirable. The least invasive of these surface probes are TENS[6] probes, as they use a light conductive adhesive to make electrical and mechanical contact with the plant. Although slightly more invasive, micro-probes made of "Ag/AgCl wire, moistened with 0.1% (w/v) KCl in agar and wrapped in cotton" can be used with high accuracy, but these are quite

[3] More commonly known as the "Venus Flytrap."
[4] Electrical signals in plants that are either "on" or "off."
[5] Electrical signals in plants that have a sliding range between "on" and "off."
[6] A transcutaneous electrical nerve stimulator (TENS) sends electrical pulses through the skin to start your body's own pain killers. The electrical pulses can release endorphins and other substances to stop pain signals in the brain. TENS can reduce pain (University of Iowa Hospitals and Clinics).

costly and extremely fragile (Fromm and Lautner 250). The TENS pads are very cheap and easily replaceable, although they work best on plants with waxy and strong leaves like, Dracaena trifasciatarather[7], rather than those found on acers[8].

The Interface

To take the electrical signals from the plant and make them useable by a computer, an interface is required for this. It consists of an amplifier to boost the weak plant signal, an analog to digital converter to turn the amplified voltage into a digital value for the computer, a Max/MSP patch to scale and modify these values for tonal and visual interpretation, and Ableton Live for added musical capabilities (see fig. 1 for block diagram of the process).

Fig. 1; block flow diagram of interface from plant to product

Amplifier Circuit and Design

When reviewing the possible designs for an amplifier, the following must be considered: the low signal strength of the plant and that the signal can be easily influenced by outside noise. Common NPN or PNP transistors would do an adequate job of amplifying a small signal,

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[7] More commonly known as the "Snake Plant."
[8] Family of trees and shrubs known as "Maples."

although several stages may be needed due to their limited gain. However, their input resistance puts too much strain on the plant and draws their electrical signals down. This creates great inaccuracies in measurement and crates an unusable device. However, operational amplifiers or op-amps suit these requirements far better. Op-amps are DC-coupled[9] and high-gain amplifiers with inverting and non-inverting differential inputs. The high input impedance of the op amp allows for little load on the plant as well as a high gain. In this case, the UA741P from Texas instruments has an input impedance of 2MΩ. To avoid clipping, two stages are employed in the amplifier circuit. See figure two below for a schematic of the design:

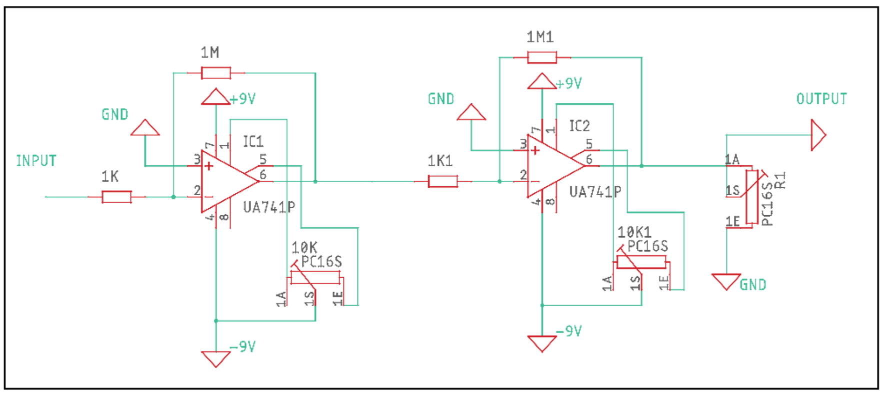

Fig. 2; schematic of amplifier, drawn in Eagle CAD. Designed by Christopher Cox

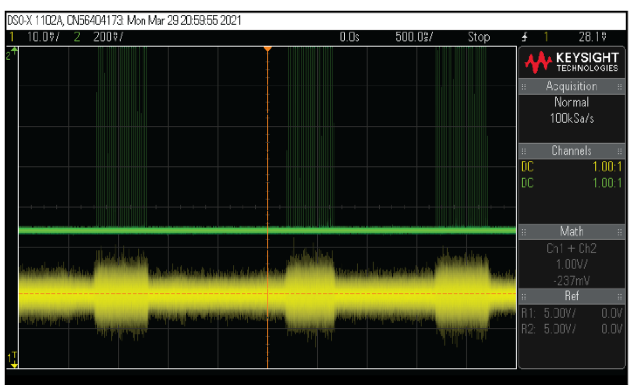

Fig. 3; oscilloscope snapshot of amplifier. Plant signal in yellow (~60 mv), amplified signal in green (~6v). Signal change is result of human touch, not solely the plant signal.

[9] This allows all signals present in the plant to be observed, from constant voltages to small variations.

Analog to Digital Converter (ADC)

After the plant signal is successfully amplified, it must somehow be converted to something that the computer can interpret. This is the job of an analog to digital converter, which in this case gives the plant voltage a digital value that can be sent as serial data to the computer. The ADC works by sampling the analog voltage at a given rate of time intervals and assigns it a binary value. We have used an Expert Sleepers ES-8 USB Audio Interface Eurorack[10] module for this application. The ES-8 is especially useful because of its USB interfacing capabilities. The computer will recognize this module as an audio interface and take the data directly without any extra coding, making it very easy to interface with other software or programs.

Max/MSP Patch

After the data is successfully communicated to the computer through the ES-8, the Max/MSP patch interprets this data to make it usable. Firstly, the Max/MSP patch takes the input values from the ES-8 and scales them to a different value range. The reasoning for this is that every time the plant is reconnected to the interface, the exact same voltage will not be present. This allows for easy setup and adjustment at any point. However, this does not force the data to conform to any guidelines, as it still accurately represents the highest and lowest signals measured from the plant. Then takes the scaled values and plots them on a graph as visual interpretation. These values are then quantized to MIDI[11] notes where they can be interpreted by

[10] A standard for modular synthesizers, popularized by Doepfer Musikelektronik in 1996. All units have the same vertical heigh and use the same operating voltage.
[11] MIDI is a communications protocol that assigns a number (0-127) to a note on the keyboard. Sounds and samples are then assigned to these numbers. This allows for fast transfer speeds.

other software and assigned different sounds and effects. The patch is also able to change the speed at which these values are interpreted, so rhythmic variation can be achieved.

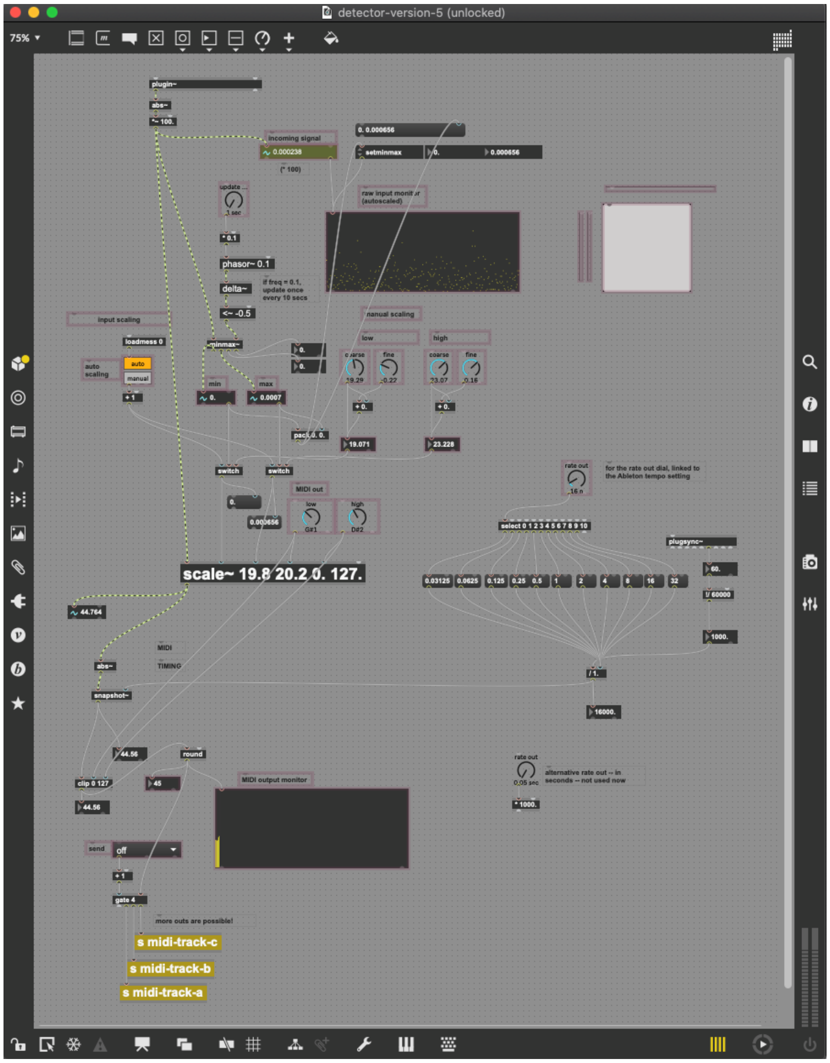

Fig. 4; Snapshot of the Max/MSP patch is shown above. Designed by Paul Miller, Ph.D.

Max/MSP is also capable of generating video effects using jitter[12], which has been an integral part of their software since 2003. This adds video capabilities to the software. In this case, the plant's signals were used to invert and rotate the image at rates according to the plant's electrical

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[12] The jitter patch functions by modifying the video matrix using values collected from the plant in real time. However, it can also be used to control the playback speed of a video

state. A demonstration of this (Jitter Demo) is available for download from

http://theoryofpaul.net/plants/max-msp/.

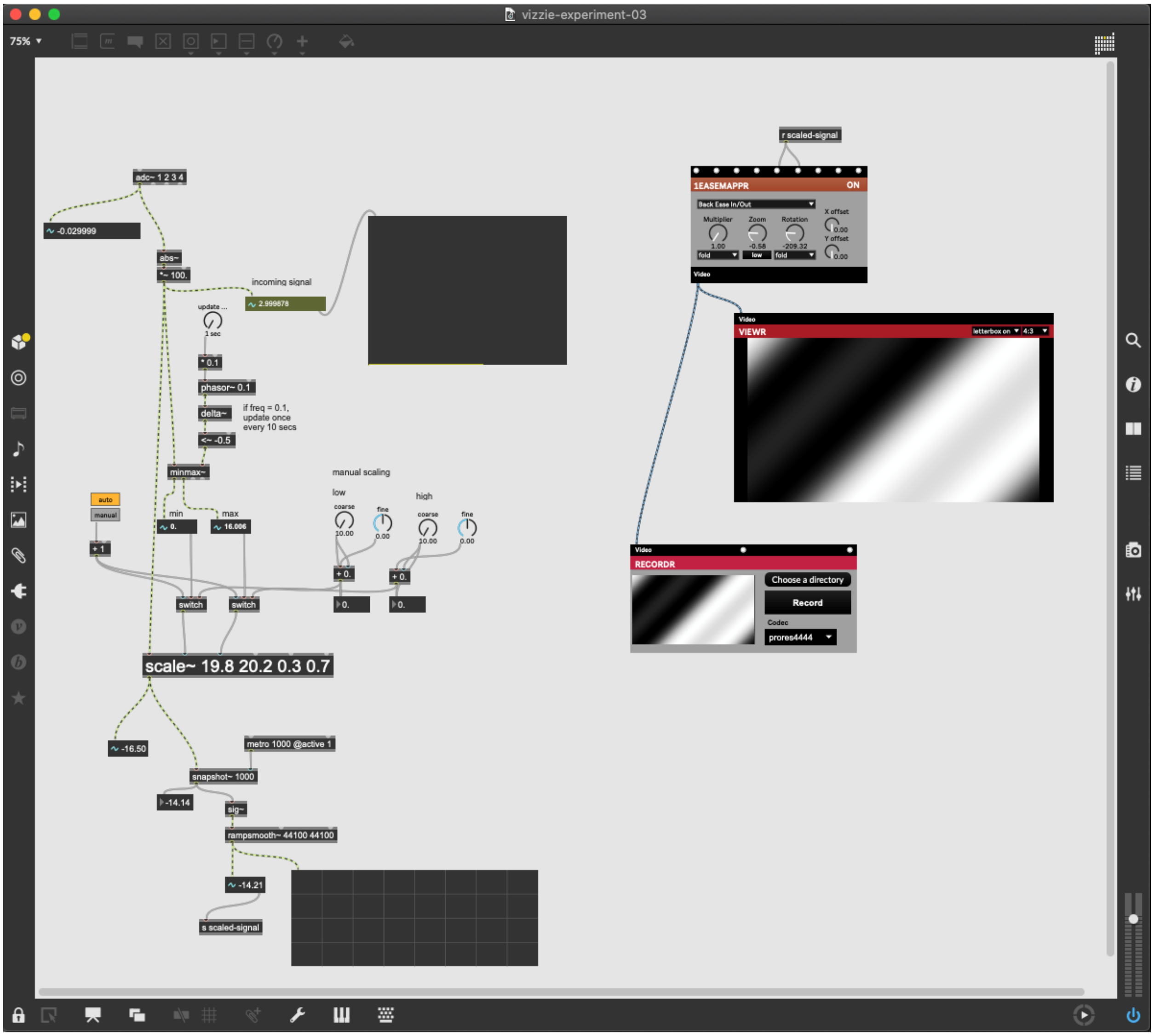

Fig. 5; Snapshot of jitter patch in Max/MSP. Designed by Paul Miller, Ph.D.

Ableton Live/MIDI Capabilities

To gain more sound possibilities and musical expression, the plant data is interfaced inside of a digital audio workstation (DAW) called Ableton Live[13]. The Max/MSP patch that was seen in figure four is running inside of Ableton Live. This embedded version of Max/MSP runs

[13] Ableton Live includes many features geared towards live performance and real-time processing that lend well to interpreting plant data.

slightly differently compared to the standalone version of Max/MSP, so some modifications to the initial patch were necessary for the two to cooperate. In Ableton Live, there are multiple types of tracks set up to divide all of the data according to use. The detector tracks convert the incoming signal to MIDI in the Max/MSP patch and scale the values to the desired range. Busses are then used to organize track and or detector groups. In our case, we used this to group different types of sounds that could be turned on or off. Lastly, the remaining individual tracks synthesize sound or trigger samples according to the state of the plant.

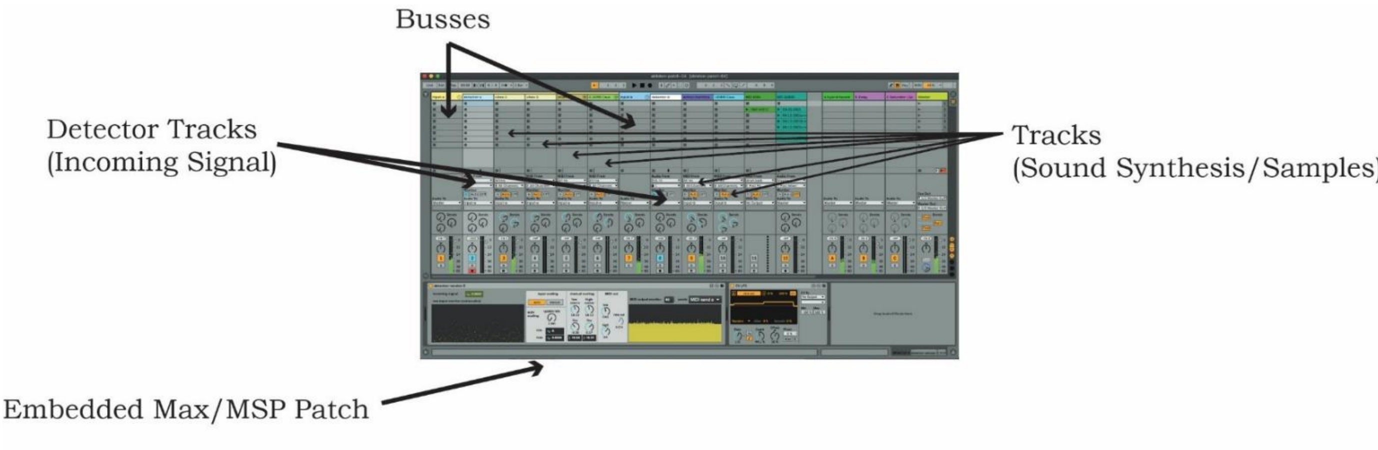

Fig. 6; Ableton Live interfaced with embedded Max/MSP patch. Designed by Paul Miller, Ph.D.

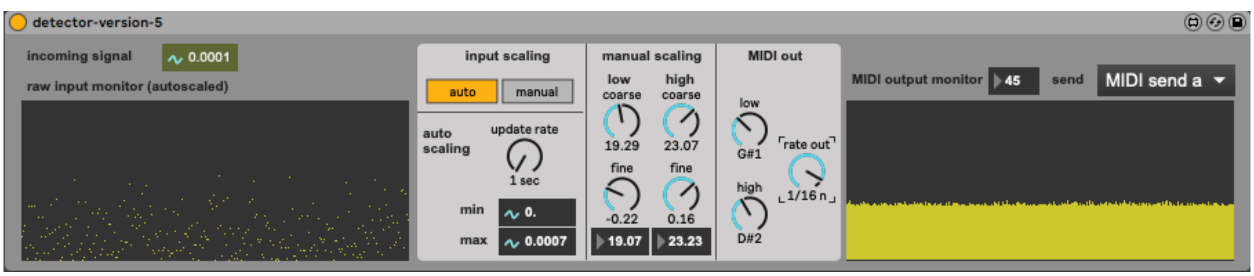

Fig. 7 (above); "Presentation Mode" Max/MSP patch snapshot. Plant data plot on the left, MIDI out on the right. Scaling controls and rhythm rate of MIDI out controlled with knobs in the center. Designed by Paul Miller, Ph.D

Fig. 8 (left); MIDI receive module. Velocity (volume/intensity of attack), delay (comparable to reverb), duration (the length of the notes), the pitch, and different inputs can be changed and controlled on this panel. Designed by Paul Miller, Ph.D.

As the MIDI notes are not actual sound, but rather a number assigned to a note, they can be quantized to any sound possible. Something more pleasant such as a marimba could be used, or a more grotesque and abstract sound could be used with a delay added for additional changes of color. Ableton Live also includes many different LFOs[14], or low frequency oscillators that can be synthesized within the software. We employed this to play more MIDI notes as the LFO ramps up over the phrase as to simulate a musical phrase. The notes are, however, still solely driven by the plant. Sound examples of this (Ambient Plant Music, Cave Plant Music, Nightingale), including bird samples triggered by the plant, are available at http://theoryofpaul.net/plants/max-msp/. This is just a means of making the outcome more usable for musical interpretation and for the possibility of interspecies collaboration.

Discussion

Working with bioelectric signals in the aesthetic domain can yield interesting results, but there are many points in the process where the outcome can be skewed, or misinterpreted as some kind of agency by a plant where there are actually none present. According to Augustine Leudar,

> Numerous attempts by artists to sonify electrical activity in individual plants have been undertaken... For example... the artist touches the plant, claiming a response, when in fact their own electrical field is causing the signal in the electrodes, not the plant. (Leudar 521).

Nevertheless, the informed practice of using plant signals to generate the “raw material” for musical, visual, or multimedia experiences is appealing for many reasons. First, it brings us into

[14] LFOs typically synthesize a waveform below 20 Hz that is used to give a rhythmic pulse or sweep.

closer contact with the world we live in, allowing many to appreciate better the many extraordinary processes in the plant domain. It stimulates artists to design interfaces and software that…

Second, a plant typically produces noticeable chances in voltage output on a longer time scale than we are accustomed to (i. e., morning, afternoon, evening), it invites us to listen outside of our normal temporal bounds, which typically extend to seconds, minutes, or hours.

We intend to use the knowledge we gained from this project to create several small sound installations in the next year, both in the Mary Pappert School of Music and the Gumberg Library at Duquesne University, as well as expand upon and improve the current interface to allow for more accuracy, musical features, and for the use of multiple plants.

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