The Lorentz Lap Brass: Method for Frugal Integrated Sonic/Haptic Interaction

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ABSTRACT

This paper presents an affordable and accessible method for integrated sonic/haptic interaction via a low-cost setup utilizing Lorentz Force Actuation – a form of electromagnetic actuation – and exemplified by the The Lorentz Lap Brass, a new electromagnetically-actuated musical instrument and interface (EMAII). This style of actuation is uncommon in NIMEs, though it presents rich opportunity for cost-effective tactile feedback, infinite sustain, and feedback control. In an effort to encourage open-source knowledge sharing, replication, and adoption of this novel technique, we describe the underlying concepts, designs, and techniques for this method and distribute schematics, CAD, and code used in the setup. Results of a preliminary user study are discussed and offer perspectives and avenues for improving, extending, or iterating on the current system.

Author Keywords

actuated instrument, electromagnetic actuation, acoustic synthesis, instrument design, haptics, feedback

CCS Concepts

•**Human-centered computing** → *Interaction design process and methods;* •**Applied computing** → *Sound and music computing;* •**Computer systems organization** → *Sensors and actuators;*

1. INTRODUCTION

Haptic feedback has been increasingly understood to be vital to instrument learning and playing[25]. Commercially available haptic prototyping platforms such as Phantom[1] or Omega[2] products are typically expensive and complex, while more accessible toolchains utilizing affordable components such as vibrotactile haptic motors facilitate haptic interactions that are independent and/or causally separate from acoustic systems.

The Lorentz Lap Brass was born from a series of experiments in attempt to electromagnetically actuate the strings of a harpsichord. After successfully sustaining vibrations in brass strings via optical feedback and Lorentz Force Actuation, we felt there was unexplored potential in electromagnetically actuating brass strings in a new haptic contexts. Though the final result of this exploration was a new musical instrument, the design process was experimental and exploratory in nature and only two goals were explicitly stated upon beginning the process of developing the new interface:

1. Utilize the authors' established toolchain for Lorentz Force Actuation of brass strings for simultaneous sound generation and tactile feedback and
2. Use the displacement from a user's pressing or pulling of interface strings as control signals for sonic and haptic feedback

1.1 Related Work

1.1.1 Infinite Sustain/Actuation

There is extensive literature on exciting and sustaining steel strings, metallic bars, and other idiophones by means of acoustic and/or electromagnetic feedback [4, 26, 10, 17]. Most electromagnetically actuated instruments/interfaces (EMAIIs) utilize electromagnetic coils to induce vibrations into magnetized steel or directly into magnets attached to an acoustically resonant body [6]. Some instruments utilize dynamic-coil speakers with controlled feedback from microphones or electromagnetic pickups such as the Halldorophone [31], the Feedback Cello [7], and the Feedback-Actuated Augmented Bass [19]. Actuated instruments might also utilize tactile transducers marketed as "bass shakers" typically used for gaming or home theatre setups. This style of transducer is essentially a cone-less speaker and will attempt to drive whatever rigid material or surface you mount it to. The Feedback Lap Steel by Jiffer Harriman [9] and the Overtone Fiddle by Dan Overholt [24] are such instruments. Instruments that employ electromagnetic or acoustic feedback control are most frequently augmentations of existing musical instruments. As Schmidt has observed, examples of instruments developed with electromagnetic actuators from their genesis are far less common and present a rich opportunity for exploration [28].

1.1.2 Optical Pickups

Piezoelectric and electromagnetic pickups are probably the most common forms of transducer for capturing the movement of a vibrating string. Electromagnetic pickups are

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[1] `https://www.3dsystems.com/haptics-devices/3d-systems-phantom-premium`

[2] `https://www.forcedimension.com/products/omega`

widely used in electric guitars, tone wheel organs, and Rhodes pianos, while piezoelectric pickups embedded within the bodies of instruments such as acoustic guitars or violins are used for amplification. Optical pickups emerged as an alternative technology in the early 2000s. Marketed for having the most "transparent" tone possible, this style of pickup commonly uses infrared LEDs paired with photo transistors. The ōPIK [3] and Lightwave pickup[4] are two commercially available optical pickup systems.

In previous attempts to sustain vibrations in harpsichord strings, which are traditionally made of brass, we utilized custom-made optical pickups to act as the sensor for a controlled feedback loop. Though electromagnetic pickups are perhaps more readily available or typical, brass strings are non-ferrous and therefore do not induce any signals in electromagnetic pickups, which rely on the magnetization of a ferrous string such as stainless steel.

1.1.3 Haptic Feedback

The tactile force feedback experienced by musicians when playing acoustic and electroacoustic instruments is considered an important factor in facilitating learning and playability. There is a growing body of research that addresses the typical unidirectional communication from performer to DMI by introducing force feedback through haptic actuators, and researchers now generally agree that haptic feedback increases the intimacies between musician and instrument and can even make them easier to play [25, 30, 22, 3]. Research by Luciani et al. demonstrated compelling results from using audio signals to drive the force feedback of a cello-like haptic simulation [14].

There are a number of NIMEs that have utilized off-the-shelf controllers such as the NovInt Falcon [12, 21]. Off-the-shelf haptic solutions can be expensive and require complicated programming, though there have been numerous efforts to make low-cost, accessible, DIY solutions [29, 1, 20] and create toolchains for implementation [5, 13]. A number of these devices have been used for navigating digital synthesis models [29, 12, 2, 27]. The system presented below affords simple, audio-driven haptic feedback from any audio source.

2. SYSTEM OVERVIEW

In this section, the mechanical, electronic, and software design involved in the Lorentz Lap Brass is described. This EMAII was developed in response to the previously stated exploratory goals. The current design consists of two brass strings tensioned and tuned with harpsichord tuning pegs. Optical sensors placed near the bridges of each string sense the displacement of each string as the player presses or pulls them. An optical pickup senses the vibrations of one string while the other string is used to control the excitation signals sent into both strings (Figure 1). Schematics, CAD, and code for this system is distributed in the following repository: https://github.com/aschmidt99/LorentzLapBrass.

2.1 Lorentz Force Actuation

The cumulative force felt by a charged particle exposed to electric and magnetic fields is known as the *Lorentz Force.* A special case of the Lorentz Force, sometimes referred to as the *Laplace Force*, describes the magnetic force felt by a multitude of moving charges (cumulatively an electric current) in a wire exposed to a magnetic field.

2.1.1 Electronics

To generate vibrations in the strings, audio signals are sent to a 5-Watt audio amplifier module [5] based on the PAM8406 IC [6] typically used to power small 4Ω or 8Ω speakers. Rather than connect to speakers, the output terminals of the amplifier are connected to each end of the string, passing an alternating current through the string. The current-carrying strings generate modest magnetic fields that interact with strong magnetic fields from permanent neodymium magnets located directly below the strings. To the authors' knowledge, this style of actuation has yet to be utilized in any commercially-available musical instruments, though it was outlined and directly inspired by Andrew McPherson's 2012 NIME paper about techniques for electromagnetic actuation [18], hinted at by inventor Paul Vo's Moog Guitar patent [11], and notably used by Alvin Lucier in his performances of *Music On A Long Thin Wire* [15].

The PAM8406 chip supports loads down to 2Ω, and features short circuit protection preventing the outputs from activating if a load less than 2Ω is detected. The brass strings are highly conductive and measure much less than 1Ω, so 10 Watt 2Ω Power Resistors are placed in series with each string to keep the board out of short circuit protection mode.

2.1.2 Magnets

The system uses N52 neodymium magnets to create the necessary magnetic field for actuation. The strength of the induced vibration is proportional to the cumulative strength of the magnetic field, and although the presence of just one or two magnets is sufficient to induce and feel vibrations, a higher density of magnets placed along the string evokes a stronger response.

2.2 Audio Hardware

The vibration of the sound-generating string is picked up with a custom optical pickup made using a ITR9608 photoelectric switch. Dave Corsie's optical pickup blog[7] outlined a schematic for creating optical pickups for upright bass. Modifications were made to Corsie's circuit, although the working principle is the same: the vibrating string varies the base current of a phototransistor by occluding an infrared LED directed at the detector. This, in turn, modulates the current flow from the collector to emitter. The voltage across a fixed resistor in series with the emitter then varies proportionally. When placed in an optimal position, this voltage is directly analogous to the position of the string and can be treated as an audio signal. It is amplified and buffered by a preamp circuit which is then connected to an audio interface with a standard 1/4" guitar cable.

2.3 String Displacement Sensing

ITR20403 Optical sensors similar to the above ITR9608 optical sensor are mounted in the bridges of each string. Each string has two custom 3D-printer bridge mechanisms that allow for precise placement of the string within the sensor's field of operation. An adjustment screw can fine-tune the height and length of the string, while a V-wheel adjusts the

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[3] `https://www.light4sound.com/`

[4] `https://www.willcoxguitars.com/lightwave-optical-pickup-system/`

[5] From Droking.com or Amazon.com

[6] `https://www.diodes.com/part/view/PAM8406/`

[7] `https://www.davecorsie.com/optical-pickup-blog`

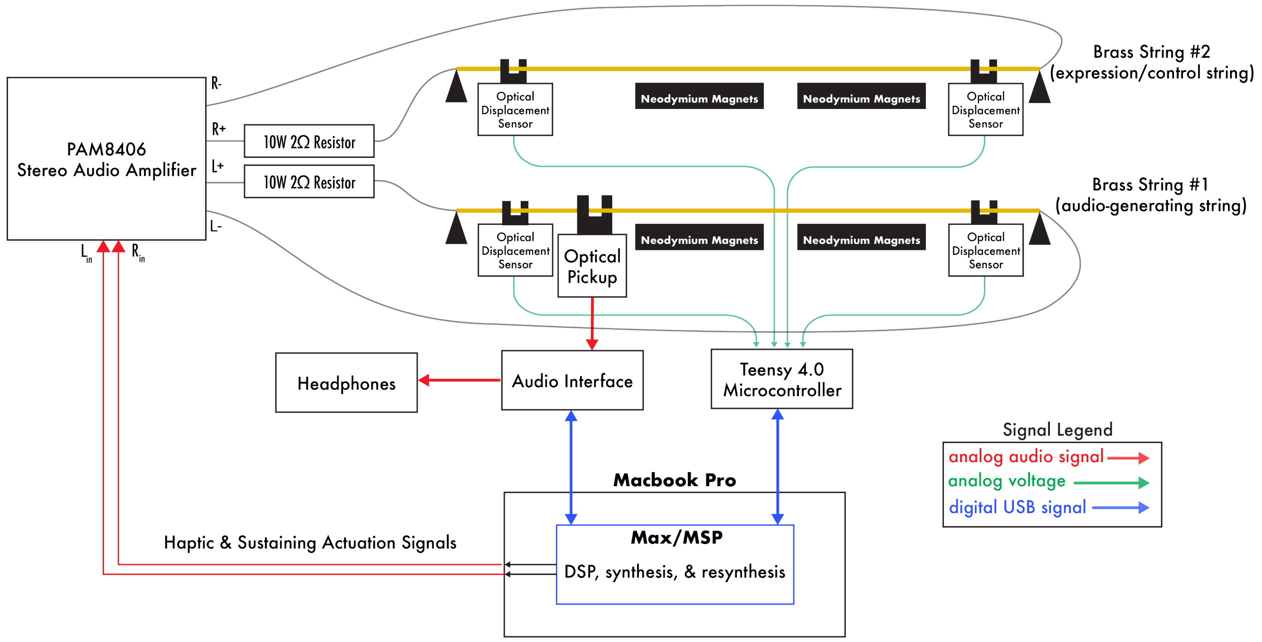

Figure 1: Full System Block Diagram

position the string within the optical sensor gap (Figure 2). Once again, a voltage divider is created between the sensor's photo sensitive resistor and a predetermined resistor value. A Teensy 4.0 reads the outputs of each of the four voltage divider circuits. The values are measured and reported to Max/MSP every 10 milliseconds via a serial port.

2.4 Digital Signal Processing

The audio interface is connected to a laptop utilizing Max/MSP for audio analysis and generation, which will be described in detail with each of the interaction modes.

3. PERFORMANCE INTERFACE

The Lorentz Lap Brass has two brass strings stretched across custom 3D printed roller bridges. Each string can be pressed or pulled with the player's hands or played with a brass or glass guitar slide. One string is the designated "sound generating" string, which has an optical pickup located at the left end of the string. The string further from the player is the "expression" or "control" string, which also incorporated haptic feedback. The form of the instrument is reminiscent of a lap steel guitar and can be played similarly (Figure 3).

3.1 Interaction Modes

O'Modhrain's research in utilizing haptic feedback for a theremin-style musical interaction inspired haptic approaches to the design of the instrument's interaction [22]. We devised 4 modes of interaction that were explored in the user study described below. In most modes, the interaction evokes that of a theremin, with one hand controlling the termination point (and thus pitch) of the "sound-generating" string while the other hand contributes to the amplitude and timing of the signal injected into the string, which more or less acts as a volume control. In most performance modes, the expression string controls the amplitude of the input signal or the amount of feedback injected into the strings.

3.1.1 Percussive actuation mode

In this mode, when the user presses or pulls the expression string (the further string) beyond a threshold, an 808-style percussive signal is sent into both strings. The user may fret the sound-generating string (the closer string) with their hand or a guitar slide to achieve a note with a percussive attack.

3.1.2 Noisy actuation mode

In this mode, the expression string simply controls the amplitude of pink noise being injected into the string, exciting the string at its open or fretted frequency.

3.1.3 Sustain mode

The Sigmund external library[8] for Max/MSP is utilized to track the pitch of the incoming signal from the sound generating string. The estimated pitch value controls an oscillator signal that is sent back into the string, achieving an infinite sustain. The amount of feedback is controlled by depth of press on the expression string.

3.1.4 Harmonic Scanning mode

An extension of the Oscillator sustain mode, harmonic scanning mode adds a level of control over of the harmonics present in the system. The fundamental frequency continues to be sustained via an injected pitch-matched sine wave oscillator, but now several harmonics are calculated and injected. The gain of each harmonic is controlled by the displacement of the left side of the expression string, while the overall gain of the feedback remains controlled by the right side.

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[8] `https://github.com/v7b1/sigmund_64bit-version`

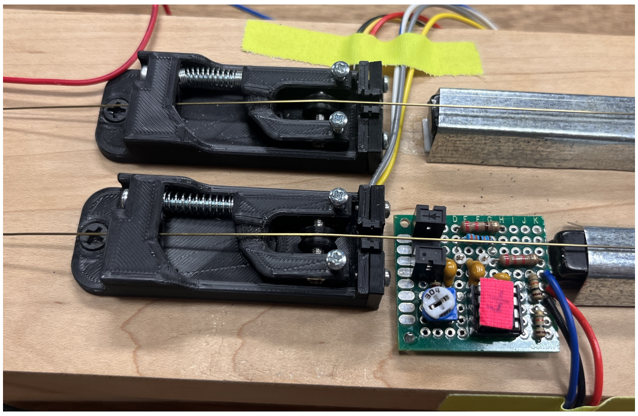

Figure 2: 3D Printed Adjustable Bridge and Optical Pickup

Figure 3: The Lorentz Lap Brass

4. USER STUDY

4.1 Methodology

The Lorentz Lap Brass is part of a larger project examining ways that instrument design practice can reside in communities embodying diverse cultural values. Informed by Marquez-Borbon's work on collaborative learning and communities of practice [16], as well as a wealth of research stemming from the concept of design probes [8], we therefore sought to engage peers in the design process, using the initial iteration of the instrument as a basis. Rather than evaluation in the traditional sense [23], the goals are: 1) to gain experiential impressions of the interaction modes, with particular focus on the haptic/sonic integration; and 2) to engage peers in open-ended ideation on future developments of the instrument or applications of these techniques.

4.1.1 Participants

The 5 participants all self-identified as musicians, ranging from 12 to 20 years of experience with playing one or more musical instruments. All participants had at least 5 years of experience working with music technology. All participants considered themselves familiar with Digital Musical Instruments or Alternative Musical Interfaces, and 3 of 5 participants expressed familiarity with the New Interfaces for Musical Expression (NIME) Community.

4.1.2 Protocol

Participants were presented four modes of interaction order of increasing complexity: percussive audio playback mode, noisy sustain mode, regular sustain mode, and harmonic scanning mode. Participants were encouraged to think aloud throughout the process, vocalizing what they liked and disliked, found interesting or off-putting, or any other stream-of-consciousness thoughts. Limited instructions were offered upon initiation of each mode to encourage exploration of the system, though the facilitator demonstrated or described additional possible interaction methods upon request or if users appeared stuck or confused. After experiencing the four modes, participants were asked follow-up questions to encourage deeper discussion.

4.2 Feedback and Discussion

Participants were asked to rank the modes from most to least favorite and provide rationale for their ranking. Though several users were initially delighted by the feeling of percussive 808-style signals, most participants ranked this among their least favorite modes. Multiple participants noted that a hammer-on with their a finger was more effective at exciting the string than the percussive actuation signal. The noisy actuation mode was also commonly ranked lower, with most users noting how the noisy cross-talk between the actuation signal and the speaker was distracting. The regular sustainer mode consistently ranked more favorable amongst users and was frequently compared to eBows for its slow attack and timbre. Harmonic scanning mode was most divisive, ranking high for some users and low for others. Some participants found the unpredictability and instability of the re-synthesis algorithm in this mode sonically interesting while others noted frustration with the lack of precise control.

Common themes emerged when probing participants' rankings and answers to follow-up questions. Multiple users noted how two identical strings possessing completely different functions was not intuitive and subverted expectations. This was most noticeable in the percussive actuation mode, where pressing one string to create sound in the other was considered strange. Some participants suggested that the discrete action of triggering a sound was probably a better fit for discrete interactions such as button presses and that their prior experience with stringed instruments prompted them to anticipate plucking and fretting interactions instead. The theme of prior musical practice shaping expectations persisted throughout the study, and we speculate established practises similarly informed the responses to our open-ended prompts to imagine different ways to remix the underlying technology in new ideas for instruments and/or interfaces. 4 out of the 5 participants are proficient stringed-instrument players, so it was not surprising that many noted the desire to have multiple sound-generating strings to play harmonies and chords. One participant's background in modular synthesizers likely influenced their idea to add a patch bay to excite and control dozens of strings with any audio signals a user wishes rather than ones predetermined by a designer. Most participants also expressed interest in scaling different aspects of the system, imagining larger or smaller string lengths/thicknesses or reorientation/relocation of the strings.

Many remarks were made about the multi-modal sensory experience, not only commenting on the audible and tactile aspects of the system, but also the visual feedback from the Max patch and the string itself. Users enjoyed seeing the string's vibration, nodes, and anti-nodes, suggesting this quality was perhaps as important to them as the tactile feedback itself.

4.3 Limitations

The system presented to participants contained finicky technology elements that compromised some aspects of functionality during user studies, but the authors were ultimately interested in using this setup to facilitate discussion and direction for future creative applications of this technology rather than assessing the Lorentz Lap Brass itself. Though technical issues might traditionally need total mitigation before attempting a user study, the decision to seek user feedback tried to circumnavigate apparent engineering issues in pursuit of assessing new creative potentials. Despite the technical challenges, what came out of the study has proven stimulating and facilitated discussion about how DMI designers can glean insights from presenting in-progress technology before it is very refined. This shift from a more typical design paradigm allows artistic and creative feedback to drive and influence future engineering decisions that might otherwise be approached on exclusively technical terms.

5. FUTURE WORK

5.1 Electronic Crosstalk

The current system has noticeable electronic cross-talk between the optical pickup circuit and the signal present on the brass strings that must be addressed. Follow-up versions of this system should take additional care to in electromagnetic shielding.

5.2 Optical Sensing Improvements

The current sensors' range and placement only allowed for a general displacement signal – the system does not know whether the strings are pushed down or pulled up. Looking into more thoughtful sensor placement or sensors with a larger range could allow for disambiguation between more gestures, and additional signals could be used for more complex and nuanced control over the system.

5.3 Participant-described instruments

The user study was useful in establishing longer-term collaborations centered around composers co-defining and creating new interfaces with music technologists. Several of new instruments/interfaces that were described by participants will be pursued as an outcome of this project.

6. CONCLUSION

The final result of this exploratory research was a new method for frugal integrated haptic/sonic interaction exemplified by the Lorentz Lap Brass. The design process and user study identified new potentials and directions for utilizing Lorentz force actuation in musical interactions. Although the form was reminiscent of familiar instruments such as lap steel guitars, the use of additional sensing proved a worthy endeavor and revealed new methods for inventing new, haptic-feedback driven electromagnetically actuated instruments - an emerging area of inquiry the authors finds to be underexplored yet ripe with potential.

7. ETHICAL STANDARDS

This research was conducted in accordance with the NIME Principles & Code of Practice on Ethical Research, and in compliance with the standards and practices of the University of Michigan. All participants were volunteers and granted informed consent. The author states no conflict of interest.

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