Sonic Virtual Reality Game: How Does Your Body Sound?

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ABSTRACT
In this paper, we present an interactive system that uses the body as a generative tool for creating music. We explore innovative ways to make music, create self-awareness, and provide the opportunity for unique, interactive social experiences. The system uses a multi-player game paradigm, where players work together to add layers to a soundscape of three distinct environments. Various sensors and hardware are attached to the body and transmit signals to a workstation, where they are processed using Max/MSP. The game is divided into three levels, each of a different soundscape. The underlying purpose of our system is to move the player's focus away from complexities of the modern urban world toward a more internalized meditative state. The system is currently viewed as an interactive installation piece, but future iterations have potential applications in music therapy, bio games, extended performance art, and as a prototype for new interfaces for musical expression.

Keywords
biomusic, interface for musical expression, collaborative performance, musical mapping strategies, interactive sonification, HCI, interactivity design, multimodal, expressive interface, biosensors, bend sensors, Arduino.

1. INTRODUCTION
The integration of mind, body, and sound is the focus of this sonic virtual reality "jam". This is an interactive "gaming" system that uses body movements and vital signs to generate soundscapes. Choosing from single player or multi-player mode, each player wears biosensors that capture data from actions of the body. This information is compositionally mapped to sounds for artistic, interactive, and therapeutic purposes. In this paper, we describe our system from its original conception to its current version, including the player interaction (or game play), software, hardware, possible future iterations, and current direction.

2. BACKGROUND RESEARCH
Biofeedback is a process that measures a person's bodily functions (heart rate, skin temperature, muscle tension, brainwaves, etc.) and conveys the information back to them in real-time. [15] There have been quite a few games on a consumer level that have offered feedback in the form of intelligent agents and tutors; some with visualizations, and some limited sound variations. C. Wehrenberg implemented one of the first biofeedback games "Will Ball Games" in 1974. It was a "competitive-relaxation" game structure, which moved a ball across the game field using comparative GSR inputs. [15] In 2001, Journey to the Wild Divine released a game that included hardware, such as biosensors linking to the computer via USB, and software with challenges such as levitation of objects or sound generated with laughter. [16] In addition, in 1992 the BioMuse was introduced. In its original version, it was a large and expensive development platform that collected bioelectric signals and allowed musicians and developers to control MIDI code, video game objects, robotic devices and more with brainwaves, eye glances, and hand gestures. Atau Tanaka, who continued to perform worldwide with a group called Sensorband until 2003, first used BioMuse in performance at Stanford in 1989. The technology available in BioMuse v.1 is now compacted into wireless wearable sensor systems, including the BioFlex, which captures EMG data from muscles, the BioBeat, which captures ECG signals, and the BioWave, which captures EEG, EOG and facial EMG signals. [2] Other noted biofeedback software is the Mind WorkStation, which uses a single dry sensor attached to wireless headphones to capture brainwave data. The CyberYoga Biofeedback Software uses heart rate and skin conductance measures that are worn while doing yoga. The ThoughtStream Personal Biofeedback System also uses a software-hardware package to provide audio-visual feedback. [7] Artists such as M. Peretti and musicians such as D. Rosenboom have also used biofeedback in their art works. [15]

One system that inspired our work was Paint and Lem's velocity-sensitive non-speech audio system, which has been used in rehabilitation therapies in Australia. [6] Another is the commercial product called RESPeRATE, which uses stretch sensors placed around the upper torso to sense breathing movements and play music based on those breathing pattern, thus regulating breathing with the ultimate goal of lowering blood pressure. [9] A similar musical biofeedback system that was designed by one of the authors of this paper was presented at NIME 2009 as a demo. [12] The project was designed as an installation version to a musical biofeedback system for breathing regulation for patients undergoing MRI and CT scans. This system explored how the body moves during respiration by sonifying the patient's breath in comparison to a pre-determined steady musical line. The similarity or dissimilarity between the steady state and the malleable musical lines would provide musical feedback to the patient to indicate how regular his or her breathing was compared to a steady state musical line. As an extension of this initial study, our system is focusing on developing an interactive music interface that uses more of the body's vital signs for generative and sample-based real-time composition.

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Much of our soundscape design is taken from Barry Truax's models of acoustic communication regarding the relationship of the listener to the sound environment. [13] In our system, the player is simultaneously creator and listener, constantly 'listening-in-search', and responding to the surrounding sounds. Using Schafer's categorization of elements within a soundscape, we can properly realize keynote sounds, soundmarks, or signals. [10] Valle, et al.'s work also describes a three-part categorization model classifying: atmospheres, events, and sound subjects that provide a different window through which to layer and create sounds. [14]

3. DESIGN

In this section we will discuss the different components to the iterative design process for this interactive system. This includes reviewing the original design and how it changed throughout the design process. We will also review the design of the hardware, sensor, software, aesthetic and technical decisions for the soundscape, and the overarching game structure.

3.1 Original System Design

The original concept was a self-realized class project to create a compositional tool that used the body as a sensing and input mechanism. We decided on the creation of an installation piece using the paradigm of a game for the first iteration, leaving other applications of the system as future expansions. Our initial body function sensors were pulse, breathing, and galvanic skin response. We then began to explore expanding the range of sensors and, over the course of development, we looked at pedometers, bend sensors (attached to knees, elbows and fingers), voice sensors, blood pressure monitors, EEG devices, temperature sensors, and motion tracking analysis as possible sensory inputs. Originally, we envisioned one generative model using electronic sounds and one linked to pre-composed loops of a more classical style. We came to the idea of using soundscapes as the base to create a unified, yet complex sound. Max/MSP was our software of choice, and as we explored hardware options the tangible layout changed, but the concept remained the same.

3.2 Hardware

The hardware we began with was the heart rate monitor. It is a fetal heart rate monitor, which we found gave good amplification of the heartbeat when pressed against the chest to the left of the sternum. When listening to the raw heartbeat, one can hear that there are some filters already built-in to the device, such as a low pass filter on the signal, which helps to amplify the low pitch of the heartbeat inside the chest cavity. The sound of the heartbeat is sent via analog input through the audio jack to the computer, and received via ADC in Max/MSP. A band-pass filter is applied to isolate the heartbeat's fundamental frequency, which ranged from 20-30Hz. This was the only sensor used during the single player mode.

We chose the Arduino Duemilanove microprocessor to receive additional sensor data, and can be run from one laptop. The Arduino takes the signals from the sensors, and with the proper programming, parses the signals out of separate outlets, giving six discrete digitally converted outputs from the six discrete analog inputs.

3.3 Sensors

Player 1 uses the baby heart rate monitor whose output can be fed through a mixer into the computer, or directly into the audio input jack.

Player 2 has a stretch sensor and a bend sensor. For strength and durability, we used two stretch sensors in the same unit, which was a strap around the mid section of the body to measure chest expansion, or breathing rate. The bend sensor attaches to the middle finger and responds to inward bending of the finger.

Player 3 uses two bend sensors. The first sensor is attached to the middle finger, similar to Player 1, and the second is attached to the bottom of the knee to measure the bend depth.

3.4 Software

Each player currently uses a separate Max/MSP patch. Player 1's patch filters the incoming analog pulse signal into corresponding bang messages. Using a modified version of *taptempo*, Max calculates and then scales the average pulse rate, allowing game play to continue or stop based on heart rate. The player has manual control to choose level between 3 levels to begin the game.

Player 2's patch takes data from a bend sensor and a stretch sensor through the Arduino. The bend sensor data is scaled in 8 levels and sent through *phasor* & *cycle* objects to harmonize with a continuously playing 440Hz sine tone. The scaled values of the bend sensor are 220, 330, 440, 550, 660, 770, 880, and 990 in Hz. The stretch sensor input range is scaled into 4 values and runs through an *sfplay~* object that filters the sound in 4 ways: LPF, HPF, bandpass, and notch - according to how much the stretch sensor is extended.

Player 3's patch takes data from two bend sensors through the Arduino and scales it into two sets of seven levels. Each level corresponds to a pitch of a chosen instrument for each set. Thus, as the bend sensor contracts and expands, the pitch rises and lowers accordingly. Control of each instrument's attack is manual through a button push on the patch.

3.5 Soundscape

The motivation behind our soundscape design is to move the players away from the complexity and noise of the external world. We chose archetypal soundscapes from nature that were analogies of inner processes. The progression of the soundscapes helps the player move further into a meditative state. The game levels move from an urban soundscape to a busy forest and conclude with an ocean soundscape. This is reminiscent of the approaches of Pauline Oliveros's "deep listening" technique, and creates a space for what she calls 'listening as meditation' to occur. [8]

Level 1, "The World Around Us", begins with an urban soundscape, with the sounds of traffic and pedestrian noises to immerse the player in a disorienting, but typical city setting. It transitions to a more suburban soundscape of "Main Street", with sounds of fewer cars and more people. In the smaller town soundscape, one can hear the sound of children laughing and playing. This might represent the "inner child" in all of us, and a reminder that we must all continue to laugh and play.

Level 2 is called "The Forest of Our Minds" and represents all of the chatter of our logical thoughts and intellect within the context of our multitasking daily activities. Appropriately, the first layer of sound introduced in this level is a thunderstorm, with the sound of thunder rumbling in the distance while rain falls gently. This transitions into the sound of a forest, with birds, crickets, and cicadas chattering in a symphony of nature. If this layer is maintained, a gentle stream is added to this second layer to create a calm soundscape, which hopefully, in turn, calms our busy minds.

Level 3 is called "To Calm A Turbulent Ocean" and begins with the sound of a strong wind whistling and waves crashing loudly and urgently. If the target heart rate (THR) is maintained, the 3-minute loop transitions into a calmer ocean soundscape. Once again, if the THR is maintained then another layer is added over the calm waves. This new layer has distant seagulls, and adds some vitality to the serene seascape.

3.6 Game Play

This system was designed to be a simulation of actual soundscapes, using an interface that encourages what has been called "kinetic gestural interaction," where the player "bodily participates with the sound." [3] The game can be played by a single player, or by two or three players. In single-player mode, the player wears the heart monitor and focuses on maintaining a THR, specified at the start of each level, to progress the game through multiple soundscape layers, which are designed to create a meditative space. In multi-player mode, the game begins when Player 1 selects a level; at this point, the first layer of the 'lo-fi' [10] soundscape begins to play. Player 1, wearing the heart monitor, attempts to reach and maintain a specified THR range. After a specified duration of time, Players 2 and 3 are enabled to join in as the soundscape cross-fades into a less hectic variation. Player 1 must continue to maintain the THR range while the other two players use their sensors to 'play' their instruments collaboratively. If Player 1 continues to maintain the THR for another specified duration of time, a second layer is added to complete the soundscape. The level is considered a success once this full soundscape has been maintained for a given amount of time and the full soundscape continues to play indefinitely after this point as long as Player 1 maintains the THR. If Player 1 moves outside of the THR range, the sound transitions back into the hectic urban 'hi-fi' soundscape and the entire 'calming process' must begin again. Player 3 decides to either end the game or move on to a different game level. The same pattern follows for each of the three levels.

4. PROTOTYPE ANALYSIS

In general, the sensors for Players 2 and 3 were difficult to control, making interaction with the system and with other players problematic. Additionally, Player 3 has the difficult task of playing two different instruments simultaneously. With our current and forthcoming advancements in software design for the purpose of making these virtual instruments more intuitive, a training period will still be required. Player 2's stretch sensor does not fully accomplish the goal of monitoring breathing, which calls for development of a proper mounting device or different sensing method. Once a mounting device is built accordingly, the auditory feedback can be linked to the breathing sensor's need to accurately reflect the action of breathing. The sensitivity of Player 1's heart monitor makes it difficult to move while wearing the device, but another alternative is being developed to allow for more freedom of expression. All of the sensors are currently being optimized to be converted into "wearables".

In the development of the system, the ultimate objective was to have a multiplayer experience through the use of body movements, which is arguably a relatively novel concept in the field of music technology. More energy needs to be devoted to the development of the single-player version, by refining the sound sensing device and the transitions between layers for a more realistic experience.

5. FUTURE ITERATIONS

The future applications of this system are numerous. It could be applied to therapeutic or rehabilitative environments, as a performance or installation art system, or could even be set up as a network game, where various players work together to simulate an auditory experience. General directions that future iterations will be taking include exploring Bluetooth wireless Arduinos for a less constricted experience when wearing the sensors, and developing more refined "wearables", such as gloves, leg warmers, or hats. The development team recently acquired the Biograph Infinity biofeedback hardware with the Physiology Suite, and we will be experimenting with integrating this sophisticated technology into our system. We have also been developing integration with the NeuroSky Mindset single-dry sensor EEG device with its open-source SDK.

We will continue to develop the three difficulty levels, including more choices in the soundscape, and a general tuning of the system so that anyone can easily wear the devices to create the soundscape. A GUI will need to be created for optimum game play. The Max/MSP patches will have to be slightly redesigned to fit each of the needs of the proposed applications; however, a stable, functional, and adaptable framework is already in place.

5.1 Game Design Application

Using "kinetic gestural interaction" with biosensors, the game is designed to add an interactive and enjoyable experience for a therapeutic exercise, performance, or group activity. Thus it is closely linked to therapeutic applications. The objectives of this game system are in alignment with the "Serious Games" initiative to "help forge productive links between the electronic game industry and projects involving the use of games in education, training, health, and public policy". [11] The initiative for developing games for therapeutic applications is evidenced by such conferences as "Games for Health", where experts gather to discuss and demo the latest games in "exer-gaming, physical therapy, disease management, health behavior change, biofeedback, rehab, epidemiology, training, cognitive health, nutrition and health education". [4] This game has "aesthetic goals" that guide the player to experience naturally occurring soundscapes, but no visual components have yet been implemented. [5] Adding biosensors and other types of input devices to the gaming world could enhance existing game experiences, especially if a player would activate the soundscapes with their body functions.

5.2 Therapeutic Application

The field of technology in music therapy is rapidly expanding as interest in technology's ability to create unique therapeutic situations grows. We hope to expand the system to include more therapeutic aspects, but currently it has two possible means by which it can be applied to music therapy. One is the ability to encourage body awareness, movement, and control through auditory feedback. The other is the ability to give the player an opportunity to create sounds in non-traditional ways, so that the user who has limitations in movement in everyday circumstances may be able to create music using our system.

Alternative Heart Rate Monitors (HRM) are being explored such as non-coded wireless HRM straps or the Thought Technology Biograph Infinity device, which can detect the heart rate more accurately in a 'lo-fi' environment where the system may be installed (such as museums, spas, rehabilitation centers, healing clinics). Another consideration in a therapeutic or rehabilitation setting is to introduce a "God" mode, where a simulated target heartbeat is aurally introduced. A player would have to match this target in order to trigger the soundscape. This would allow for entrainment of relaxation states.

5.3 Generative Music Application

One of the original design concepts that initiated this project was a musical biofeedback system designed to regulate breathing rate. [12] While working to extend that project idea, the idea of generative music composition came about, where mapping the values to more abstract generative music concepts would create unique compositions each time the system was explored. Similar to a previously presented iteration of the system, the player would go through certain motions, and he or she could create specific music or sound phrases, either singly or along with other players. The foundation for such an expansion is in place. Birchfield et al. have proposed another framework for a user adaptive model for dynamic soundscape creation, which we also used as a proposed model in the development of our system. [1]

6. CONCLUSION

There is much potential for our interactive system, and we have only begun to explore the ways that it may be integrated in a gaming scenario, therapeutic setting, generative music performance application, or art installation. The fundamental framework for our application has been established, and the next phase is to make it more adaptive and user-friendly. We have shown that this system provides an innovative way to control soundscapes and instrument samples with sensors, and are developing this system further in 2010.

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