MM-RT: A Tabletop Musical Instrument for Musical Wonderers

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ABSTRACT

MM-RT (material and magnet - rhythm and timbre) is a tabletop musical instrument equipped with electromagnetic actuators to offer a new paradigm of musical expression and exploration. After expanding on prior work with electromagnetic instrument actuation and tabletop musical interfaces, the paper explains why and how MM-RT, through its physicality and ergonomics, has been designed specifically for musical wonderers: people who want to know more about music in installation, concert, and everyday contexts. Those wonderers aspire to interpret and explore music rather than focussing on a technically correct realization of music. Informed by this vision, we then describe the design and technical implementation of this tabletop musical instrument. The paper concludes with discussions about future works and how to trigger musical wonderers' sonic curiosity to encounter, explore, invent, and organize sounds for music creation using a musical instrument like MM-RT.

Author Keywords

Electromagnetism, Tangible User Interface, Tabletop Musical Instrument, Acoustic Synthesis

ACM Classification

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing, H.5.2 [Information Interfaces and Presentation] User Interfaces — Haptic I/O, I.2.9 Robotics — Propelling mechanisms

1. INTRODUCTION AND MOTIVATION

MM-RT is a tabletop musical instrument that expands on an interface for musical expression created by the author in 2011 called DrumTop [25]. DrumTop uses impulses from voice coils as sound actuation mechanism to turn everyday objects into percussive musical instruments. The objective in making DrumTop was to create a simple physical interface that gives voice to random and found objects, affords self-expression and immediate engagement for novices, and encourages everyone to explore the musical potential of their surroundings. With DrumTop, the potential for generating new sounds was in the hands of the players. Their creative expressions were stimulated by what they found around them and how they decided to play and combine everyday objects on the tabletop interface to make music.

Figure 1: MM-RT Interface. Electromagnets are installed beneath each pad.

Players are generally very surprised when experiencing DrumTop for the first time. They react with genuine excitement and quickly grasp the basic concept of the system: you place any objects on any of the 8 pads and choose a drumming rhythms that you can change interactively. Part of the attraction for novices lies in the simplicity of the instrument that can be used as a percussive drum sequencer. But this simplicity is also limiting if the players want to orchestrate a full range of music with the addition of melodic and harmonic patterns. One solution is to incorporate a loudspeaker system that accompanies DrumTop. Our solution was to keep the aspect of using physical objects and realize ways to increase sound variation in a similar configuration as DrumTop. This is when we started to develop MM-RT.

MM-RT employs electromagnetic actuators and small permanent magnets to physically induce sound signals into various artifacts (See Figure 1). Through our experiments with MM-RT, we found that applying digital sound synthesis techniques on electromagnetic actuators coupled with permanent magnets on physical objects increases the number of sound variations a player can obtain beyond percussion sounds. MM-RT can not only be used to generate rhythms and percussive sounds like DrumTop does, but also be used to generate drones, melodic patterns, and abstract granular textural sounds through various objects by making use of mechanical/acoustic sound synthesis technique [3, 6]. As Berdahl et al., notes, such technique can also make musical interactions more intuitive for both players and audience.

Players of MM-RT can directly touch electronic music with their own hands through any non-magnetic object coupled with a permanent magnet. We experimented with a wide range of objects and some that work particularly well include cups, plates, boxes, bottles, vase, jars, paper of plastic containers, tubes, shakers, books, CD cases, teapots, and etc. The permanent magnet can be coupled in differ-

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ent ways, either fixed to the surface of the object or simply enclosed inside the object in the case of boxes, bottles, and tall jars. When, for example, a non-magnetic box, with a permanent magnet inside, is placed on top of an electromagnetic actuator equipped pad, a sawtooth wave generated through the actuator can rapidly move the permanent magnet to bounce and hit the walls of the box, causing the production of acoustic sounds similar to what a digital granular synthesis may generate.

MM-RT is designed for interpreting and exploring music rather than for emphasizing a technically correct realization of music. In doing so, we target a population that we call *musical wonderers*: people who want to find out more about music in installation, concert, and everyday contexts. MM-RT, a musical instrument for musical wonderers, focuses on turning our environments into musical instruments and materials for composition. It assists listening experience by enabling players to directly touch electronic music with their own hands.

2. RELATED WORKS

Electromagnets are pervasive and used in electronic devices ranging from loudspeakers, motors, hard disks, and generators. In particular, loudspeakers are one of the most essential tools to researchers, engineers, and artists working with electronic music. Loudspeakers are very practical for new musical interface designers, but they also decouple the actual sound source from the musical interface, leading audiences and artists to a disembodied experience of music [5, 8]. Cook notes that this ambiguity in sound production is caused by the design practice of separating the *controller* from the *synthesizer* which is the case with most modern digital musical instrument designs [7].

There are exceptions to this design practice. One way is to co-locate the loudspeaker or transducer with the interface of musical instruments [22, 26]. Another is to use electromagnets to design actuated musical instruments [23]. Since the core design of MM-RT involves electromagnetic actuators, this section emphasizes on prior works associated with the use of electromagnets.

2.1 Electromagnetically Augmented Musical Instruments

In recent years, the NIME community has seen a trend to apply electromagnetic actuators to augment existing acoustic musical instruments. McPherson demonstrates two types of objects that can be actuated with a magnetic force: either a magnetized object or a ferromagnetic object [13]. The actuator design for the augmented instrument may differ based on the object, but the fundamental technology and techniques are broadly applicable to both.

Existing augmented musical instruments include, but not limited to, piano, vibraphone, and drum [2, 4, 19]. Electromagnetism in such musical instruments demonstrates the fundamental techniques in how existing instruments can be expanded, often with additional sensors. The technical and aesthetic decisions that the creators made for these electromagnetic instruments anticipate the future new musical instruments that incorporate the effect of electromagnetism.

2.2 Musical Interaction using Electromagnets

We also find examples of using electromagnetic effect in designing unique musical instruments/interactions, as opposed to simply augmenting existing musical instruments. Electromagnetic tagging system in Paradiso et al., utilizes realtime tracking of passively tagged objects with a reader to create musical interaction [16]. Rowland demonstrates the use of printed loudspeakers with gloves equipped with magnets to realize colocated surface sound interaction [21]. Musical interaction created in this project is unique in that players not only hear sounds but get direct tactile feedback from the magnet on the glove. These projects show that electromagnetic effects can also be used to create musical interactions that are intuitive for musical novices.

2.3 Tangible Tabletop Musical Interface

Tangible tabletop musical interfaces typically fuse physical and virtual environments with a projector and a camera to display useful musical information around the physical artifacts to the players [12, 17]. Players of tangible tabletop musical interfaces often manipulate physical artifacts on tabletop surfaces to build and modify musical topologies [10]. These tabletop interfaces enable players to freely and quickly move around physical objects on a tabletop surface to progressively affect the sound outcome. The design aproach in these projects demonstrates ways to visually guide players in understanding the current musical state of the system. Tangible scores and the Sound of Touch which treat a physical interface as a score of a musical instrument and are also fascinating projects to think about how to explicitly indicate the players the state of the musical instrument [24, 14].

We recognize that most tangible tabletop interfaces for musical purpose revolve around the use of computer vision technology. While the physical object themselves do not produce sound, they tend to focus on the manipulation of physical objects to affect the resulting musical outcome.

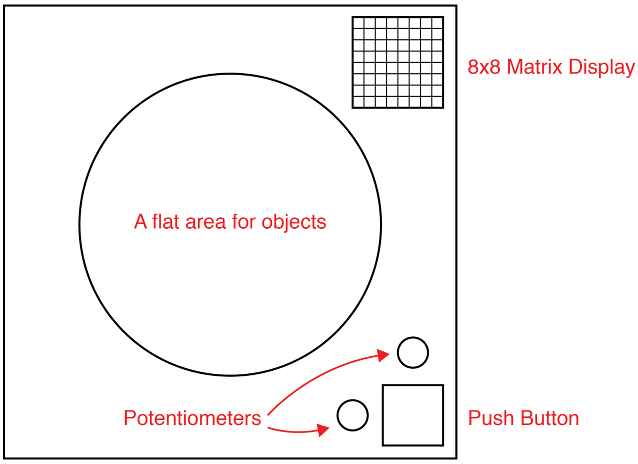

Figure 2: A top-down view of a single pad of MM-RT.

3. IMPLEMENTATION

MM-RT consists of four identical areas. Each of them contains a small display for feedback; a button and two potentiometers for controls; and a flat circular area called *pad* to place objects (See Figure 2). With MM-RT, any magnetic or ferromagnetic objects can become musical sound sources. By placing an object on the pad, it becomes musically activated in one of four ways called the *musical modes*: percussion, melody, grain, and microphone input. By playing on the four pads simultaneously, the players layer sounds into a complex interactive musical composition.

The dot matrix display is utilized to inform the player what musical mode a pad is currently in. A button is for switching between different musical modes. Dynamics and timbre on MM-RT are controlled using knobs which manipulate electromagnet actuation strength, pulse frequency, and waveforms. Figure 3 shows the cross section of a single pad on MM-RT. As we can see from the figure, an electromagnet (actuator), control by a waveform, is placed right beneath the pad so that any objects placed on top of the pad have a minimal distance to the actuator. The distance between an actuator and an object can be as close as 3mm to make best use of the magnetic force.

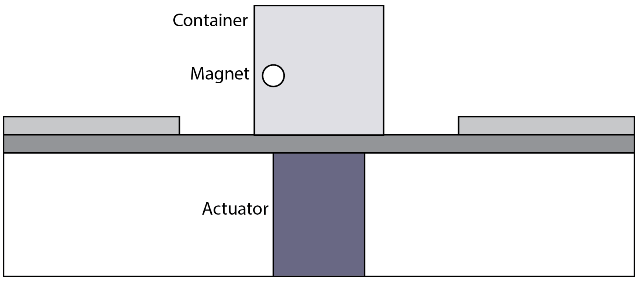

Figure 3: A cross section of a pad on MM-RT. A container with a permanent object is used as an example object a player can put on top of the pad.

3.1 Percussion Pad Design

In order to replicate the percussion mode we had in DrumTop, we designed a custom 3D printed solenoid in a pad format (See Figure 5). This custom solenoid pad contains a permanent magnet at the bottom so that when the magnetic force is applied, the pad is mechanically constrained to move vertically. The solenoid is designed to move up to 4mm. The surrounding materials of the pad are composed of masonite board and a neoprene sheet. Each solenoid pad has four circular velcro points to stay firmly attached to MM-RT.

Figure 4: A percussion pad that attaches on top of MM-RT. A custom 3D printed solenoid is attached in the center of the pad. (a) A solenoid at rest. (b) A solenoid actuated.

We experimented with what type of electromagnetic waveform the custom solenoid pad mechanically reacts the best (See figure 7). In general, the DC offset was set higher than 0 for all waveforms to ensure they stay positive to push the solenoid upward and avoid pulling down when negative signals are applied. Using an impulse signal exhibited no mechanical response on the custom solenoid (Figure 7-a). We suspect that this is because the time interval of the impulse is too short for the electromagnets to exhibit any magnetic force on the solenoid. Applying a half cycle of a cosine or square wave (Figure 7-b and 7-c) resulted in double triggering the solenoid where the transient of the waveform happens. In the case of a cosine wave, the displacement of the solenoid was reduced by approximately half in comparison to square wave. We think that this is because the transient of a cosine wave is much longer than that of a square wave and the electromagnet is not capable of applying the instantaneous force on the solenoid. Sawtooth wave (Figure 7-d) demonstrated the best result in correctly moving the solenoid as desired. From this experiment, we found that the solenoid is sensitive to the transient of the waveform being used.

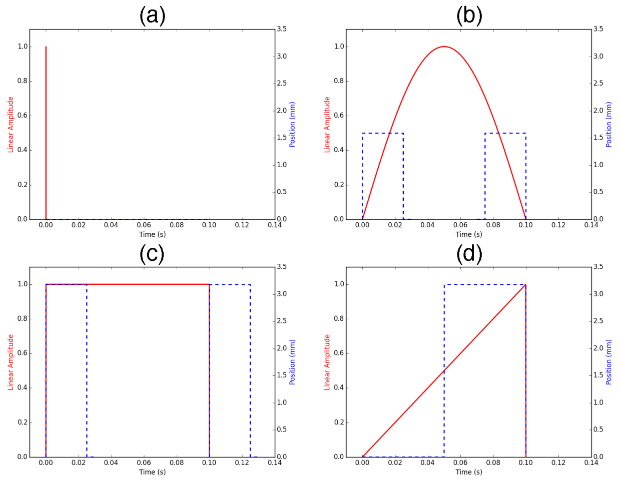

Figure 5: Graphs comparing the solenoid behavior with different electromagnetic waveforms. Red lines represent the audio signal generated by the computer and dotted blue lines correspond to the approximate behavior of the solenoid. Waveforms are (a) impulse, (b) cosine, (c) square, and (d) sawtooth.

3.2 Software

MM-RT software consists of three parts: Arduino[1], NW.js[2], and SuperCollider[3] (See Figure 4). Arduino, a microcontroller designed for building an interactive application, is responsible for acquiring knob and button data as well as rendering graphics on 8x8 dot matrix display. An application written in NW.js, a Node.js module designed for writing a desktop application using web technologies, acts as a bridge between Arduino and SuperCollider to translate OSC messages to Serial data and vice versa. NW.js also handles the graphic rendering for the 8x8 dot matrix display. SuperCollider, a text-based audio programming language, is responsible for keeping the timing among four pads on MM-RT and generating the audio signal. The signal from SuperCollider is then amplified before reaching the electromagnets.

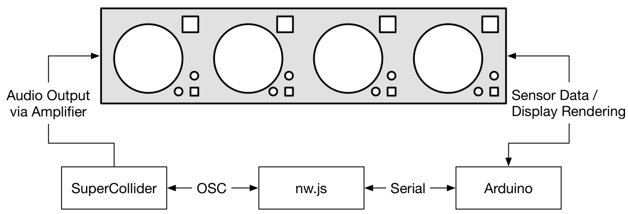

Figure 6: Software Architecture

3.3 Visual Representation of Musical Mode

The tricolor 8x8 dot matrix displays in MM-RT play a major role in informing the players about the current musical mode of each pad. In fact, without an object to react to the electromagnet, the magnetic force generated by a musical

[1]https://www.arduino.cc/
[2]https://nwjs.io/
[3]https://supercollider.github.io/

mode and its parameters are invisible to the naked eye. When the force of an actuator is changed with a knob, the brightness of the display changes to indicate the strength. As such, a different musical mode realizes different display behaviors.

Figure 6 depicts the four display representations simulated in the NW.js bridge application, each one corresponding to one of four musical modes. In the percussion mode (Figure 6-a), the matrix is divided into rows and columns to mimic the step sequencer like interface. A green color indicates *on* state and a black color represents *off* state. A yellow color cursor is utilized to show which beat a sequencer is currently on. The visual representation for the melody mode (Figure 6-b) functions the same way as the percussion mode but with added pitch information when the step sequencer turns to on state. The grain mode is represented with a sine-like waveform and the frequency of a generated audio signal affects the horizontal scroll rate of the display. The microphone input mode displays the amplitude level of the microphone input. The amplitude value is shown with square shapes with changing size in 10 steps.

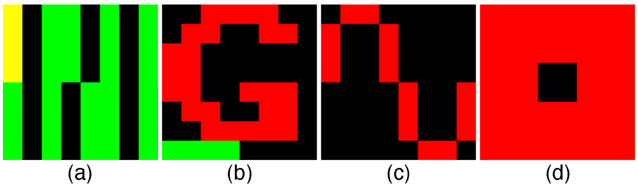

Figure 7: Visual Representation of four musical modes. Modes are: (a) Percussion, (b) Melody, (c) Grain, and (d) Microphone Input.

4. MUSICAL MODES OF MM-RT

MM-RT players are free to design their own objects. However, there are some restrictions and guidances on what type of objects work best depending on the musical mode of the machine. MM-RT currently has four musical modes –percussion, melody, grain, and microphone input– to accommodate different kind of musical interaction.

4.1 Percussion

The percussion mode inherits most of the functionalities from DrumTop with one major difference. In DrumTop, each pad was represented as a beat in a measure. Since DrumTop has 8 pads, the total number of beats was constrained to 8 beats in which a step sequencer sweep through in a looping fashion. In the MM-RT percussion mode, each pad is treated as a separate step sequencer but with one master clock that syncs the tempo across all pads. The drum patterns for the pads are preprogrammed and the players can scrub through different patterns using one of the potentiometers.

In the percussion mode, the object must not be magnetic as the magnetic force is applied through the added custom percussion pad described earlier. Since the maximum displacement of the solenoid is about 4mm, the percussion mode prefers objects that are flat on the bottom. If, for example, an object has a foot that raises the bottom surface, the tip of the solenoid will not be able to reach the object and no sound will be produced from the object. We are also aware that the heavier the object gets, the softer the resulting sound gets.

4.2 Melody

Just as the percussion mode, the melody mode is also driven with a step sequencer. In this mode, a pitched sound is generated. While there are many ways to produce a pitched sound using waveforms, we are currently using a sawtooth wave for simplicity and exprimentation. The melodic patterns are also preprogrammed and the players can scan through different patterns using one of the potentiometers. Since the preprogrammed melodic patterns are described only with interval relationship, the players have additional capability to change the root note of the melodic pattern being played if MM-RT is connected to an external midi keyboard.

The most effective object the players could use in this mode is hollow objects such as a box, balloon, and bucket that resonate well with a specific frequency. The players can even add rocks, sands, and beads inside the objects to physically affect the resulting pitched sound.

4.3 Grain

The grain mode exhibits a granular-synthesis-like behavior with physical objects. Currently, the audio signal generated for this mode also utilizes a sawtooth wave between 1hz and 60hz. The player can change the rate of the sawtooth wave using one of the potentiometers.

A typical configuration of an object in this mode is to use a non-magnetic closed container with a permanent magnet trapped inside (See Figure 3 for example). This way, the magnet is free to move around the container when it is applied with a magnetic force. We also obtained interesting results using cups, bottles, and vases that have a tall side wall so that a magnet cannot easily jump out. Utilizing a ballon equipped with a magnet creates a surprising sound effect since the balloon resonates very well around 30 60hz producing low frequency rumbling.

4.4 Microphone Input

The microphone input mode routes externally generated audio signals directly in to the electromagnetic actuators. The players are not restricted, but we often use this mode for real-time cal collaboration with other musicians. This mode requires practice to refine what objects can be used depending on what kind of sound is picked up through the microphone being used. Any objects described in the previous three modes can work in this mode in investigating what type of objects might work the best. We have so far experimented with taking a cello sound and found that objects used in the grain mode were most effective in generating interesting sounds.

5. DISCUSSION

Neuromusic researchers claim that all people are capable of demonstrating musicality to some extent [18]. This is an enlightening finding, but music interaction designers can still benefit from considering how *difficult* and *rewarding* a music system is to the players of different skill levels. This is because, often in particular with music, an appropriate level of difficulty can lead to a long-term engagement and flow-like experience, a mental state in which a person performing an activity is fully immersed in a feeling [9].

On the one hand, easy-to-master music systems can result in immediate pleasure and fun, but they may prohibit the interests of players for a further musical evolution [27]. On the other hand, music systems that are hard to use can discourage beginners. This design consideration is known as the *low-floor/high-ceiling* criteria [20] and creating musical systems that satisfy both is a quest for musical instrument designers.

5.1 Musical Wonderers

Our goal in developing MM-RT is to enable anyone interested in music, regardless of their skill levels, to easily learn the instrument but also encourage them to develop advanced skills and sound production through hours of practice. Such music players focus on the aspects of music interpretation rather than on technically correct realization. We call such players musical wonderers whom their musical mental model is set to encounter, explore, invent, and organize sounds for music creation. To set MM-RT to this interaction design constraint, we define a framework that realizes musical exploration environments for musical wonderers that feature the following capabilities:

1. Help players think like a composer and musician
2. Turn the environment into musical instruments and materials for composition
3. Explicitly expose musical parameters through an ergonomic interface of a musical instrument
4. Assist listening experience with other sensory modalities to explore sounds

Following this framework, MM-RT reduces the musical wonderers' cognitive load and lead them to focus on sounds as a creative medium to interact with in both short- and long-term contexts. MM-RT offers the basis of music to the player including loudness, pitch, timbre, and duration [11].

5.2 Evaluation

As one way to evaluate MM-RT, we have employed the instrument in performance contexts. In fall 2016, we performed professionally at the Packard concert hall in Colorado College, the University of Vermont Recital Hall in Vermont, and the Lincoln Center in NY. These performances were a collaboration between an MM-RT player and a cello player. MM-RT in these performances also involved the intensive use of theicrophone input mode as it is the most ideal way to collaborate with other musicians to correlate the sound event generated from other instruments in real time.

We have so far conducted the evaluation of MM-RT through performances which require consideration from four perspectives: the audience, the performer, the composer, and the instrument designer [15]. Digital Musical Instruments (DMIs) are typically made for musical performances involving at least an audience and a performer. In this context, a DMI is typically evaluated by audiences for its aesthetic quality of music and effectiveness to convey musical information. A performer typically evaluates a DMI from its playability: how challenging the instrument is to master and how engaging the instrument is to develop virtuosity with. Furthermore, a performer requires a score or instructions prepared by the composer who needs to understand the mechanism of that DMI to be able to write a music piece for it. In this sense, composers evaluate DMIs in terms of how robust their musical effect is. Finally, DMI is designed by an instrument designer who typically thinks through the design specification and playing experience of that DMI in mind.

Through our three performances, we found two limiting factors about the current MM-RT design. The loudness of the acoustic sound generated from MM-RT can be too soft in a large performance space. To increase the dynamic range of sounds produced by MM-RT in concert halls, we employed a pair of microphones to amplify the resulting sound via loudspeakers. Another limiting factor is the difficultly for the audience to see the subtle musical interaction from the audience seat in big concert halls.

Figure 8: A collaborative music performance between MM-RT and Cello players. Photo courtesy by Kevin Sword.

6. FUTURE WORK

We have thus far mostly experimented MM-RT using an electromagnetic sawtooth wave for almost all the musical modes. In moving forward, we would like to continue to experiment using different synthesis methods. For instance, we think that using a band-limited pulse generator can potentially improve the richness of timbre coming out of a resonating object when used in the melody mode. Since the generator is often used for acoustic measurements and assumed to have flat power spectrum across all harmonics, applying such signal to a hollow object can bring up the natural resonant frequency of that object, making the resulting sound closer to how the object will sound in everyday context [1].

We are also considering the use of core-less electromagnet to avoid permanent magnets to be constantly attracted to the core of electromagnet actutor even when it is not in use. Although not having a ferromagnetic or magnetic core in the design of electromagnets reduces the effect of magnetic force, we think that this approach might enable the instrument to maximize the translation of electrical to mechanical motion much more efficient in a tabletop configuration.

Another near future improvement of MM-RT is to implement operational transconductance amplifiers suggested by [13] instead of using an audio amplifier which is largely based on voltage amplification.

We also recognize that the instrument needs an additional interface to control the global parameters of the instrument instead of relying on an external MIDI controller. Implementing such functionality will eliminate the need for external MIDI controller.

We strive to expand on applying mechanical constraints on permanent magnets to increase different musical modes. For example, we believe that if we can design a system to mechanically constrain a permanent magnet to spin in a circular motion, MM-RT may be able to produce similar sounds produced by a Tibetan bowl.

7. CONCLUSION

We presented MM-RT, a tabletop musical instrument equipped with electromagnetic actuators that offers a new paradigm of musical expression and exploration. It is inspired by preceding works on electromagnetically driven instruments and tangible tabletop musical interfaces. The instrument is intended for musical wonderers who encounter, explore, invent, and organize sounds for their music creation. Musical wonderers focus on interpreting and exploring music rather than technically correct realization. We described the design and technical implementation of MM-RT. It also discussed about a framework that takes in account musical wonderers in designing a musical instrument. The paper touched on future works and how to trigger musical wonderers' sonic curiosity to encounter, explore, invent, and organize sounds for music creation using a musical instrument like MM-RT.

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