Extending Instrumentality Through Mechanical Augmentation and Sound Synthesis in a Microtonal Harp

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Figure 1: Augmented Harp-E in participatory improvisation music performance, *De-dimension*, 2025.

Abstract

This paper presents an augmented Harp-E that extends instrumentality through mechanical augmentation and synthesis continuity. Built upon a harp with a microtonal lever system, the instrument is mechanically extended via counterweighted fishing lines coupled to suspended textile surfaces. Gestural force propagates physically across distributed components before entering the sensing and digital processing chain, preserving excitation logic across acoustic, material, and computational domains. Sound synthesis is designed to align with characteristic string articulations for digital response functions as a continuation of string behavior rather than as an abstract control mapping. Realized within the multimedia improvisational performance, the system distributes gesture across sonic, visual, and spatial dimensions, transforming the instrument into a multimodal and participatory environment. By grounding digital extension in material continuity, this work proposes a model of augmentation that shifts emphasis from parameter expansion toward the extension of instrumentality itself.

Keywords

Augmented instrument, Interactive installation Performance, Multi-agent Participatory Performance, Live Audiovisual Ecology

1 Introduction

Mapping has long been central to digital musical instrument (DMI) design, enabling gestural data to be connected to sound synthesis parameters and extending the performer's expressive bandwidth. In augmented acoustic instruments, this strategy supports hybridization between acoustic and electronic domains, yet it has also raised concerns regarding the perceptual arbitrariness that can arise when embodied gesture is abstracted into control data.

This paper proposes a mechanically grounded approach to augmentation that preserves excitation continuity across acoustic, material, and digital layers. The system is realized through an augmented Harp-E, whose microtonal lever and string structure is extended via counterweighted fishing lines into architectural space. Gestural force propagates physically before entering the sensing and synthesis chain, allowing digital sound to function as a continuation of string articulation rather than a mapped overlay.

Developed within the multimedia improvisational performance *De-dimension*[1], the instrument distributes gesture across sonic, visual, and spatial domains while supporting participatory interaction. The instrument is designed to operate across both virtuosic and participatory modes through a shared material structure. By grounding digital extension in material continuity, this work proposes a model of augmentation that shifts emphasis from parameter expansion toward the extension of instrumentality itself.

2 Theoretical Positioning

Mapping has long been central to digital musical instrument (DMI) design. Foundational works establish mapping as the process through which gestural data are connected to synthesis parameters, enabling sensors to extend the performer's expressive bandwidth[3, 4, 8]. Within this discourse, mapping is understood not simply as a technical connector between gesture and sound, but as a structuring layer that informs how musical interaction is represented and organized in the perceptual and conceptual domains[5, 10]. In augmented acoustic instruments, this paradigm often extracts NIMEphysical gestures and routes them through configurable digital structures to expand timbral or processing domains[9]. While such strategies facilitate hybridization between acoustic and digital systems, they have also prompted recurring critiques concerning the perceptual arbitrariness of gesture–sound relationships[7]. When embodied action is abstracted into control parameters prior to synthesis, the resulting sonic response may lose the material continuity, resistance, and constraint that characterize traditional instruments. The issue, therefore, is not solely one of intuitive mapping design, but of how digital mediation reorganizes the causal structure of instrumental interaction. Amongst the discussions in this discourse, media theorist Alexander Galloway's notion of the "intraface" has been mentioned by some researchers to be a good conceptual framework[7]. They suggest that mapping constitutes an internal mediating topology—an infrastructural layer that organizes how signals are transformed and rendered audible, as the defined layer of mediation as "an interface internal to the interface"[1]. Importantly, Galloway characterizes the intraface as possessing an interrogative or inward-orienting dimension, in which external conditions feed back into and reshape the interior organization of the system. From this perspective, the issue of arbitrariness is not simply one of designing more intuitive parameter correspondences; it becomes a question of how exterior material realities can reconfigure the internal logic of digital mediation itself. Augmented acoustic instruments offer a particularly fertile ground for this inward-oriented restructuring. Unlike purely digital DMIs, augmented instruments begin with an existing material and acoustic structure whose physical constraints already organize gesture–sound relationships. Prior work on physical modeling and mechanically coupled augmentations such as the Magnetic Resonator Piano[6] demonstrate that preserving excitation logic and material continuity can reduce abstraction in digital extension. Rather than treating sensor signals as generic control streams, the physical properties of the acoustic instrument can guide the topology of the digital system. In this way, material, acoustic, sensory, and computational domains may be jointly considered, establishing continuity across them. This paper documents an augmented instrumental design, using Harp-E, that addresses gesture sound mapping strategy through mechanical and synthesis continuity, realized in a multimedia improvisitional musical performance, *De-dimension* in Figure1. Harp-E is a commercially available electro-acoustic harp with a lever-based microtonal system, in which each string can be independently retuned using onboard pitch-shifting levers[2]. Our augmented Harp-E extends its lever and string structure using counterweighted fishing lines as shown in Figure 2(a), preserving tension and excitation behaviors across spatially distributed components. Force propagates physically through the extended string system before entering the sensory system. Sensor data are therefore not treated as abstract parameters but as traces of string excitation. Sound synthesis processes are designed to align with articulatory behaviors characteristic of strings' attack–decay envelopes, excitation-dependent retriggering, and excitation-consistent timbral variation—thus maintaining perceptual coherence between gesture and sonic consequence. Furthermore, the augmentation expands the instrument beyond its physical body into architectural space, distributing gesture across spatial and visual domains. The system also supports participatory engagement, enabling multiple performers—and, in the performance context, audience members—to interact with the instrument through shared material structures.

[1]Documentation in https://www.youtube.com/watch?v=TbPbxJgP1PY and a trailer version in https://www.youtube.com/watch?v=xQRz1oH5HzY.

3 Structure for augmented Harp-E

The augmentation begins with the harp's microtonal levers (Figure 2(a)), which normally support pitch bends, vibrato, and sliding articulations. Selected levers are coupled to fishing lines that extend into the performance space and anchor to suspended fabric panels. The fabric mass functions as a counterweight, maintaining tension and prolonging the string structure beyond the harp body. Performers can adjust levers or directly pluck, pull, and vibrate the lines (Figure 2(b)); in each case, displacement travels mechanically along the line to the fabric, preserving the physical logic of string excitation while providing an expanded gestural surface.

When force reaches the suspended textile, displacement spreads across the surface, producing visible swaying and rippling. Flex sensors printed with conductive ink capture these deformations as continuous motion data (Figure 2(c)). The signals are routed to an Arduino MKR WiFi 1010 (Figure 2(d)), encoded, and wirelessly transmitted to a laptop via OSC[11]. Ableton Live and Max for Live patches process the incoming data, execute sound synthesis, and manage performance logic. Through this chain, gestural energy moves from lever to line to fabric before entering computation, preserving continuity across acoustic, material, sensing, and digital layers.

The main latency arises not from the digital chain but from physical propagation along the extended lines. Because this delay is visible in the fabric motion, the performer can integrate it as material behavior rather than a timing disruption. In practice, the performer controlled both the original harp strings and the fishing-line system with precision, moving fluidly across coupled materials during improvisation. The system's responsiveness is therefore physically mediated yet compatible with performance demands.

Figure 2: Augmented Harp-E structure: (a) the lever micro-tonal system on Harp-E and fishing lines on the lever for instrument augmentation, (b) harpist interacting with the augmented part of Harp-E with the same performance gesture as harps, (c) flex sensor attachment, (d) system dataflow transferring with Arduino.

4 Sound synthesis for continuity

Sound synthesis follows the mechanical and articulatory logic of the extended strings. Instead of assigning sensor data to arbitrary parameters, the system detects three gesture categories derived from harp technique: plucking, bowing-like sustained excitation, and microtonal lever bending. Each category is recognized through characteristic flex-sensor motion and paired with a response that preserves harp-like morphology and articulation.

Plucking produces a rapid up–down displacement in the fishing line. Because acoustic harp tones have a sharp attack and rapid decay (Figure 3, right), this gesture triggers pre-shaped sounds that combine short percussive waveforms, recorded string strikes, and spectrally decomposed harp material (Figure 3, left). The result inherits the attack–decay behavior of plucked strings, so digital sound continues the excitation rather than merely reacting to motion.

The second category extends bowing techniques sometimes used on harp strings to sustain vibration under Helmholtz motion. In the augmented system, continuously drawing the counterweighted line creates a quasi-Helmholtz oscillation in the line and fabric. The flex sensor reads this as repetitive motion; when the signal exceeds a threshold, a looping audio segment is retriggered until the oscillation stops. Functionally, this resembles a wavetable-like system in which a short sustained waveform segment is repeatedly cycled in response to continuous excitation, translating mechanical periodicity into sustained sound.

The third category is microtonal lever bending. Unlike plucking or bowing, lever movement creates slower, relatively static pitch modulation. The system detects this slower displacement pattern and uses it to control pitch-related synthesis parameters, aligning the digital response with tuning and bending gestures. Across all three categories, synthesis remains an extension of string excitation logic through transient attack, sustained oscillation, and pitch modulation.

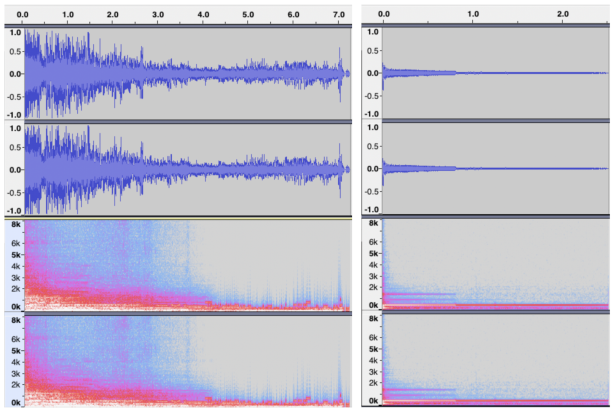

Figure 3: Left: Waveform envelop and spectrogram of the designed sound buffer; Right: Waveform envelop and spectrogram of the sampled harp.

5 Augmentation in performative domains

Beyond its mechanical and sonic extensions, the augmented Harp-E expands the instrument's performative domain. The counterweighted fabric panels act as large-scale visualizations of gesture: subtle actions such as microtonal lever adjustments—often imperceptible in conventional harp performance—are mechanically translated into visible motion across suspended textiles. This amplification renders acoustic intention legible through synchronized visual displacement.

The projection layer follows the same principle of material continuity. Motion features extracted from the flex sensor data, such as displacement magnitude and rate of change, are mapped to visual parameters including brightness, spatial deformation, and temporal persistence. This mapping preserves the directional and energetic qualities of the underlying gesture, allowing projected imagery to reflect not only the presence of motion but its dynamic characteristics.

The instrument operates across two complementary modes that emerge from the same material system. For a trained harpist, it functions as an augmented instrument that supports precise and expressive control through extended mechanical coupling. At the same time, the exposed structure—fishing lines, tension, and suspended fabric—remains accessible to non-expert participants, enabling collective and exploratory interaction. These modes are not separate configurations but coexist through a shared physical substrate.

By extending responsive surfaces into the surrounding space, the instrument brings its interactional field into proximity with the audience. In performance, audience members may touch the fabric and intervene in its motion, engaging the same sensing and synthesis processes as the performer. Rather than constituting external interference, such interactions are incorporated into the improvisational framework, where the performer negotiates and responds to distributed inputs as part of the evolving musical texture. In this way, the instrument challenges conventional associations between musical instruments, virtuosity, and fixed authorship, proposing instead a distributed and participatory model of performance grounded in shared material interaction.

Figure 4: Audiences interacting with the fabric in a performance.

6 Conclusion and future work

The augmented Harp-E demonstrates that mechanically grounded augmentation can extend instrumentality while preserving continuity across acoustic, material, and computational domains. By coupling the harp's string structure to architectural space and aligning synthesis with articulatory logic, the system maintains coherent gesture–sound relationships while expanding into visual, spatial, and participatory dimensions. The work therefore shifts augmentation away from abstract parameter mapping toward material propagation and perceptual legibility.

This paper establishes a proof of concept rather than a comprehensive technical, perceptual, or performative evaluation. Future work will study latency, responsiveness, and performer perception of physically mediated delay. It will also examine how virtuosic performance and participatory interaction coexist in larger settings, and how distributed agency, audience intervention, and shared material interfaces reshape authorship, control, and musical structure over longer temporal forms.

7 Ethical Statement

This work follows the NIME Principles and Code of Practice on Ethical Research. Any photo, video, or audio documentation included in the submission features only individuals who provided permission for recording and publication, and documentation can be removed upon request when feasible.

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References

[1] Alexander R Galloway. 2012. *The interface effect.* Polity.
[2] Harp-E. 2026. Harp·E. https://www.harp-e.com/en-us Accessed: 2026-02-11.
[3] Andy Hunt and Marcelo M Wanderley. 2002. Mapping performer parameters to synthesis engines. *Organised sound* 7, 2 (2002), 97–108.
[4] Andy Hunt, Marcelo M Wanderley, and Matthew Paradis. 2003. The importance of parameter mapping in electronic instrument design. *Journal of New Music Research* 32, 4 (2003), 429–440.
[5] Thor Magnusson. 2009. Of epistemic tools: Musical instruments as cognitive extensions. *Organised Sound* 14, 2 (2009), 168–176.
[6] Andrew McPherson. 2010. The magnetic resonator piano: Electronic augmentation of an acoustic grand piano. *Journal of New Music Research* 39, 3 (2010), 189–202.
[7] Andrew McPherson, Landon Morrison, Matthew Davison, and Marcelo M Wanderley. 2024. On mapping as a technoscientific practice in digital musical instruments. *Journal of New Music Research* 53, 1-2 (2024), 110–125.
[8] Eduardo Reck Miranda and Marcelo M Wanderley. 2006. *New digital musical instruments: control and interaction beyond the keyboard.* Vol. 21. AR Editions, Inc.
[9] Joseph Thibodeau and Marcelo M Wanderley. 2013. Trumpet augmentation and technological symbiosis. *Computer Music Journal* 37, 3 (2013), 12–25.
[10] David Wessel and Matthew Wright. 2002. Problems and prospects for intimate musical control of computers. *Computer music journal* 26, 3 (2002), 11–22.
[11] Matthew Wright, Adrian Freed, et al. 1997. Open soundcontrol: A new protocol for communicating with sound synthesizers. In *ICMC.*