Sound Space Manifold

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ABSTRACT

In this paper, the Sound Space Manifold is described as an interaction between sound and geometry that gives narrative to soundscapes. A brief introduction of historical interactions between sound and space is given, followed by the motivation behind the Sound Space Manifold. A system that allows listeners to interact with the Sound Space Manifold is described and documented. Three works prepared for this system are described and the ensuing interaction between sound and space to create narrative is discussed.

Categories and Subject Descriptors

J.5 [**Computer Applications**]: Arts and Humanities – *Architecture, Arts, fine and performing, Fine arts, Literature, Music.*

General Terms

Algorithms, Design, Experimentation, Human Factors.

Keywords

Sound, Narrative, Geometry, Topology, Manifold, Human, Audio, Music, Interactive.

1. INTRODUCTION

Since the advent of tape delay and artificial reverb, sound and space have become firm collaborators. In day-to-day life they seamlessly intertwine in our subconscious as the echo of a footstep relating the size of the room and the material of the walls, or a roar of a stadium crowd shrinking the building and focusing all attention to the field. In modern audio multitrack mixing, sounds are manipulated to create artificial spaces whether it is a cathedral, a mountaintop, or a local bar. Their ties often bind in a direct manner, sound influencing perceptions of space or space influencing perceptions of sound.

This direct binding is not necessary to influence space with sound, and vice a versa. Several trails have been blazed with more abstract fastenings. To name a few: shapes have been used as intuitive controllers to sound synthesis algorithms [4], ultra high frequency speaker drivers can localize sounds so well that it is as if they are emanating from within one's head [6], and touch free instruments such as the Theremin connect a person's motions to melodies. These explore the non-instinctual connections between space and sound. As tools, they promote the exploration of new cognitive experiences, and new connections between the senses.

The Sound Space Manifold attempts to spearhead a new connection between sound and space by realizing soundscapes upon three dimensional surfaces. These surfaces influence both the perception and creation of the soundscapes [1], giving form to narrative and a new context to location. As well, it expands how the eyes and ears experience soundscapes by creating virtual environments unrealizable in reality. For example, sounds can be placed on a torus, and the listener can walk along its rolling surface with no fear of falling off into an abyss.

The goal of the Sound Space Manifold is to use shape to create narrative architectures. The use of the word "manifold" implies two things. First, that a deep connection and reliance between sound and space exists, and secondly, it refers to the act of navigating higher dimensional spaces with fewer degrees of freedom than the actual space to be investigated. The current implementation of the Sound Space Manifold allows the listener to navigate a three dimensional Euclidean space using only two degrees of freedom. In addition, this implementation aims to give the listener as much freedom to explore as possible while maintaining the underlying narrative structure. For this purpose, additional controls allow the listener to affect the passing of time, and the decay of sound.

MAST'09, January 29–30, 2009, Santa Barbara, CA, USA.

2. IMPLEMENTATION

This implementation of the Sound Space Manifold is quite straight forward. The listener stands, surrounded by speakers, holding a wireless device with controls for audio amplitude, audio decay rate, time multiplication as well as several other position tracking elements. The software receives transmissions from the device, updates the model, and projects the model as both a 3D visualization and a soundscape. The exact hardware implementation of this device is not integral to the Sound Space Manifold, but is documented here so that it may be iteratively improved in further realizations.

2.1 Hardware

The wireless device utilizes a microcontroller that reads the values of 4 potentiometers, a 2-axis accelerometer, and communicates with a digital compass. It gathers information from these 6 sensors and transmits them over blue-tooth to the main computer. The 4 potentiometers give the listener control over the audio amplitude, audio decay rate, audio time multiplication, and space distance multiplication. The compass relates the orientation of the listener on a 2D plane and the accelerometer, strapped to the foot of the listener, detects when the user takes a step.

Surrounding the listener are several speakers (min. 3) that receive spatialized audio from the main computer. It is intended that the listener always stay in the center of the speakers so audio is properly spatialized. The virtual position of the listener is tracked in software. They move within the space by essentially marching in place and pointing the wireless device in the direction they wish to travel. When s/he takes a "step", the compass captures the listener's orientation, and s/he is moved within the computational model based upon the space distance multiplier and the orientation. The updated model is then projected and sonified.

2.2 Software

The software residing on the main computer loads, visualizes, and sonifies the model as well as tracks the listener position and parameters. It is primarily written in C++ utilizing the openGL framework for model visualization, Graphics Library of Views [2] for the GUI and layout, and Open Sound Control [7] for communication between the software and the Bluetooth receiver. In addition to these frameworks, libraries, and protocols, the software implements a phase vocoder for time manipulation and performs its own brand of audio spatialization. Further discussion of the algorithms used in the software can be found in the Computational Model section.

3. COMPUTATIONAL MODEL

This implementation of the Sound Space Manifold places points of sound on 2-manifold surfaces. The audio spatialization, and visualization are computed in Euclidean 3 space ($\boldsymbol{E}^3$). For practical reasons, the final audio spatialization output is projected onto a plane since the current speaker arrangement is positioned on a plane. Time is controlled through time multiplier that utilizes a phase vocoder to travel through sounds at varying speeds.

3.1 2-Manifold Topology

In general, a manifold is a mathematical object that looks locally like Euclidean space. The listener can only move upon two axes, therefore, in order to move upon a 3D surface, the surface must be 2-manifold. In this implementation, only 2-manifold spaces are used, but allowing the listener to move upon three or more axes could permit higher dimensional spaces.

3.2 Sound Spatialization

Sounds, speakers, and the listener are modeled as single stationary points in $\boldsymbol{E}^3$. The distance (d) from the sound source ($\boldsymbol{ss}$) to the listener ($\boldsymbol{u}$), as well as an additional variable decay factor (r), determine a sound's overall amplitude (A). They are played out the nearest two speakers ($\boldsymbol{s_1}$, $\boldsymbol{s_2}$) with appropriate delays (se_1, se_2) determined by the distance from the sound to the respective speaker (sd_1, sd_2). The angle between the sound, speakers and the listener (θ_u, θ_{s1}, θ_{s2}) determine the final speaker amplitudes (sa_1, sa_2). The equations below describe the 2D spatialization scheme, which could be expanded to a 3D scheme by choosing the nearest four speakers, though this would require a more complex speaker arrangement than is currently set up.

$$\theta_u = \cos^{-1}\left(\frac{u \cdot ss}{\|u\|\|ss\|}\right), \quad \theta_{si} = \cos^{-1}\left(\frac{u \cdot s_i}{\|u\|\|s_i\|}\right)$$

$$d = \|ss - u\|, \quad A = 1 \big/ \left(1 + d^r\right)$$

$$sa_i = A\frac{|\theta_u - \theta_{si}|}{|\theta_{s1} - \theta_{s2}|}$$

$$se_i = sd_i \big/ \left(340.29\, m/s\right)$$

3.3 Time

Within the model, time is controlled by a time multiplier that ranges from -50 to 50, with 1 being normal play speed, 0 being paused play speed, and -1 being reverse play speed. A phase vocoder is used to alter the play speed of individual sounds while maintaining their frequency content.

4. PIECES

Three pieces were made for the maiden presentation of the Sound Space Manifold in order to illustrate several interactions between sound and space. Each utilizes a particular 2-manifold shape to mold the narrative space. The pieces range from data sonification to mercurial storytelling.

4.1 Skywalking

Skywalking demonstrates data sonification by projecting the stars as sine waves upon a sphere.

4.1.1 Space

The listener travels upon a sphere, which reflects the shape of earth and our relation to the stars above us.

Fig 1. Sphere

4.1.2 Sounds

Each star sound will be placed upon the sphere based upon its latitude and longitude. The star's luminosity determines the sound's frequency and the star's mass determines the sound's amplitude. Greater mass results in higher amplitudes, and greater luminosity results in higher frequency.

4.1.3 Discussion

The sphere's great influence on the narrative of this piece is its similarity to the shape of the earth's surface. It immediately gives the listener the impression of being larger than life, able to cross continents in leaps and bounds. It also reorients how we think spatially of the stars above us. They are presented as points projected onto our planet rather than large objects scattered off in the great vastness of space. The star data, collected from NEsTED [5], is given new life by letting the listener interact with the sounds projecting onto a new narrative space.

4.2 Circular Argument

Circular Argument demonstrates applying the Sound Space Manifold to enhance a dialogue with a preexisting structure.

4.2.1 Space

A torus is doubly circular. The surface is created by moving a circle around the circumference of a larger circle. In *Circular Argument* the sounds are placed on a torus in a pseudo-double helix configuration.

Fig 2. Torus

4.2.2 Sounds

The sounds in this piece are two distinct voices, each with their own circular argument that progresses as the listener travels along the circumference of the torus's larger radius.

4.2.3 Discussion

The dialogue would still have the semblance of a cohesive narrative without placing it upon a torus; yet, the torus adds an additional element of structure, which allows the listener to investigate the dialogue more thoroughly while preserving the original circular structure. Imagine, for instance, placing the dialogue on straight line upon an infinite plane. While the listener would have the advantage of traveling back and forth through the dialogue so that s/he may investigate it more closely, the circular structure would be lost. By placing the dialogue on a torus, the listener can travel as s/he pleases. When s/he reaches the "end" they are concurrently at the "beginning" of the dialogue, reinforcing its circular nature.

4.3 Enneper's Murder

Enneper's Murder is an immersive story that relies upon the Enneper surface to conduct the narrative flow. Without the surface, the complete structure of the narrative would be lost.

4.3.1 Space

An Enneper Surface [3], in contrast with the previously mentioned surfaces, is self-intersecting. That is, the surface passes through itself as a hand might pass through fog. Visually, it looks similar to an origami butterfly. Despite its complex appearance, it is still constructed from a single surface.

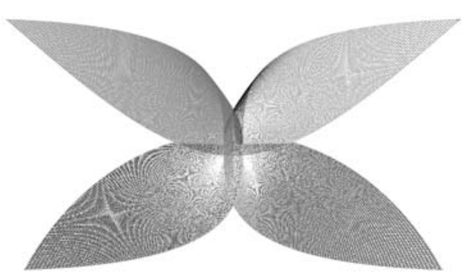

Fig 3. Enneper Surface

4.3.2 Sounds

The sounds in *Enneper's Murder* are clues that lead to the murder's motive, weapon and identity. They also reflect the victim's actions and association with the murderer.

4.3.3 Discussion

An Enneper surface swoops out in long wings and then converges in the center of the shape, intersecting itself at several different angles and locations. In this story, the intersections of the surface are also the intersection of the murderer and victim, and the long wings are either the murderer or victim alone. Here the surface is obligatory to the narrative. The listener can travel around the murderer, or the victim, but can only experience both of them at the self-intersecting points of the surface where the murderer meets the victim in the narrative. Concurrently, the large swoops of the Enneper surface reflect the undulating and frantic emotive qualities of the characters.

5. CONCLUSION

The Sound Space Manifold proffers new collaboration between sound and space by allowing space to form narratives of soundscapes. A hardware/software implementation was described that enabling a listener to move through the space and control various parameters such as amplitude, audio decay rate, and time multiplication. Three pieces were discussed, *Skywalking, Circular Argument,* and *Enneper's Murder*. These pieces demonstrated several ways in which space can influence narrative by creating a narrative context, reinforcing narrative structure, and/or collocating narrative elements.

6. REFERENCES

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