MagneTip: Reintroducing a Physical Interaction Loop for 3D Musical Drawing in Extended Reality

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ABSTRACT

Extended Reality interfaces open numerous opportunities for musical expression. One of them is 3D musical drawing, *i.e.,* the ability to draw sonic and visual paths in virtual and physical spaces. However, in existing instruments (controllers, hand tracking) most of the interaction happens in the digital/virtual space, which reduces primary audio and haptic feedback and might limit the expressiveness one has with physical drawing and acoustic instruments.

In this paper, we propose a novel design approach which moves part of the 3D interaction back to the physical space for more intimate controls and more direct feedback, creating a physical interaction loop connected with the virtual interaction loop. We then present MagneTip, a first implementation of this approach for 3D musical drawing, which enables one or two handed interaction and combines co-localised and spatialised feedback.

Author Keywords

3D musical drawing, extended reality, audio-haptic feedback

CCS Concepts

•**Applied computing → Sound and music computing;** Performing arts; •**Human-centered computing → Mixed / augmented reality;**

1. INTRODUCTION

Musical expression and (live) drawing have often been associated, from drawing-based composition tools (*e.g.,* Iannis Xenakis' Upic) to instruments that generate both visual and sonic traces. What they have in common is the use of movements and positions to create audiovisual spaces.

The generalisation of Extended Reality (XR) display technologies now facilitates the design of instruments based on 3D musical drawing. We believe that these constitute an important research subject, because: 1) they associate expressiveness in both visual and auditory modalities; 2) they allow for a variety of mappings between gestures, visuals
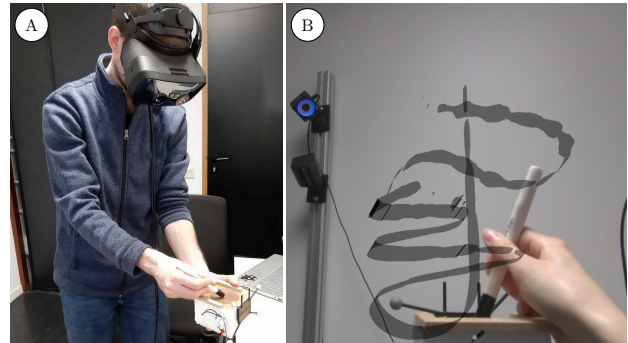
Figure 1: A) User equipped with a mixed-reality HMD and using MagneTip B) 3D drawing as seen through the HMD

and sounds; 3) they may benefit from the expertise of both musicians and visual artists.

However, the devices available for 3D drawing are far from providing the expressiveness of physical drawing, *i.e.,* intimate brush to paper interaction and the corresponding audio and haptic feedback. In particular, all controls and feedback go through a digital loop that induces latency and reduces complexity through gestures tracking, audio/haptic/visual processing and feedback rendering.

In this paper, we propose to achieve more intimate interactions in 3D musical drawing by: 1) introducing a novel approach that moves part of 3D musical interactions out of the digital space and back to the physical space, and 2) designing a novel 3D drawing device that relies on this approach.

1.1 Related work

1.1.1 Audio-Haptic feedback in 3D interaction

While 3D interactions in virtual environments rely mostly on visual feedback and gesture tracking, multisensory feedback can help with the perception of a given space and its content [15] [17], and reduces the uncertainty of an event [19].

In the context of musical creation (digital instruments), audio and haptic feedback are combined as an attempt to replicate the intimacy provided by an acoustic instrument. Leonard *et al.* [13] propose a platform for multisensory interaction in virtual reality using mass-interaction physical modelling. Çamcı and Granzow tackle musical expression with Hyperreal Instruments [10] by constructing an instrument providing audio, visual an haptic feedback. Arslan *et al.* [5], in Vibrating Shapes, combine 3D interaction in Spatial Augmented Reality (SAR) and actuated instruments to

generate sound in the physical space.

In our approach, audio and haptic feedback come from the virtual interaction loop, but also as part of a physical interaction loop that communicates with the virtual components and provides active feedback which the user can appropriate, so that the result of the musical interaction is both virtual and physical.

1.1.2 3D drawing devices and techniques

3D drawing implies more constraints than 2D drawing, as it has more degrees of freedom. It, however, allows for interesting or unusual interaction techniques, which would not be possible inside a 2D space.

Dudley *et al.* [11] use a HoloLens to create an application for lines, splines and freehand drawing. With HoloARt, Amores *et al.* [4] also use a HoloLens to paint, spray or splatter virtual paint onto the environment. *"Drawing on air"* [12] mixes 3D drawing in virtual reality with haptic feedback, using a Phantom force feedback stylus. A number of commercial 3D drawing applications have been implemented in recent years, such as Gravity Sketch [2], A-Painter [1] or TiltBrush [3].

It is important to note that 3D musical drawing is a more specific case. The main focus is split between the visual and the audio feedback, meaning that less complexity can be expected on the drawing side of the application.

1.1.3 2D/3D musical drawing

Drawing has been used to create music or sounds on several occurrences. In Levin's work on audiovisual interfaces [14], both *Yellowtail* and *Loom* use drawings as a way to generate sound, by either animating or looping them. With Different Strokes [20], particles spawn and follow the drawing according to the user's gesture to produce sound. In Illusio [6], the drawings serve as a control interface for live-looping performances.

Fewer projects have explored 3D musical drawing. Magical Brush [18] uses a mobile device to draw in augmented reality, with audio and visual feedback mapped to its motion characteristics. In the Reflets system, Berthaut *et al.* [9] use a SAR display to create 3D sound paths that are revealed by both musicians and spectators. Nakagawa *et al.* [16] present a 3D audiovisual environment where users can draw bare-handed, with sounds mapped to the height of a stroke.

Although there are projects which explore musicality, haptic feedback and drawing, none actually combine all of them. MagneTip aims to create a 3D musical drawing environment for both musicians and visual artists, that is focused on achieving more intimate interactions with the system.

2. PHYSICAL AND VIRTUAL 3D INTERACTION LOOPS

Expertise in physical drawing and acoustic music playing relies on an interaction loop with fast, precise and rich auditory and haptic feedback. Transferring these activities to a virtual space, for instance in the case of 3D musical drawing, implies the creation of an interaction loop which involves gesture tracking, 3D interaction techniques, visual to sound and visual to haptic mappings, and audio/visual/haptic rendering. This virtual interaction loop introduces indirections [7] and a potential loss in temporal and spatial accuracy of both control and feedback. This loss comes from the choice of gestures tracking and feedback technologies, and of soft-
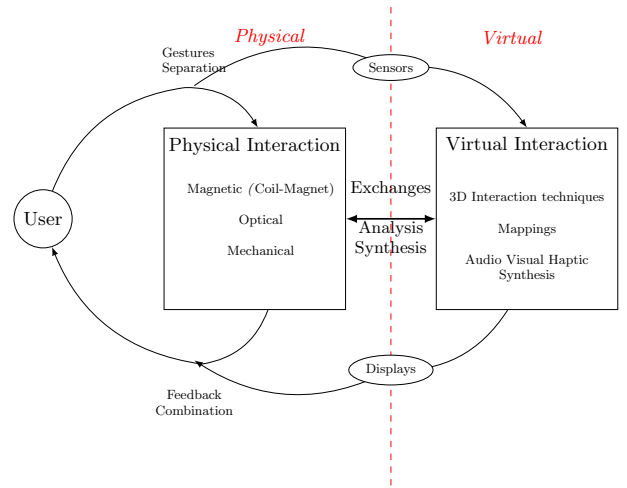
Figure 2: General Approach: Gestures are separated between physical and virtual interaction loops which exchange data. Feedback from the two loops are combined for the user to perceive.

ware mapping and rendering techniques. In addition, most feedback on the resulting visual and sonic drawing remains secondary, meaning that it is produced after virtual processing of gestures and mappings. One solution to bring virtual interaction closer to the physical one is to improve hardware and software components of the virtual interaction loop, *e.g.,* increase sampling and display rates and resolutions.

Instead, we propose to take elements of the interaction loop out of the digital (virtual) space and place them back into the physical space, so that part of the 3D musical interaction happens without sampling and synthesis steps, and benefits from the richness of interaction in the physical world.

As shown in Figure 2, our approach relies on a separation of musical gestures, on physical and virtual interaction loops that exchange data, and on the combination of feedback.

2.1 Gestures Separation

Gestures can be used in both the virtual and physical interaction loops. In the virtual one, they will be sensed, through motion tracking and the various sensors present on controllers, sampled, and used as part of interaction techniques to select, manipulate and navigate 3D content [8]. In the physical one, they will directly affect the behaviour of physical components (magnetic, mechanical, optical) which in turn will generate audio, haptic and/or visual feedback.

2.2 Physical Interaction

Components of the physical interaction loop enable the direct production of sounds, visuals and haptic feedback from artists' gestures, co-localised with these gestures, without the need for digital conversion, *i.e.,* without sampling, processing and displaying steps. Audio and haptic interactions can be obtained, for example, through the manipulation of mechanical devices, *e.g.,* vibration speakers or actuators, or electromagnetic devices, *e.g.,* coil-magnet pairs. Visual interactions can be performed using projectors, mirrors, lenses, and so on. The result of the physical interaction loop is intimately connected with the performed gestures, co-localised and temporally synchronous.

2.3 Virtual Interaction

Components of the virtual interaction loop are comprised of 1) 3D interaction techniques that allow users to manipulate a virtual scene, 2) audio, visual and haptic synthesis processes 3) mappings between the manipulated scene and synthesis parameters. In the case of 3D musical drawing, the virtual interaction consists in moving a 3D brush inside a virtual space and generating a 3D geometry in addition to a soundscape.

2.4 Physical-Virtual Exchanges

Between the two loops, visual, audio and haptic content can be exchanged through analysis and synthesis.

Exchange of sound from virtual to physical can be done via coils, actuators, vibration speakers, so that the sound produced through 3D interaction techniques can be modulated. In the other direction, microphones/piezoceramic transducers can capture the sound to be transformed digitally (amplified, processed...) or to serve as input for the 3D interaction techniques. In our 3D drawing context, perceptual sonic features (loudness, brightness, noisyness...) could drive the appearance of the visual brush. Exchange of haptic data from virtual to physical can be done using actuators, vibrotactile, force-feedback devices and from physical to virtual using passive magnets, tangible objects that will influence the gestures performed in the virtual space (*e.g.,* as done in encounter-type haptics). Finally, exchanges of visual data is enabled in one direction by projecting visual content with projectors, such as with SAR displays [5], and in the other direction using cameras or photoresistors.

Exchanges also provide the opportunity of many types of multimodal physical-virtual feedback loops, where capture of physical audio interaction can drive visual interaction resulting in virtual haptic feedback, which can in turn generate vibrations picked up as a sound signal...

2.5 Feedback Combination

Finally, the feedback, *i.e.,* result of interaction, of both loops, is merged and provided to the user. Part of the feedback will be co-localised with the device, *e.g.,* sound and haptic display from the physical loop or visual feedback from a head-mounted display (HMD) or SAR. Another part can be distant, *e.g.,* audio display from an array of speakers or visual content placed away from the user. In the case of 3D musical drawing, visual feedback from the virtual loop will consist in drawings placed around the user in the virtual space. Audio feedback can be both localised at the current brush position, but it can also come from non-spatialised ambient sound generated from the combination of previously drawn paths.

3. DESIGN OF MAGNETIP

In this section, we describe how we implemented our approach in the form of MagneTip [1].

For the physical interaction loop, MagneTip relies on the principle of a loudspeaker. A membrane with a flat coil (created using a LPKF ProtoLaser H4 device and an 8.5x8.5 cm copper panel on fiberglass) is attached to a wooden sound box (figure 4). The audio signal generated from the virtual interaction loop (using a PureData patch), which depends on 3D drawing brush movements, is transmitted to the coil through a soundcard and amplifier, hence generating an oscillating magnetic field (figure 3). When a magnet

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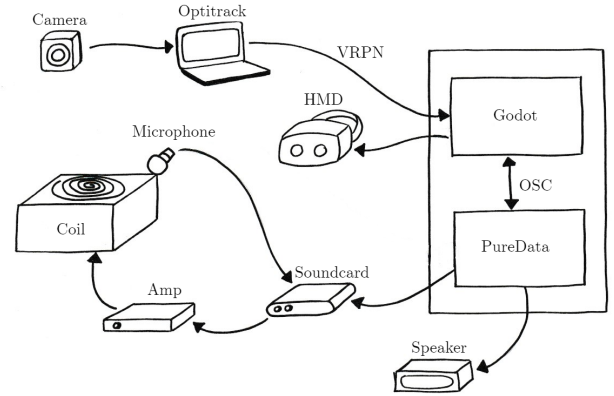[1] A video of interactions with MagneTip can be found here

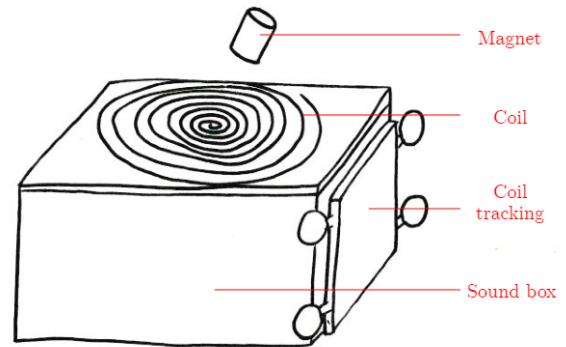**Figure 3: Base components and signal/data flow in MagneTip**

Figure 4: Sketch of MagneTip's device

is brought closer to the coil, the magnetic attraction makes both the membrane and the magnet vibrate. This produces an audio-haptic feedback directly from the physical space, co-localised with the user's gesture. Movements of the magnet above the coil affect both the amplitude of the feedback but also the sound timbre. [2] The virtual interaction loop receives sound captured from the physical one to influence brush properties. It also receives the overall position of the coil (with 4 Optitrack cameras) which is used in the virtual interaction loop to control 3D drawing (inside Godot 4.2), in turn influencing the sound generated which is sent back to the physical loop. Virtual sound feedback relies on granular synthesis with controls in grain window position and pitch, which passes through a feedback delay and a volume envelope modulator with controllable tempo and sustain. The volume envelope of this synthesis is also applied to a low frequency signal added to the output in order to increase the haptic vibrations felt from the physical loop. Fine grained gestural control of the magnet position constitute the physical interaction, while larger gestures are used to drive virtual interaction. Audio feedback can be output from both interaction loops, while the visual feedback only comes out of the virtual loop, using a Varjo XR-3 mixed-reality HMD, and haptic feedback only from the physical loop.

4. CONCLUSION

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[2] This work was in part inspired by Belgian sound artist Els Viaene
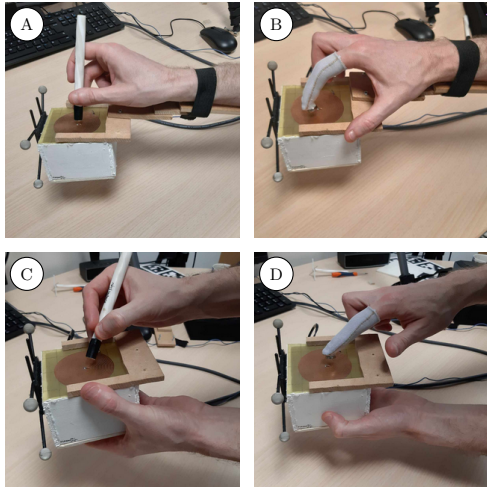
Figure 5: Interaction configurations with MagneTip: A) Unimanual version with coil attached to forearm and stylus B) Unimanual version with finger glove C) Bimanual version with stylus D) Bimanual version with finger glove

In this paper, we proposed a novel approach for 3D musical interaction that reintroduces a physical interaction loop in addition to the digital/virtual one. We implemented this approach for 3D musical drawing with the MagneTip system.

Future work will investigate long term appropriation of this device by musicians and visual artists and explore the various mappings for 3D musical drawing that can be created in the physical and virtual interaction loops.

5. ETHICAL STANDARDS

6. ACKNOWLEDGMENTS

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