AN INTERACTIVE BIO-MUSIC IMPROVISATION SYSTEM

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ABSTRACT

In this paper, we focus on electrical bio-signals of humans as a core musical material. Typically, interaction is under-utilized in bio-music; an improved system can offer alternative design opportunities compared to a collection of instruments controlled by bio-signals in real-time. Our Interactive Bio-music Improvisation System (IBIS) is capable of rendering pre-recorded bio-signals under controlled situations, and allows two performers to interact with the computational representation of a third one in real-time. These capabilities afford a multitude of narratives. Here, we present our bio-signal instrumentation and audiovisual synthesis strategies in detail; we aim to demonstrate the components of the IBIS during the ICMC-08 Conference.

1. INTRODUCTION

Bio-music is an experimental music form that is based on sensor data obtained from living organisms. In this paper, we focus on electrical bio-signals of humans; on their acquisition, processing and feature extraction, and particularly on their usage in concurrent audio-visual synthesis within an interactive improvisation system.

The performing characteristics of bio-music make bio-signals an important and meaningful source of musical information both in composition and interactive improvisation. Many bio-music controllers have been used as computer interfaces for composition and performances [1]. Early pioneers, such as Alvin Lucier, Richard Teitelbaum, and David Rosenboom have produced important bio-music works [2], some of which are direct mappings of the performer's onto musical structures. In these works, interaction was rather limited; such works can be regarded as direct sonification of the biofeedback systems.

Rosenboom has systematically investigated the neurological interaction in order to extract musical features. In his work *On Being Visible*, he has developed a self-organizing, dynamic interactive electronic music system that constructs musical forms as a result of real-time analysis of the EEG parameters of two performers [3]. In other words, his work provides an excellent example of how to interpret the interaction between two human performers in computational terms.

An interactive bio-music system can also be considered as an ecosystem that situates performers within an environment [4]. This situation enables another mode of interaction; the *stigmergy*, that is; the indirect interaction between performers via the environment [5]. In this interaction mode, one performer modifies the environment and the other responds to the modified environment rather than directly to the actions of the first performer. Such interactive systems can offer alternative interaction design opportunities rather than just a collection of instruments controlled by bio-signals in real-time.

In this paper, we introduce our Interactive Bio-music Improvisation System (IBIS). IBIS is an extension of our previous audiovisual bio-music implementations. The performances *Improvisation for Live Bio-Signals* (2007)\(^1\) and *Time Series* (2007) involved the early modules of this system. The core novelty of IBIS lies in its capability to render the pre-recorded bio-signals and to allow the two performers to interact with the computational representation of a third one. This carries interaction into another level by retrieving pre-recorded and controlled data during a live performance. Video demonstration files of IBIS modules can be found at the following URL, http://mlab.taik.fi/~koray/ibis.

Besides its obvious bio-music orientation, IBIS also relates to other contemporary themes in computer music, e.g., emotion-aware interaction, audience as a partner, and networked and graphically displaced performance. In order to explicate these relations, we first describe our bio-signal instrumentation in Section 2, our visual and audio synthesis strategies in Sections 3 and 4, respectively, and the novel computational representation of the third state in Section 5. Finally, we present our conclusion and indicate our future work.

2. BIO-SIGNAL INSTRUMENTATION

This project and previous works by the authors have utilized general purpose biofeedback units which feature a range of different sensor types intended for various therapeutic applications. In addition to collecting signal these units also amplify and perform analogue to digital conversion allowing them to be interfaced with a computer. Appropriate software can then analyze the data and produce outputs for patient training or assessment. Typically systems are compatible with these sensor types;

- a) Temperature ; most usually attached to the finger.

\(^1\) Koray Tahiroğlu and Selçuk Artut performed the piece *Improvisation for Live Bio-Signals* together with Hannah Drayson (live visuals) at the eNTERFACE 07 workshop in Istanbul, Turkey on Wednesday 10 August 2007.
b) Respiration; an elasticated harness worn around the chest which measures chest or abdominal extension via a strain sensor. The subject’s rate and depth of breath can be inferred from the data collected.

c) Skin Conductance (Galvanic Skin Response). Skin conductance is a measure of the electrical impedance of the skin measure between two electrodes, most usually worn on the fingers of the non-dominant hand.

d) Blood Volume Pulse (BVP). BVP is recorded with a fingertip sensor, which uses a process called photoplethysmography to measure blood pressure in the extremities.

e) Electromyogram (EMG). The electromyogram uses electrode applied to the skin to record the electrical potentials which stimulate movement in the underlying muscle.

f) Electrocardiogram (ECG). This measurement reveals the muscular activity of the heart via its electrical activity.

Biofeedback is a therapy which allows patients to become aware of and regulate what were once considered the involuntary portions of the nervous system controlling such things as heart rate, blood pressure and body temperature. Biofeedback technology uses sensor based systems to ‘feed back’ information about the physiological function of the of the user’s body, usually in the form of an auditory or visual stimuli, such as a changing musical tone or graphical display. By using these technologies the IBIS system manifests both the voluntary and involuntary activity of the performer’s bodies. Through the biofeedback paradigm, it then allows performers to become aware of, and eventually modify, their own involuntary processes.

The software infrastructure for bio-signal acquisition and management during the improvisation uses an implementation of the Bio-Music Platform. This platform is suitable for the communication of a wide range of data types in real time, between multiple machines and software. To achieve this, the OpenSoundControl (OSC) protocol, is employed, using a multicast server architecture. The Bio-Music Platform includes an OSC specified namespace intended for the flexible management of bio-signal data.

The hardware signal acquisition setup consists of one Nexus-10 and one Nexus-4 physiological monitoring systems. Combined, the two units provide a total of 12 channels for data acquisition, six channels suitable for EEG, EMG and ECG, and a further six for BVP, Skin conductance, Respiration and Skin Temperature. Both Nexus units use wireless communication to send sensor data to the manufacturer's API, which performs primary analysis of signals (e.g. artefact removal). A custom script is then used to read this processed data from a constantly updating .bin file within the application directory. It is then de-coded and converted into the OSC namespace, at which time it is sent over the local network via UDP Multicast.

The Bio-Music platform has been chosen in order to improve the real-time computational efficiency of IBIS. Bio-signal data acquired by multiple users can be processed, sent and received via the Bio-Music Platform within a local area network. This setup provides fast and direct connections between diverse bio-signal sources and IBIS for real-time data processing.

Performers’ machines connected to the network and receiving multiset data can apply it within a range of software. For this interactive system, Pure Data, Biotrace and Python have been chosen for further audiovisual synthesis, processing and control.

3. VISUAL SYNTHESIS STRATEGIES

The visual synthesis for the improvisation uses a subsequent version of Circles (2007) a bio-signal visualization program created in Pure Data. The program processes raw bio-signals in real-time, applying them as variables in an audiovisual display generated by using GEM (Graphical Environment for Multimedia), a library for Pure Data.

Circles was originally developed for a performance at Bogazici University entitled Time Series: an uncontrolled experiment (2007). During this performance data was collected using a Thought Technology ProComp Unit, developed for therapeutic biofeedback and research processes. This instrument was used by the performers to collect a number of bio-signal data modalities from a volunteer 'subject', which were then converted in real-time into the audiovisual display.

The visual output of the Circles Pure Data patch is a 3-dimensional sphere comprised of rotating disks. Each representing one channel of bio-signal data the display is modified by the live bio-signals, which are related to variables such as disc spin direction, size, color, speed and other render and graphical aspects. For example, during Time Series (2007), raw amplitude signals were normalized and their value were calculated as a percentage of 360° and applied to the disc's angle of rotation. In the case of the ECG and Respiration signals, the semi-abstract representation of the data in the on screen activity can be perceived by the viewer as corresponding to the activity of the organs and systems monitored.

Program inputs can be varied so as to make use of a variety of signals. For Time Series (2007) blood volume pulse, temperature, respiration, and electrocardiogram were used. Even with simple mappings of the raw data, the display created by Circles makes apparent the relationships between the various instruments, illustrating to the viewer dynamic and relative change, between the sensor modalities and the subjects resulting bodily response.

A more advanced version of the program is employed

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1 The Bio-Music Platform was developed at the eNTERFACE ’07 Workshop on Multimodal Interfaces, hosted by Bogazici University, Istanbul. http://www.cmpe.boun.edu.tr/enterface07/

2 Open Sound Control (OSC), a communication protocol developed as a successor to MIDI, and used for networking computers to multimedia devices, synthesizers and other music technology. http://www.opensoundcontrol.wordpress.com

3 Nexus-10 and 4 are designed and manufactured by Mind Media BV. http://www.mindmedia.nl/

4 http://www.puredata.info

5 http://www.mindmedia.nl/english/biotrace.php

6 http://www.python.org
for the visual synthesis section of the improvised performance, processing incoming live and pre-recorded bio-signal data and applying it as control data for the 3D visualization. Projected within the performance environment, the resulting visual output will contribute to the Stigmergic dynamic between performers and the resulting improvisation.

4. AUDIO SYNTHESIS STRATEGIES

*Improvisation for Live Bio-Signals (2007)* is an improvisation for digital musical instruments controlled by the biological signals of two performers. Each performer wears a set of different bio-sensors which control the instruments during the improvisation. The audio synthesis strategies of IBIS were developed taking the sound modules of this earlier interactive performance system as a basis.

The audio synthesis strategies in IBIS consist of a number of audio modules, which are controlled by parameter mapping modules. The system responds to the bio-signal data received from the IBIS network, analyses the signals and maps them onto a number of musical textures.

Measures of Skin Conductance and an Electrocardiogram (ECG) are combined to control the digital musical instrument that creates dynamic rhythmic patterns. The rhythmic period of heart is mapped by detecting the peak level for each beat and these peak level values are synchronized with the amplitude-modulated noise.

The changing patterns of the heart’s electrical activity also provides more possibilities to create a dynamic pattern with sound synthesis; however, the common sonic representation of heart beat and ECG monitoring sound responses is avoided intentionally. Instead, noise sound sources are combined together with glitchy sound samples in order to create a rhythmic pattern; where the heart beat structure can be still traced in the sonic texture. Periodic changes in the skin conductance sensor and inter-beat variability of the performers showed the greatest usable variation for dynamic rhythmic patterns.

Each audio synthesis module in IBIS generates a class of sounds with multiple sonic gradations and variants. The parameter mapping techniques used in the audio synthesis modules rely on the extraction of information from the internal states of the performers and their interaction with the improvisation environment. The two main modules are described here.

The *freqModIBIS* sound module is based on frequency modulation. Normalized raw data of the respiration rate determines the pitch, modulation points and amplitude values. Through various mapping strategies it is possible to generate alternative frequency modulations.

The instrument *polysynthIBIS* applies parameter changes to the transformations of sampled sound materials, using them as a source for the synthesis of a new sound output. In this sound module, the EMG measured raw data range of muscle responses determine the index of the wave-table. The instrument loads sound samples in advance to multiple arrays for use as a voice source for the instrument. The transformation of the sound uses a polyphonic synthesis patch with five different parameters. Pitch, amplitude, duration, the number of sound samples from the wavetable and starting point in milliseconds are all modified by variations in the parameter mapping.

5. THIRD STATE

Each performer’s internal state control the audiovisual synthesis in the performance system; live bio-signals representing the real-time internal state are complemented by pre-recorded bio-signal data representing "frozen" internal states.

The real-time data controlling elements of the audiovisual output makes detectable the mainly involuntary responses of the performer's sympathetic autonomic nervous system to the performance environment.

In contrast to the 'somatic' portion of the peripheral nervous system, which receives sensory information and controls skeletal muscle and voluntary movements, the autonomic ('self governing') nervous system is concerned with regulation of smooth muscle, cardiac muscle and glands. The sympathetic and parasympathetic autonomic nervous systems sub-divide this system. The sympathetic system is associated with activities that increase the expenditure of energy and levels of arousal, for instance, speeding the heart, raising blood sugar levels, erecting fur or hair, or creating goose bumps. It is the involuntary activity of this system that is revealed most prevalently by Skin Conductance, Electrocardiogram, Temperature and to Respiration sensing.

In addition to live physiological data, performers make use of additional pre-recorded data-sets (frozen data), which can be introduced in response to developments during the improvisation. These datasets represent a physiological history of responses to earlier recordings and improvisation activities. Their content draws upon the literature of physiological responses to musical, visual and auditory stimuli, such as the effects of respiratory feedback on emotion [6] and the relationship between skin conductance and auditory stimuli [7].

The interaction of the performance output and environment with the performer's results in feedback effects within the improvisation that are not limited to voluntary acts - such as introducing frozen state data, but also upon what are arguably involuntary modifications of the live-data through the responses of the performer's nervous systems. In this sense, the third state can be considered a combination of the voluntary and involuntary use of bio-signal data for the control of audio-visual synthesis open to real-time modification via the channels of biofeedback and performer control.

5.1. Improvisatory Context

Musical improvisation is a process formed by interaction between musicians, based on an exchange of musical events and gestures, which flow in the moment of playing. Whether a performance is human-with-human or human-with-machine collaboration, the
common characteristic of this activity is that it requires active participation within a linear time structure.

In an interactive system, a linear communication flow within the system develops an implicit feedback loop between the performer and the system through its audio-visual outputs. The output then influences the performer’s decisions about their real-time interactions with the control data structures. Figure 1 shows the performance settings and block diagram of IBIS.

![Figure 1. Block diagram of IBIS system.](image)

There is a closed loop feedback between the performer and an interactive performance system. However, during a real-time bio-music improvisation process another type of feedback loop can also be achieved through the acquisition of biosignals. Sonic relations during a period of improvisation cause changes in the emotional arousal levels of the performer, and directly alter the bio-signal acquisition. IBIS uses bio-sIGNALS as the main source for the improvisation process.

Improvisation is based on exchanging musical events; however, the effects of audiovisual output, represented by the vectors $a$ and $v$ (indexed by the performer ID) in Figure 1, on the acquisition of biosignals have more weight on the progress of the improvisation in this system.

In the performance setting, the interaction between the real-time internal states of the performers creates another internal state, the third state, which generates its own channel for the resulting audio-visual outputs through bio-signal data of the frozen state.

![Figure 2. Sonic and visual characteristics of each state can be identified in the improvisation performance.](image)

The indirect and the direct interaction modifies the interactive system output in alternative ways allowing the audience to better discern and identify the sonic and visual characteristics of each individual state in an IBIS performance. Figure 2 demonstrates the visual representation of different states. The system can incorporate multiple performers real-time internal states and multiple frozen internal states creating numerous interaction channels for the improvisation process.

6. CONCLUSIONS AND FUTURE WORK

In this paper, we have concentrated on the very act of interaction, which is typically under-utilized in bio-music. With a novel design strategy based on an abstract representation of the performers’ physiological states (i.e., the third state), we have explicated the combination of the voluntary and involuntary use of bi-signal data for the control of audio-visual synthesis in real-time modification via the channels of biofeedback and performer control. Our IBIS system is thus capable of rendering pre-recorded bio-signal under controlled situations allowing two performers to interact with the computational representation of a third one in real-time.

The capabilities of our system afford a multitude of narratives; exploring these narratives fully is our most important future task. We then can make use of these narratives in explanatory and conceptual models around the central theme of the living body akin to Emmerson’s work [2]. We aim to demonstrate the components of the IBIS, and the whole system within an interactive performance during the ICMC-08 Conference.

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8. REFERENCES


