SoundThimble: A High Resolution Real-Time Gesture Sonification Framework

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ABSTRACT

We introduce *SoundThimble*, a platform for sonic interaction based on the relationship between human motion and virtual objects in 3D space.

The installation employs a Vicon motion capture system and custom software to track, interpret and sonify the movement and gestures of a performer in 3D space.

We distinguish between three interaction scenarios, centred around object searching, manipulation and arrangement. We illustrate the resulting extended possibilities of perception and expression via two case studies: a participative installation and a dance performance.

The software developed is open source and portable to similar hardware systems, leaving room for further extension of the installation mechanics.

Author Keywords

sonification, motion tracking, gesture spotting, interactive installation, synthesis

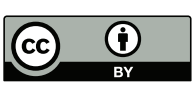
ACM Classification

- Applied computing → Sound and music computing
- Computing methodologies → Motion capture
- Human-centered computing → Gestural input
- Human-centered computing → Auditory feedback

1. INTRODUCTION

High resolution three-dimensional motion capture systems are traditionally used for animation in film and games, as well as for life sciences research and engineering applications [**?**]. This technology has long been mined by the NIME community [3, 9], although in many early cases, technological limitations meant that the motion data transmission and the sound generation processes were not simultaneous [3, 7].

The *SoundThimble* project harnesses current motion tracking technology and gesture detection algorithms to develop new modes of sound exploration in an interactive installation context. Our aim is to push beyond the standard paradigms of isolated body motion audification [3, 7] or parameter mapping-based new instruments [9], towards deeper narrative structures coupled with layered arrangement of music patterns.



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Our implementation uses a state-of-the-art Vicon motion capture system[1] based on eight Vantage 5-megapixel infrared cameras and two Bonita video cameras. Since the open-source software developed in this project[2] is built around Vicon's Datastream SDK,[3] the platform can be ported to both older and future Vicon-based systems.

In the remainder of the paper, we review relevant existing projects and technology (section 2), we describe the *SoundThimble* concept and development (section 3), we propose two applied case studies (section 4), and we conclude with a survey of remaining challenges and future perspectives (section 5).

2. RELATED WORK

- interactive / movement sonification examples[5].
- Vicon & related projects
10+ year history of Vicon+sonification
- micro
[13]
- vicon + OSC de la iem.at

The current decade has seen qualitative advances in the interaction between human gesture and sound behaviour [6]. ... [4].

3. PROJECT DESCRIPTION

3.1 Concept

The sound-thimble, as the basic building block of our framework, is based on the concept of *sound object* in the Schaefferian sense, as a clearly delimited sounding unit, open to manipulation, arrangement and composition [10].

Such an entity, once instanced, can retain an ambiguous nature (spatially and acousmatically) or can switch to a more material state (positioned in space and tied to a causal source) [1]. The duality between the latent positioning of the object (which can be inferred from phenomena other than spatial sound reproduction), and the active sound spatialisation, once tied to motion data, becomes an innovative tool for sonic arts through sound sketching, auditory games and other realtime interaction scenarios.

3.1.1 Interaction scenario

SoundThimble can be viewed as both an interactive sound installation and an auditory game, comprising three phases: search, manipulation, arrangement.

The game's narrative starts with a human player attempting to find a sound-thimble (a stationary virtual object, randomly positioned in 3D space), by analysing cues that

[1]See `https://www.vicon.com`.
[2]Available at `https://github.com/RVirmoors/viconOSC`.
[3]See `https://www.vicon.com/products/software/datastream-sdk`.

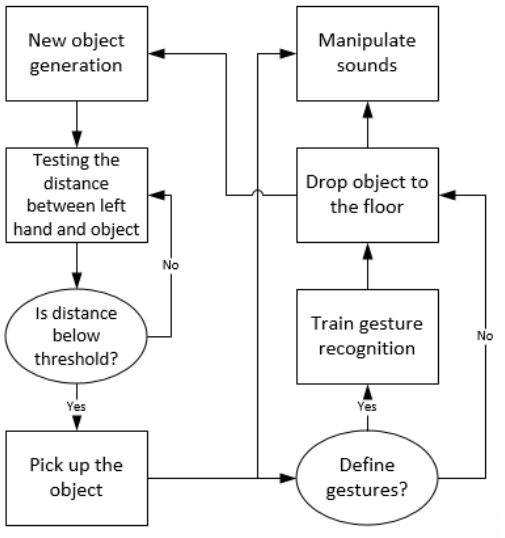

Figure 1: *SoundThimble* interaction workflow.

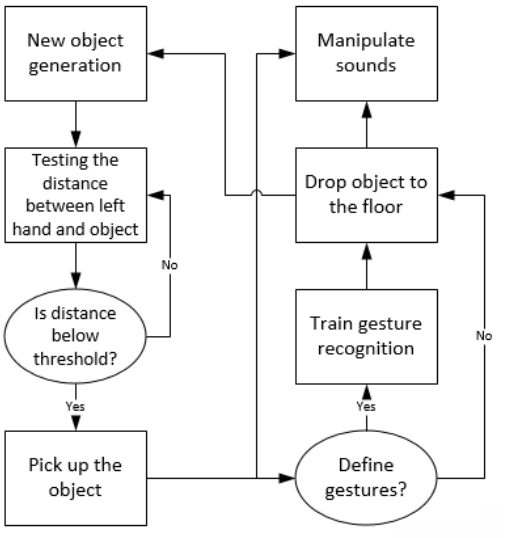

Figure 2: *SoundThimble* framework architecture.

are constantly shifting in the sonic fabric based on the human's movement relative to the object. Analogously to the traditional game of *Hunt the Thimble* (a.k.a *Hot or Cold*), the space between the human and the virtual object is correlated to sound synthesis and modulation parameters. Briefly, the closer one comes to the object, the more coherent the sound and vice-versa.

Once the object is found, its sonic manifestation gains a richer causal relationship to the human: the player becomes a performer, and is now able to explore the object's sonic palette, and record a number of gestures that can be re-performed later, re-called, and used to trigger or manipulate sonic shifts and events.

Finally, the performer can drop the virtual object to the floor, or discard it by "pushing" it outside of the installation boundaries. This triggers a new object to be randomly generated, while the player retains a degree of control over the initial object via the recorded gestures. Both objects are now in a latent state, with the new one guiding the player's search, and the previous one responding to the learned set of gestures.

This repeating scenario is outlined in Figure 1: objects are randomly generated, the performer finds them, defines gestures and interacts sonically with them before arranging them in a pleasing configuration. With each spawning of a new object or assignment of a new gesture, the game becomes more challenging and complex, but also more flexible and rewarding.

3.1.2 *Performance aesthetic*

- text Bogdan

3.2 Implementation

=== FIG: Framework Diagram: Senzori, Camere, Nexus, C++ SDK, Max, Speakers ====

The framework architecture diagram is laid out in Figure 2. Three-dimensional sensor data is streamed into the Vicon Nexus software, which is able to reconstruct and label the underlying character skeleton. The gesture recognition and sonification algorithms are programmed in Max[4], which generally receives control data via the OSC[5] protocol. Since Vicon systems do not support OSC out of the box, we used the *oscpack*[6] library to extend the DataStream C++ SDK and send OSC bundles to Max.

3.2.1 *Character design*

Figure 3 shows a skeletal reconstruction in the Nexus environment. Since our project is intended as a public installation, we pursued a minimal amount of markers, for ease of setup and prototyping. The resulting configuration—sufficient for tracking hand and arm gestures, while ensuring the redundancy needed when one marker is obscured from the cameras—consists in 5 markers: two positioned on the head, one on the forearm, and two on the hand (thumb and index finger).

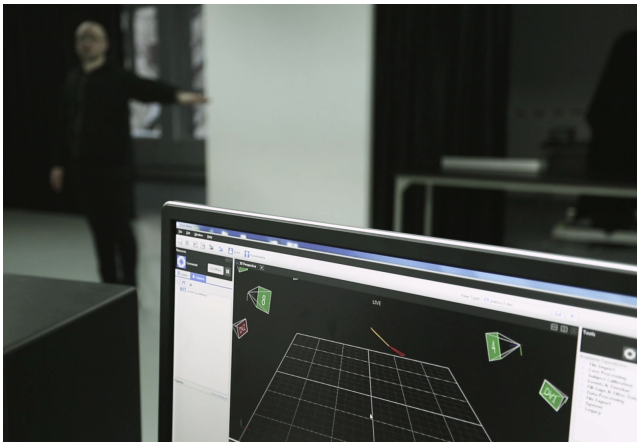

Figure 3: A performer tracked in Vicon Nexus. Two visible segments: head-forearm, forearm-hand.

Each OSC bundle sent through the SDK consists of the following:

- 3D coordinates for the head (averaged from the two head markers);
- 3D coordinates for the hand (averaged from the two hand markers);

[4]Max is a state-of-the-art programming environment for realtime multimedia performance: `http://cycling74.com/`.

[5]OpenSoundControl is a multimedia communication protocol: `http://opensoundcontrol.org/`.

[6]See `http://www.rossbencina.com/code/oscpack`.

- distance between thumb and index finger.

All three items are sent only if non-zero, i.e. for the head and hand coordinates at least one of the respective markers is active, while for the distance computation, both markers need to be visible and correctly labelled. The forearm marker is used only for segment reconstruction, and is not sent via OSC.

The described configuration produces highly stable and responsive inputs into the Max system, with a spatial resolution of 1mm and a latency of 5ms at a frame rate of 500hz.[12] Bonita sub sample ratio 5:1 = 500

3.2.2 Object generation & interaction mechanics

The following object-related mechanics are implemented as basic algorithms in Max: generation, detection, dropping.

Object generation is executed randomly within the boundaries of the motion capture field, as defined in the Vicon calibration phase. Detection of the sound-thimble occurs when the distance between hand and object falls below a set threshold. By default this threshold is set at 200mm radial distance; lowering it can make the game considerably more difficult. Once the object is detected, it becomes mobile, its coordinates tracking those of the hand's.

Finally, a simple thresholding of the z-axis (height) value of the hand position serves to put down the object. If the velocity computed on the x or y axes (horizontal plane) is high enough, then the object is pushed in the respective direction, and is able to leave the area of the installation, essentially being removed from the game. At this point, a new object is introduced. The system keeps track of all object coordinates, as they appear and disappear over time.

3.2.3 Gesture recognition

We use the thumb-index finger distance value to enable gesture recording while the two fingers are kept close together. The input data captured into *MuBu* multi-buffer containers [8] consists of pairs of values:

- $\sqrt{\frac{(\Delta x)^2+(\Delta y)^2}{2}}$;
- Δz,

where Δx, Δy, Δz are the respective differences between head and hand coordinates. This feature preprocessing serves two purposes:

Firstly, gestures are recorded based on the position of the hand relative to the head, thus becoming invariable to the performer's absolute *position* within the space. Secondly, by composing the x and y values into a single feature, gestures become invariable to the performer's *orientation* on the horizontal plane. Thus, gestures can be recorded and recalled anywhere within the space, irrespective of the direction the performer is facing.

The input features are fed to one of two gesture recognition algorithms, both part of the *MuBu* package. The first, based on Hierarchical Hidden Markov Models (HHMM), is implemented in the `mubu.hhmm` Max object. HHMMs are a generalization of HMM where each state is considered to be a self-contained probabilistic model [4, 11]. The second is the *Gesture Follower* `gf` Max object, based on a Sequential Monte Carlo inference engine [2].

The first method allows for *gesture spotting*, i.e. it constantly produces likelihood values of a certain gesture being active, together with an approximation of its completion rate. If these are over a certain threshold, the respective gesture is triggered. The second method is more flexible and precise: the detected gesture can be followed at a variable rate or scale, even backwards. The only drawback is that it requires a start trigger, which we send by quickly attaching and separating the thumb and index finger.

Each generated object has a number of gestures associated to it. When an object is dropped to the floor, the classifier is (re)trained with the new data, and consequently gestures can act as on/off switches for a particular sonic behaviour (if they are performed/spotted once at a time), or as continuous controllers (if they are repeated). When several objects exist on the floor, one specific movement might act on one or more objects, depending on which detection likelihoods exceed the threshold.

3.2.4 Sound design

Each sound-thimble has a corresponding sound design *patch*, differing in (a) the source sound material used, (b) the synthesis techniques applied, and/or (c) the control mapping schema to the object search and manipulation variables. The various combinations of (a), (b) and (c) give rise to a growing library of objects, each with its own character.

...

In this way, the whole soundscape can be generated in a continuous, organic manner by correlating markers' positions with synthesis parameters.

The interactive experience can be described as having two main paradigms: object finding and object interaction.

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By using noise-like carriers, complex sonorities occur with a variable harmonic content. In both cases, the performer tries to find the object by listening to these variations. By correlating small and large variations to its position in the 3d field the performer receives meaningful clues about the object location, as well as an interesting and engaging soundscape.

Another patch uses granular synthesis to read short grains from a sound file and scatter them in either a regular or random manner. Among the parameters that can be mapped are: grain position, grain size, envelope shape, level of scattering, pitch, stereo width. Multiple parameter states can be stored, saved as presets and interpolated between. In this way, several parameters can be controlled by a single aspect of the movement. This patch is effective in both the object search and manipulation phases, differentiating the two paradigms by the dimensionality of control.

...

Another patch uses a concatenative synthesis engine to read through a segmented sound file at a rate and position determined by marker velocity and location.

In the search phase, all sound design is based on two channels that can either be routed to multiple pairs of speakers or downmixed to mono and diffused on an arbitrary number of speakers. In the manipulation phase, the sound is spatialised using Ambisonics (using the ICST implementation[7]) to track the position of the performer. In the arrangement phase, the dropped object retains a "root" source location, which can relate dynamically to the performer position when a gesture is executed: for instance, the granular patch sends spatialised grains back and forth between the dropped object and the performer.

In developing the sound design algorithms, we used two input data sources. The first one is motion capture data recorded in Nexus and played back through the SDK. For more flexibility and immediate control, we also developed a basic interface in Jitter to monitor the input data and to manipulate it using the mouse, for instant auditory feedback. This feature comes in useful when certain motion

[7]See `https://www.zhdk.ch/index.php?id=icst_ambisonicsexternals`.

data is not available and needs to be roughly simulated.

4. CASE STUDIES

We present two applications of our platform: a participative installation, and a performance piece. They are two manifestations of the *SoundThimble* concept and infrastructure, following a sequence of two experiences: (1) the direct interaction with sound in space, and (2) the mediated interaction with sound and space of an audience member. In both cases, the range of sense and perception is extended through new experiences.

4.1 Interactive installation

- interaction analysis: Bogdan

4.2 Dance performance

The following is a sketch for a work currently under development. A performer enters the motion capture space, and commences a series of improvised motions, silently establishing the action space.

Once a threshold is reached, a virtual object is generated and the movement is no longer completely free, its range of action being directed by the relationship to the object position. Searching and finding the sound-thimble is a process of correlating the sonic characteristics to one's own movement patterns.

By "resonating" with the object's manifestation and locating it, the performer enters the manipulation phase, extending her auditive and tactile perception through embodied listening. The multimodal information processed by the performer is both cochlear and kinaesthetic/proprioceptive, tactile, vestibular and visual. Thus, the information she forms about the shape of the movement, its trajectory and spatial dynamics, is intrinsically linked to the sonic connections to these parameters. This dynamic knowledge informs the timing of new actions and the anticipation of sonic feedback. The resulting action schemas are composed as both spatial and sonic shapes.

Gradually, as the performer's control patterns become crystallised, the sonic nature of the source object moves between the abstract and the concrete. In the latter phase, the performer is able to control high-level parameters such as tempo and orchestration of a coherent musical structure which was partly a result of the generative interaction in the more abstract/exploratory phase.

5. CONCLUSIONS AND FUTURE WORK

- Areas of improvement

We have shown ... all software we developed, including... is open source ...

Future work on SoundThimble could/will include: multiple performers, eye tracking, video projection, extended synthesis and sound manipulation algorithms, additional mechanics for the auditory game (manipulating while dropped, picking up the object, throwing, ...)

... (more details on each)

6. ACKNOWLEDGMENTS

Hidden for review.

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