Modules for analog synthesizers using Aloe vera biomemristor

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ABSTRACT

In this study, an analog synthesizer module using Aloe vera was proposed as a biomemristor. The recent revival of analog modular synthesizers explores novel possibilities of sounds based on unconventional technologies such as integrating biological forms and structures into traditional circuits. A biosignal has been used in experimental music as the material for composition. However, the recent development of a biocomputor using a slime mold biomemristor expands the use of biomemristors in music. Based on prior research, characteristics of Aloe vera as a biomemristor were electrically measured, and two types of analog synthesizer modules were developed, current to voltage converter and current spike to voltage converter. For this application, a live performance was conducted with the CVC module and the possibilities as a new interface for musical expression were examined.

Author Keywords

Modular synthesizer, Aloe vera, Biomemristor

CCS Concepts

•**Applied computing → Sound and music computing;**

1. INTRODUCTION

Synthesizers have been developed as a tool for exploring new musical expressions using electrical technologies such as a newly invented transistor or integrated circuit (IC). However, the digital revolution in the 1980s changed their role to simulating sounds of various musical instruments. The original function of analog synthesizers, which was generating sounds by adjusting knobs freely to explore the possibilities of new musical expression, became complex and was replaced with presets during the transition from analog to digital synthesizers in the 1980s [9, 15].

The synthesizers have been revived with the rise of standardization of modular synthesizers, such as Eurorack, designed by Doepfer in the 1990s. This standard of dimensions and voltage levels made modules from different vendors compatible, improved accessibility, and increased sound diversity [13]. For example, *Cyclops* (2016) is a Eurorack video synthesizer module, which can control a laser show projector via control voltage [8]. *MOTOR SYNTH* (2019) is an electro-mechanical synthesizer that uses electromotors as its main sound source. The synthesizer produces sounds by controlling the rotational speed of electromotors that precisely correspond to a musical note [7]. Some of these unconventional modules integrate biological forms and structures as materials into its circuit. The history of artists using biological phenomena for musical expression is discussed in the next section.

2. RELATED WORK

The attempts to use biological phenomena for musical expression have been explored since the beginning of the 20th century. A pioneering work that transforms the brain wave of a performer into sounds was *Music for Solo Performer* composed by Alvin Lucier in 1965 [4]. The sound was emitted from loudspeakers and resonated to nearby percussion instruments. The resulting sounds, heard by the performers, affected their brain waves, and then this process was looped [12]. While Lucier did not use brain waves again, other musicians expanded the research in the 1960s and 1970s by recording and performing with biosignals, such as myoelectricity and heartbeats. The process to translate a brain wave into sound was a challenge, because the frequency of the brain wave was too low to perceive. Richard Teitelbaum solved this problem by integrating a modular synthesizer, which had been presented by Robert Moog in 1964, into his composition *Organ Music* in 1968. He used a brain wave as a control voltage for synthesizer modules such as a voltage control oscillator (VCO), voltage control filter (VCF) and voltage control amplifier (VCA) [14]. This was a pioneering work that used biological phenomena in a framework of synthesizers.

The recent biotechnological progress has been expanding the possibilities of new musical expression. For example, *cellF* (2015) was the first autonomous synthesizer aimed at collaborating with musicians or performing independently. This synthesizer was controlled by a neural network that was cultivated from the author's skin cell by induced pluripotent stem cell biotechnology [11]. *Earth Return Distortion (ERD)* (2015) is a synthesizer module that integrates a small block of earth into its circuit. The earth distorts and amplifies signals as they pass through [5]. *Sonomatter* (2017) is a sound installation and performance that uses a custom-designed synthesizer, which can transform electrical signals produced by microorganisms into sounds [1]. Miranda et al. developed a biocomputer using a slime

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mold biomemristor and presented its application to musical expression in 2016 [10]. They used the biomemristor as a data-driven processing unit in a biocomputer. The non-linear property of the memristor was used to map and generate sounds from input melodies by combining it with a microcomputer.

Our study focused on developing two synthesizer modules using the non-linear properties of an Aloe vera biomemristor. The use of Aloe vera and other biological substances in synthesizers is dependent upon the existence of a memristor.

3. MEMRISTOR

A memristor is the fourth fundamental circuit element, which was theorized by Leon Chua in 1971. He proposed many interesting and valuable circuit properties of a memristor. However, a practical physical model was not developed until 2008. Mathematically, the resistance of a memristor, R, is called memristance, M, and is described as follows:

$$M = R(q) = \frac{d\delta(q)}{dq} \quad (1)$$

where δ and q denote the flux and charge, respectively. In contrast to the other three fundamental circuit elements, a memristor has a non-linear property. Chua insisted a pinched hysteresis loop of an ideal memristor was symmetrical and passed through the origin as shown in Fig.1 [3].

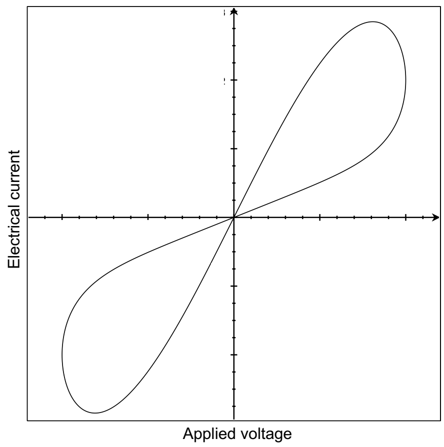


Figure 1: Pinched hysteresis loop of an ideal memristor

Other researchers reported that a memristor exhibited a current spike response to a sudden change in an applied voltage. Gale et al. reported this behavior and proposed an analytical model [6], where the current spike was observed whenever an applied voltage changed. The spike was reproducible with a high probability and its direction was the same as the change in the applied voltage. Moreover, Miranda et al. insisted that the altitude of the current spike had a positive correlation with the altitude of the change in voltage [2].

Recent theoretical analysis has revealed the existence of a memristor in neural networks, voltage-gated channels, etc. In particular, a memristor made of biomaterial is called a biomemristor. Volkov et al. found the existence of the properties of a memristor in plants such as Aloe vera and Mimosa pudica [17].

4. MEASUREMENT

Based on prior research, two experiments were conducted to electrically measure the properties of Aloe vera as a biomemristor.

4.1 Existence of Memristor

The electrical current responses to applications of a sinusoidal wave were measured to confirm the existence of a memristor in Aloe vera. Following prior research [16], the responses at two conditions were measured: inserting electrodes along the vascular bundles and on the top and bottom of an Aloe vera leaf.

From this experiment, the existence of a memristor in Aloe vera was confirmed. An Aloe vera biomemristor exhibited a pinched hysteresis loop when sinusoidal waves with a frequency of less than 0.01 and 0.1 Hz were applied from the electrodes inserted along the vascular bundles and on the top and bottom of the leaf, respectively. Fig.2 presents an example of the pinched hysteresis loop observed in this experiment. Notably, the electrical current response to an applied voltage was non-linear.

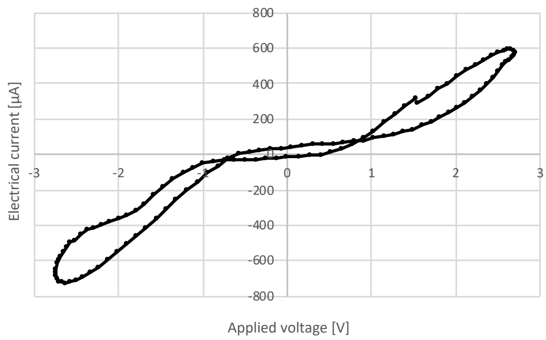


Figure 2: Example of the pinched hysteresis loop

Additionally, the pinched hysteresis loop becomes ideal as the frequency of the applied voltage becomes smaller. The properties of the memristor are affected by the positions, distance, and depth of electrodes inserted.

4.2 Current Spike

A current spike response to a sudden change in an applied voltage was measured. A prior study [6] insisted that a current spike could be observed in any memristor; however, one was never observed in Aloe vera. Therefore, an experiment was designed to observe and clarify the relationship between the applied voltage and the behavior of a current spike. The measurement was conducted with a self-building electrical circuit that could amplify and convert electrical current to voltage to improve observability.

As a result, the current spike was noted in Aloe vera, which was determined by observing the magnitude of the voltage that was applied before the change, its duration, and the magnitude of change. Fig.3 presents an example of the current spike observed in this experiment. In this measurement, the electrical current was amplified by inserting electrodes into the top and bottom of the leaf.

5. IMPLEMENTATION

Two types of analog synthesizer modules were developed with the biomemristor, the current to voltage converter (CVC), and the current spike to voltage converter (CSVC).

5.1 CVC

The CVC module uses the non-linear electrical current wave response of a biomemristor for a low frequency sinusoidal wave. The CVC comprises a simple analog circuit with two op-amps and resistors for converting the electrical current to voltage as depicted in Fig.4. A performer can connect this module to Aloe vera via two terminals (T1, T2), control

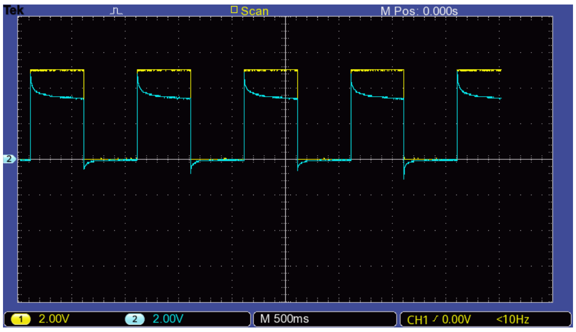


Figure 3: Current spike (blue line) response to a sudden change in the application voltage (yellow line)

the magnitude of amplification by adjusting the variable resistor (R1), and invert the output by switching (S2).

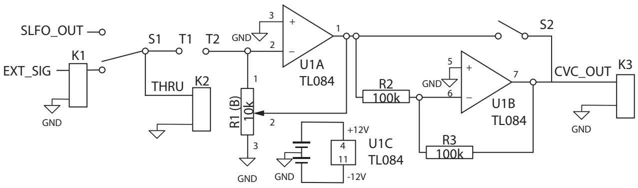
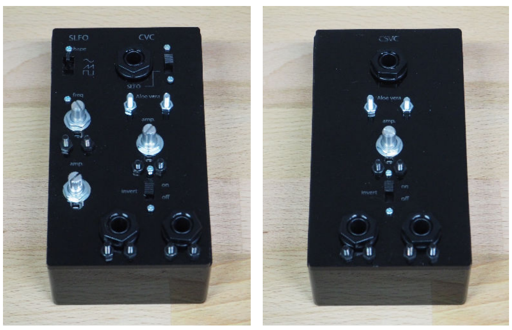


Figure 4: Circuit of the CVC module

As a complement to CVC, the super low frequency oscillator (SLFO) module was also developed, which can change the frequency from 0.001 to 0.1 Hz, and change the shape of a wave from sinusoidal to triangle or square to enhance the properties of the biomemristor. The SLFO is internally connected to the CVC, and a performer can select the SLFO or an external signal as the input of the CVC by switching (S1). This module was originally developed on a breadboard, then built on a universal board with a module box, as presented in the image in Fig.5 (a).

5.2 CSVC

The CSVC module uses the current spike response of the biomemristor to enable a sudden change in the applied voltage. The electrical circuit of the CSVC is the same as CVC, but the variable resistor is changed from 10 to 100 kΩ to amplify even a slight current spike. The image in Fig.5 (b) shows the appearance of the box.



(a) (b)

Figure 5: Appearance of the SLFO and CVC module (a) and the CSVC module (b)

6. LIVE PERFORMANCE

The performance took place at NxPC.Live vol.40 & Freq, KID × IAMAS LIVE at Kyushu University in Fukuoka, Japan with the CVC module, and it examined the possibilities of these developments as a new interface for musical expression. The applications of the modules are discussed in 6.1.

The CVC module was used with a legendary analog modular synthesizer, Roland SYSTEM 700. The SLFO was patched into the CVC, and the signal was separated on a multiple jack module and then inputted as a control voltage for other modules, such as VCO and VCF. An oscilloscope was used to observe the input and output signals of the biomemristor, and adjusted by inserting the electrodes in various places. The amplification of the output signals were modified by rotating a knob on the CVC during the performance. The performance began with only a few sounds using the module, for audiences to be able to understand the sounds driven by the Aloe vera biomemristor, and then other sounds were added.

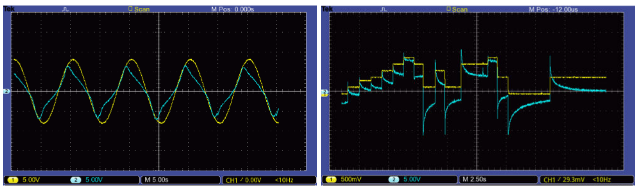
6.1 Application

6.1.1 CVC

The CVC module outputs a non-linear voltage wave response to an application of a sinusoidal wave. Fig.6 (a) depicts the output voltage of the CVC response to the application of a 0.1 Hz sinusoidal wave. The sounds could be modulated with the non-linear property by inputting the output of the CVC to other modules as a control voltage.

6.1.2 CSVC

The CSVC module outputs a voltage spike of the biomemristor in response to a sudden change in the applied voltage. The control voltage of the keyboard controller was the focus of the sudden change in voltage, because the keyboard controller in analog synthesizers produces a voltage corresponding to the key that is pressed. Fig.6 (b) depicts the output voltage of the CSVC response to the control voltage of the keyboard controller.



(a) (b)

Figure 6: Output voltage of the CVC (blue line) response to the application of 0.1 Hz sinusoidal wave (yellow line) (a) and output of the CSVC (blue line) response to the control voltage of the keyboard controller (yellow line) (b)

If the output of the CSVC is inputted as a control voltage to VCA, which is a module to amplify the signal, the current spike could be used as an envelope generator.

7. DISCUSSION

7.1 Synthesizer Module

The synthesizer modules used herein are regarded as basic modules that use the properties of the biomemristor in a framework of the voltage controlled modular synthesizer. In this experiment, the non-linear electrical current wave response to an application of a sinusoidal wave whose frequency was less than 0.1 Hz was observed. Therefore, it was used as a filter for the SLFO and its property was related to musical expression as a form of modulation. However, if a memristor was found that exhibited a non-linear property with a sinusoidal wave of audible frequency, that property could be directly applied as a filter for the VCO to generate a new basic wave shape. The CSVC module was not used in a live performance; however, its potential could expand the possibilities of analog synthesizers differently from the CVC module.

7.2 Properties of the Biomemristor

The properties of the biomemristor vary depending on the insertion parameters of the electrodes, such as position, depth and duration for which the voltage is applied. A process of changing the insertion of electrodes was developed for generating better sound resembling that of synthesizers, such as adjusting the knobs. However, it is important to clarify how the properties should be controlled in a stable and consistent manner.

Miranda et al. standardized the properties of their slime mold biomemristor by developing a receptacle for controlling their growth. In contrast, despite being easy to use and measure, it is difficult to standardize the Aloe vera biomemristor because of the 3D form of the leaf.

7.3 Biomemristor and Musical Expression

The attempts using biological phenomena as material for musical expression can be seen in the previous studies by Alvin Lucier *Music for Solo Performer* and Richard Teitelbaum *Organ Music*. In their compositions, the relationship between auditory stimulation and the biosignal (i.e., brain wave) worked as a function even during unconsciousness. In contrast to this uncontrollable relationship, it is preferable to have a more controllable function for the biomemristor.

In our modules, an input voltage was directly applied to the biomemristor, the electrical current response of the biomemristor was amplified, and the response was converted to voltage. By controlling the sounds of the synthesizer through voltage, the biomemristor in this application worked as a function that directly processed sounds.

This is different from the biomemristor used by Miranda et al. as a component of computational mapping of input melodies onto music data. These modules provide controllability, as well as direct and physical interaction with the biomemristor, such as adjusting its characteristics by changing the insertion of electrodes.

8. CONCLUSION

In this study, two types of synthesizer modules were developed using the properties of an Aloe vera biomemristor. The use of the biomemristor was presented as a direct function for analog sound processing with two modules, the CVC and CSVC. The study highlighted how biomemristors expanded the possibilities of new musical expression within the framework of an analog modular synthesizer. The possibilities of the CVC module were explored through its application in a live performance. The CSVC module was not used in a live performance, so there is further potential to expand the possibilities of analog synthesizers.

A video of the performance and demonstrations presented in this paper is available at: `https://youtu.be/5tXa7zTmDe8`

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