DRMMR: An Augmented Percussion Implement

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ABSTRACT

Recent developments in music technology have enabled novel timbres to be acoustically synthesized using various actuation and excitation methods. Utilizing recent work in nonlinear acoustic synthesis, we propose a transducer based augmented percussion implement entitled DRMMR. This design enables the user to sustain computer sequencer-like drum rolls at faster speeds while also enabling the user to achieve nonlinear acoustic synthesis effects. Our acoustic evaluation shows drum rolls executed by DRMMR easily exhibit greater levels of regularity, speed, and precision than comparable transducer and electromagnetic-based actuation methods. DRMMR's nonlinear acoustic synthesis functionality also presents possibilities for new kinds of sonic interactions on the surface of drum membranes.

Author Keywords

augmented implement, augmented instrument, nonlinear acoustic synthesis, transducers, actuators, drum rolls, percussion, cantilever, coupled mechanical oscillators

CCS Concepts

•**Applied computing** → **Sound and music computing;** *Performing arts;* •**Hardware** → *Physical synthesis;*

1. INTRODUCTION AND MOTIVATION

1.1 Introduction

DRMMR is an augmented percussion implement for membrane actuation, shown in 1.1. Housed in a compact plastic handle, DRMMR can be used as a hand-held or microphone stand mountable percussion implement. This sonic device incorporates two primary functions, achieving precise hands-free drum rolls and nonlinear acoustic synthesis [4]. Due to the way DRMMR's transducer-cantilever actuation method interacts with the drum membrane, our system can operate at broad frequency and amplitude ranges as compared to single driver actuation methods.

Following a discussion of motivations, Section 2.1 defines the characteristics of a human drum roll in order to provide a benchmark for evaluating the quality of DRMMR's rolls. In Section 2.2, we discuss previous work in augmented instrument, followed by augmented implement research in Section 2.3. We then discuss theory of operation in Section 3). Sections 4 and 5 detail design considerations and our experimental methods for comparing DRMMR against other single driver actuation systems.

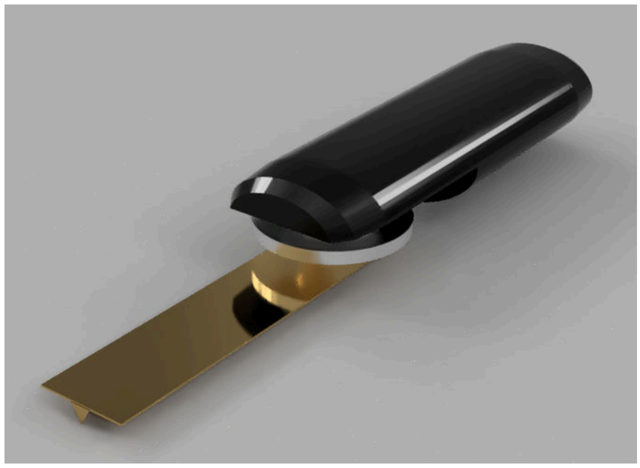

Figure 1: Rendering of the DRMMR augmented percussion implement.

1.2 Motivation

The drum roll is a common method for achieving sustained notes on drums. Our motivation is to mechanically sustain various forms of drum rolls. To achieve this, we use a transducer-cantilever based actuation method within a hand-held augmented percussion implement. DRMMR enables new timbral possibilities in sustained notes through hands-free and human-controlled computer sequencer-like drum rolls, and achieves sonic complexity via nonlinear acoustic synthesis on the surface of a drum head. When DRMMR is used as a stand mountable device, DRMMR can also act as an additional limb that enables increased polyrhythmic and timbral complexity during a performance.

2. BACKGROUND

2.1 Characteristics of a Drum Roll

The characteristics of a high-quality drum roll include evenness between strokes, maintenance of the drum's full spectral profile while rolling, and breadth of dynamic range [24]. Drum rolls are categorized either as an *open roll* and *closed roll*, where an open roll is a rudimental roll of two beats with each stick in alternation, and a closed roll possesses several rebounds with each stick motion [24].

Maintaining a drum's natural tone quality when performing a drum roll involves avoiding any slight interference that inhibit a drum head's ability to fully resonate. In other

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words, the drum sticks should not dampen the drum head in any way. Rolls that are too fast increase the length of time that the sticks are touching the head, thus muffling the drum's tone [7]. Therefore, drummers often vary the roll speed with the size of the drum to enable a given drum's full resonance.

Producing a roll at any tempo, dynamic, or dynamic shape while maintaining stroke evenness and the drum's full resonant tone are the hallmarks of a musically expressive drum roll. These characteristics are the benchmarks by which we have conceptualized DRMMR's design as an augmented percussion implement that achieves expressive computer sequencer-like drum rolls.

2.2 Augmented Percussion Instruments

Augmented instrument systems combining electronic systems into acoustic instruments is an expanding area in music technology research and design [16, 18]. Generally, acoustic instrument actuation is achieved through either electromagnetic or mechanical transduction [23]. In particular, we are interested in augmented percussion instruments utilizing electronic actuators that strike, vibrate, bow, or brush drum membranes using mechanical or electromagnetic transduction [2, 4, 8, 9, 22, 21]. By focusing on DRMMR's application as an implement rather than an instrument, DRMMR can be used a modular device within many musical contexts. This differs from previous robotic and augmented percussion instruments that operate either as a pseudo-speaker object [19, 21] or as a stand-alone robotically actuated instrument [8, 9, 13, 14, 22].

2.3 Augmented Percussion Implements

An augmented percussion implement may consist of a drum stick, mallet, brush, or beater. In this arrangement, the implement becomes a modular object the drummer uses to directly play or interact with the percussion instrument itself, as opposed to autonomous robotic systems. Early research in the domain of augmented implements focused on the control of virtual processes. Examples include Max Matthew's MIDI compatible *Radio Baton*, and Roberto Aimi's real-time convolution implement controllers [3, 2]. Recent augmented implement research has focused more on the acoustic actuation of instruments. This includes Patricia Alessandrini's work *Tracer la lune d'un doigt*, which incorporates the use of a custom glove implement that uses "tiny acrylic fingers" to sustain piano strings [17]. Steven Kemper's *multi-Mallet Automatic Drumming Instrument* and *Configurable Automatic Drumming Instrument* use standard drummer implements attached to robotic arms that actuate percussion instruments [13, 14]. Electromagnetic actuation methods have produced implements such as the hand-held EBow, enabling electronic guitars to sustain a note indefinitely [11]. Many composers and augmented instrument practitioners actuate percussion instruments by driving a surface exciter placed on the drum membrane [6]. Another commonly used technique involves using a microphone as a type of pseudo-implement to produce and control self-oscillating feedback with a surface transducer placed on an instrument's resonating surface. *The Bi-stable Resonator Cymbal* and *Metal Mirror* are examples of systems using microphone-transducer self-oscillating feedback as a controllable pseudo-implement [19, 23].

3. THEORY OF OPERATION

Nonlinear acoustic synthesis techniques provide the means to produce intermittent and time-varying control of sounds in musical instruments [4, 5]. Our approach extends recent methods utilizing a transducer-cantilever system [25] by exploiting the high spring-forces of a snare drum head for the purpose of generating a stable-state drum roll. Specifically, we characterize the behavior between the drum membrane and cantilever, or snare drum and DRMMR, as a lumped-element model with multiple spring-mass components similar to the free body mass-spring model described in [10]. The DRMMR system can therefore be described using the Kuramoto Model of coupled phase oscillators [1]. Equation 1 describes the dynamics in a Kuramoto system with N coupled phase oscillators $\theta_i(t)$ as:

$$\dot{\theta} = \omega_i + \frac{K}{N}\sum_{j=1}^{N} sin(\theta j - \theta_i), i = 1, ..., N \qquad (1)$$

where K is the coupling constant, and ω_i are the natural frequencies of the phase oscillators. However, when an external driver is applied to this system, we assume that the constant K is of sufficiently large value resulting in a full phase-locking scenario, akin to "chaos destroying" synchronization that occurs as a result of application of a periodic force on a chaotic system resulting in a new emergent periodic behavior [20]. Given this condition, it has been shown that the Kuramoto Equation 1 reduces to simply the weighted sum of the natural frequencies of the phase oscillators [15]. This in turn allows us to define a new quantity, the mean natural frequency of the the entire system, ϖ as:

$$\varpi = \dot{\theta} = \frac{1}{N}\sum_{j=1}^{N} \omega_j \qquad (2)$$

It is further noted that in phase-locking conditions, all oscillators have a phase velocity equal to the mean natural frequency ϖ of the entire system [15]. In the stand-mounted DRMMR snare drum configuration, this implies the drive frequencies necessary for generating stable drum rolls will differ from the frequency profile of the drum resonator. In our evaluation of DRMMR, we found that the mean fundamental drive frequency of DRMMR was $311.5Hz$, whereas the snare drum fundamental frequency was $304.5Hz$. This result is consistent with [15] and is notable because it would seem more intuitive that a primary resonator should, as the main contributor of frequency components, determine the resonance profile of the entire system.

This theory illustrates why stable drum rolls are possible in our system, and more broadly that systems with multiple coupled mechanical oscillators are capable of rapidly entering a phase-locked condition when driven with periodic external actuation.

4. DRMMR: INTERFACE AND DESIGN

DRMMR is both a hand-held and stand-mountable augmented percussion implement that can be used with any audio source and external control device. Based on the author's respective experiences as a percussionist and composer, our design goal is provide the user with infinite creative possibilities for using DRMMR within any musical situation. Below are just a few example's based on the author's experimental usage of DRMMR as a percussionist:

1. **Hand-held**

   (a) Using one DRMMR in one hand to create a drum roll or nonlinear acoustic synthesis effect while performing other musical gestures in their other hand.

Figure 2: DRMMR in the stand mounted configuration with a snare drum.

(b) Using two DRMMRs to create densely complex, sustained timbres on multiple drums using nonlinear acoustic synthesis.

(c) Using two DRMMRs to create multi-voice polyrhythms at speeds faster than humanly possible.

2. **Stand Mounted**

   (a) Drum-set player mounting a DRMMR for each of their drums, and controlling the DRMMRs automated mean, therefore generating many layers of complex acoustic polyphony.

   (b) Many DRMMRs mounted on various drums throughout a multi-percussion set-up and using foot controllers to control the DRMMRs while using their hands for other musical tasks.

   (c) Multiple DRMMRs mounted on various drums and using MIDI drum pads to trigger various drum rolls, rhythmic gestures, or nonlinear acoustic synthesis effects freely during a performance.

Figure 3 shows a labeled profile of DRMMR. The mountable handle was fabricated using a Prusa i3 MK3 3D printer, and is made from black PET grade plastic filament. A Dayton Audio DAEX25 transducer is attached to the end of the plastic handle using very high bond double sided tape with the transducer's driver facing downwards towards the cantilever. The end of the cantilever is also attached to the transducer using very high bond double sided tape. A small piece of foam is situated at the rear of the cantilever beneath the transducer. This foam functions as a spring that stabilizes and counteracts the spring force generated by the cantilever and drum head interaction. A piece of moleskin is applied to the cantilever's tip to soften the attack of the metal, and to protect the drum head from damage.

Our particular implementation of DRMMR in the video abstract is driven using a sine-tone generator. The transducer's audio cables run through a hollow section of the plastic handle and out to an amplifier driving the transducer. The amplifier is fed a mono audio signal from a digital sine tone oscillator in which the user can control the oscillator's frequency, amplitude, and amplitude envelopes using any physical control interface or automated control functionality. In this implementation, we used a simple footswitch to DRMMR's amplitude envelopes and an expression pedal to control DRMMR's frequency.

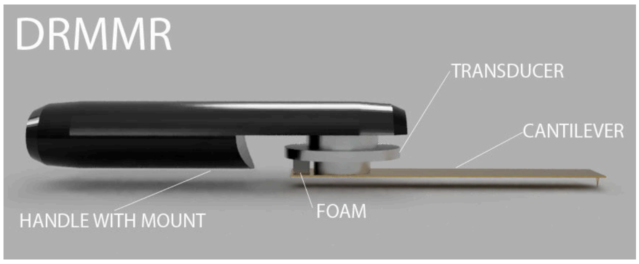

Figure 3: DRMMR: Individually labeled design components.

4.1 Sonic Control

The attributes of the cantilever enables DRMMR to expressively achieve the characteristics of computer sequencer-like open rolls. When DRMMR's oscillation speed is driven at higher frequencies DRMMR becomes out of phase with the resonate oscillation speed of the drum head, and DRMMR begins to produce sustained nonlinear acoustic synthesis, which can be used as an expressive timbral variant to the standard sustained drum roll.

When using lower sine-wave oscillation frequencies to drive the transducer, DRMMR can generate computer sequencer-like open rolls at a wide variety of speeds and dynamics, as well as an approximation of a closed roll. In one example of an open roll, shown in Figure 6, the driver's frequency is set to 9 Hz. DRMMR also demonstrates its ability to produce a closed roll when its frequency parameter is set higher, in this case, 169 Hz Figure 6. Comparing the waveforms of DRMMR's drum roll to the human drum rolls in Figure 6, demonstrates that DRMMR's rolls are indeed more precise and dynamically even that the human roll, resulting in a sound more like a computer sequenced roll than a human roll. In the case of the specific drum used in our tests, when the transducer-cantilever was driven in the frequency range of $540Hz$ to $681Hz$ the drum exhibited the sonic qualities of nonlinear acoustic synthesis [4], shown in Figure 4.1.

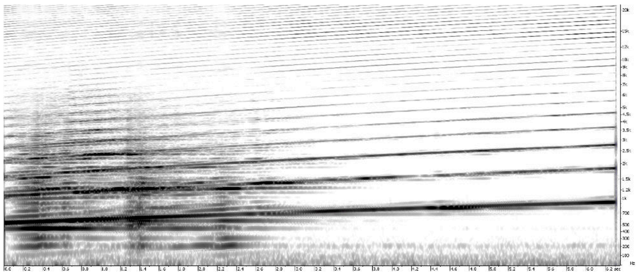

Figure 4: A spectrogram displaying the frequency response of a snare drum when driving DRMMR with an exponential chirp in a range of 1Hz to 2kHz. Nonlinear responses occur between drive frequencies of 540Hz and 681Hz as pictured here

5. EXPERIMENTAL METHODS

Our experimental methods compared our proposed transducer-cantilever actuation system against common single-driver actuation alternatives, such as mechanical and electromagnetic transduction techniques. These tests determined how well each of these transduction methods accurately produced a clean and even drum rolls at varying speeds and dynamics. We omitted two alternative drive methods: solenoids and robotic percussion systems. In the case of solenoids, they have been shown to have low drive frequencies and not suitable for drum rolls [12]. For robotic systems, we felt that the complexity resulting from multi-driver or complex gear systems was not a fair comparison to a single-driver system [14, 22].

5.1 Drum Actuator Comparison Set-up

To evaluate each actuation method, we designed a mounting device that enabled the mechanical and electromagnetic methods to interact with the drum head in a similar manner to the transducer-cantilever method. For the mechanical actuation we used a Dayton Audio DAEX25 transducer, and for the electromagnetic transduction we used an $e-77-82-35$ tubular electromagnetic from Magnetic Sensor Systems. Since the transducer-cantilever device is housed in a plastic handle, the transducer-cantilever does not move around the drum while actuating. If the mechanical or electromagnetic actuators are not mounted in a similar way, they would chaotically bounce around the drum head and thereby sacrifice the tone quality and evenness of the drum roll. By mounting the mechanical and electromagnetic transducers, these devices actuate the drum in precisely the same location as the mounted transducer-cantilever.

Mounting the mechanical and electromagnetic transducers was also in effort to minimize the length of time these devices muffled the drum head during actuation. If the mechanical and electromagnetic transducers were to be simply placed on the drum-head during actuation, they would muffle the drum's full resonate capabilities. This mounting device allows for the mechanical and electromagnetic transducers to actuate the drum from a higher plane, a fair comparison to DRMMR's placement above the drum head.

5.2 Variable Amplitude-Frequency Experiment

Each transduction method was tested for its ability to produce a drum roll at various roll speeds and dynamics.

Figure 5: Drum Actuator Comparison: Top image-transducer, Bottom image-electromagnet

To test various roll-speeds, we drove each actuator with an exponential series of nineteen discrete sine-tones with frequencies between 1 Hz and 361 Hz. Each sine tone was generated for four seconds followed by four seconds of silence. After each composite eight-second routine, the next discrete frequency in the exponential series was used as the sine-tone's frequency. In terms of amplitude, the volume of the sine-tones were empirically adjusted to obtain relative perceptual estimations of three dynamic levels on the drum, *Piano, Mezzo Forte,* and *Forte.*

6. RESULTS AND DISCUSSION

6.1 Drum Actuator Comparison Experiment

Table 1 details the performance of DRMMR in the Variable Amplitude-Frequency Experiment detailed in Section 5.2. Our results show that DRMMR executes drum rolls that adhere to the characteristics of a high-quality drum roll, discussed in Section 2.1, with computer-like precision better than the other testes actuation methods at all three dynamic levels. It is agreed upon by drummers of all styles that an open or closed drum roll must have "evenness between each stroke and a smooth sustain" at all dynamic levels while maintaining the natural tone of the drum to be considered a high quality roll [24, 26]. In equation 3, a *successful* roll was determined by a consistent "even" and "smooth" quality when evaluated empirically through critical listening. Table 6.1 shows the ratio of successful drum rolls from each actuation method at various dynamic levels. In terms of nonlinear acoustic synthesis, DRMMR was the only actuator able to produce this effect due to the findings in [4].

$$r = \frac{successful\ rolls}{total\ rolls} \tag{3}$$

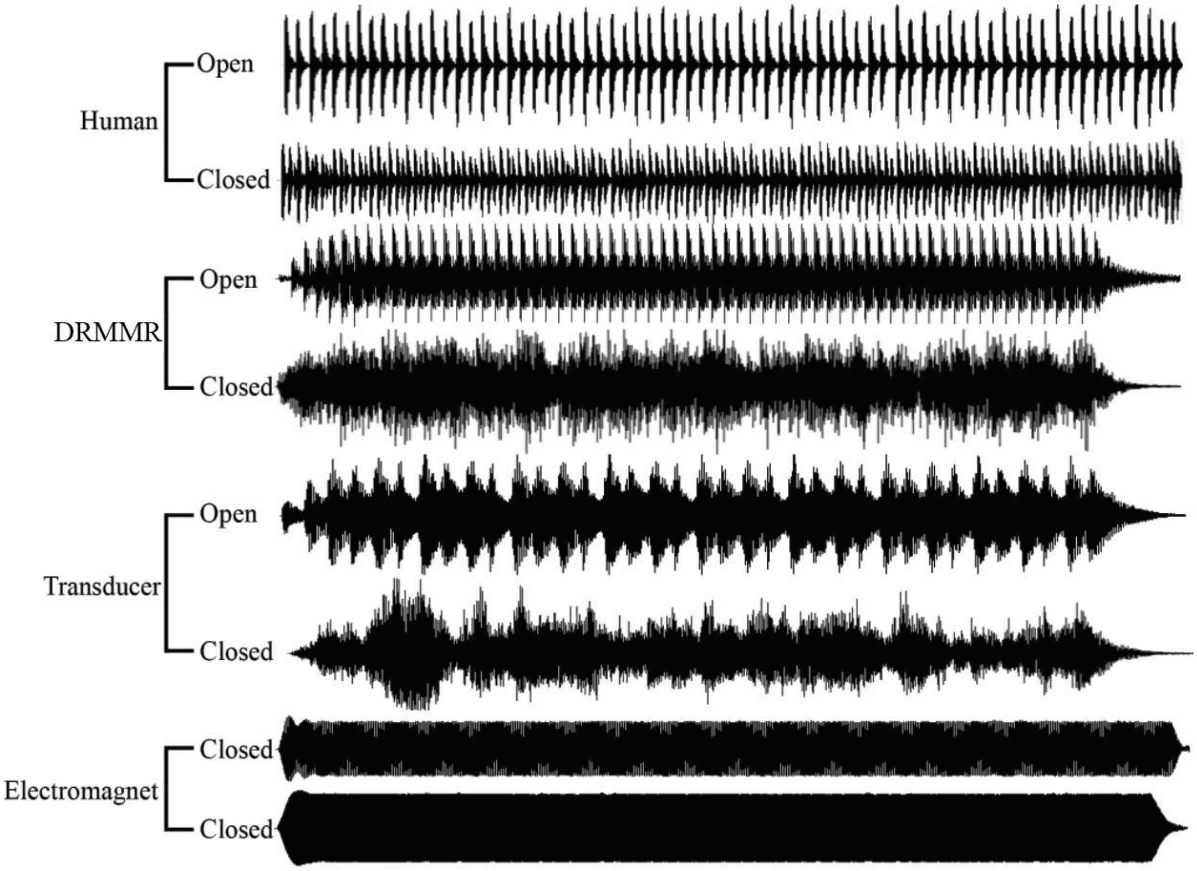

Figure 6: This figure contains waveforms recorded during the Variable Amplitude-Frequency Experiment, plus a human roll for reference. The highest quality roll from each actuation method at a Mezzo forte dynamic level is represented here as a fair comparison. The driver speeds from the displayed recordings are as follows, Cantilever: Open-$9Hz$, Closed-$169Hz$. Transducer: Open-$4Hz$, Closed-$49Hz$. Electromagnet, Closed-$225Hz$, Closed-$324Hz$.

LEVEL	DRMMR	TRANSDUCER	EM
Piano	59%	12%	0%
Mezzo forte	64%	18%	0%
Forte	70%	41%	0%

Table 1: Comparison of drum rolls at relative dynamic levels between DRMMR, surface transducer, and electromagnetic actuators.

6.1.1 *Open Rolls*

The waveforms in Figure 6 clearly show that DRUMMR's open roll, compared to the transducer and electromagnet, has a more dynamically stable and temporally regular transient response. The transducer's lack of stability and large striking surface resulted in a uneven and muffled open stroke roll. The electromagnet was unable to produce an open roll due to its inability to resonate the drum head below $121Hz$.

6.1.2 *Closed Rolls*

While DRMMR and the transducer's closed roll waveforms look more similar than the open roll waveforms, DRMMR demonstrates more dynamic stability and and smoothness for the same reasons discussed in 6.1.1. While the electromagnet did produce substantial sound when driven at higher frequencies, the sound produced was a byproduct of the driver frequency and possessed no characteristics of either an open or closed drum roll shown in Figure 6.

6.1.3 *Tone Quality*

DRMMR's transducer-cantilever method of actuation was superior to maintaining the drum's natural tone quality throughout the drum roll. This is due to the cantilever's elasticity, and subsequent ability to rebound off of the drum head quick enough to not dampen the drum's resonance. The transducer's large actuation surface, and lack of rebound ability effectively muffles the drum head during actuation. Figure 7 compares a single drum strike executed by DRMMR and a standard transducer actuation method. It is clear from these spectrograms that DRMMR enables the drum's natural resonate frequencies to resonate stronger and longer than the transducer. The transducer dampens many of the drum's resonate frequencies, thus causing the drum's tone to die out around 1.3 seconds while the cantilever enables the drum's resonance to last approximately 2.2 seconds, shown in Figure 6.1.3.

7. CONCLUSIONS AND FUTURE WORK

DRMMR is a new augmented percussion implement that better achieves better computer sequencer-like drum rolls as compared to other single-driver actuation methods. [1] In addition to improved functionality our system is simpler, and due to its modular capabilities, DRMMR can be employed

[1]A video abstract of this paper can be found at: `https://www.youtube.com/watch?v=Jdf9emtTQ1g&feature=youtu.be`

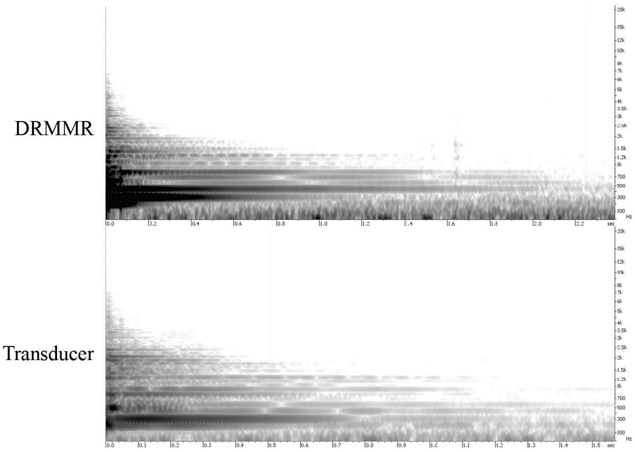

Figure 7: Comparing the resonant response of the drum when struck with the proposed transducer-cantilever actuation method and transducer actuation method.

in a broader range of contexts compared with multi-driver robotic systems. DRMMR also allows users to employ non-linear acoustic synthesis techniques at higher drive frequencies.

Future work includes designing and fabricating cantilevers that use different materials for their tips as such as wood, felt, and steel. These cantilevers will be interchangeable within DRUMMR, as to give the user more timbral choices. While the proposed DRMMR system is mainly designed for small drums such as toms and snare drums, future variants will include transducer-cantilever actuators for large drums such as timpani and bass drums, and for various sized cymbals.

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