Better Drumming Through Calibration: Techniques for Pre-Performance Robotic Percussion Optimization

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ABSTRACT

A problem with many contemporary musical robotic percussion systems lies in the fact that solenoids fail to respond linearly to linear increases in input velocity. This nonlinearity forces performers to individually tailor their compositions to specific robotic drummers. To address this problem, we introduce a method of pre-performance calibration using metaheuristic search techniques. A variety of such techniques are introduced and evaluated and the results of the optimized solenoid-based percussion systems are presented and compared with output from non-calibrated systems.

Keywords

musical robotics, human-robot interaction

1. INTRODUCTION

Robotic percussion systems typically use solenoids as actuators to strike drums. While such solenoid-based systems are usually inexpensive, electronically simple, and reliable, they lack performance characteristics that musicians used to working with electronic instruments have come to expect. This paper focuses on our efforts to overcome one such major shortcoming of solenoid-based robotic drumming systems: that of a lack of linearity in the solenoid actuators' dynamic response. Digital protocols such as MIDI and OSC afford musicians the ability to specify volume (also called velocity) of musical events. While the expected behavior of systems utilizing such velocity control schemes would be a linear response of output velocity in accordance to input velocity, due to their mechanical construction and the nonlinear response of electromagnetic solenoids, solenoid-based percussion systems typically do not follow the expected linear velocity curve.

To address the problem of nonlinear velocity output in response to a linearly increasing series of velocity input signals, we chose to implement pre-performance calibration routings: an approach that can be readily applied to our existing musical percussion systems. While other techniques warrant much investigation (see section 5), the use of calibration systems allows us to augment our existing robotic drummers without the need to greatly rework their mechatronic systems. The authors have a large number of existing robotic percussion systems utilizing single solenoid striker assemblies; the ability to retroactively implement velocity response linearization through the use of minimally-invasive techniques is thus highly attractive.

The procedures undertaken to calibrate the robotic drums fall into the field of search techniques. Such techniques allow for the optimization of systems without a great degree of *a priori* knowledge. We explored a variety of metaheuristic optimization procedures and evaluated each in regards to their respective average speeds.

Before examining the approaches that we took to optimize and calibrate out robotic systems, we present a short background of related work in robotic percussion in section 2.1. Additionally, we discuss our existing musical robot systems in section 2.2. Section 3 provides an overview of our experimental optimization setup, preparing readers for a discussion of the search techniques and results, which are discussed in section 4. Finally, section 5 concludes the paper with an evaluation of the suitability of such techniques in a performance context as well as an example of real-world use of such techniques.

2. PRIOR WORK

2.1 Robotic Music

Contemporary musical robotics began in the 1970's with the work of Trimpin [13] and Godfriend-Willem Raes [14]. Trimpin's work is highly diverse in nature, ranging from kinetic sculpture to new musical interfaces and utilizing a wide range of materials [6]. Highlights of his work include "IPP 71512" (1992), an automated prepared piano, "If VI Was IX: Roots and Branches" (2000), an array of self playing and automatically tuning guitars, and "Gurs Zyclus" (2011), an operatic work highlighting many of his technological innovations over the last two decades. Godfriend-Willem Raes is another early pioneer in the field of performance oriented musical robotics [18]. His works, often focusing on interactions between the human body and mechanical systems, typically consist of mechatronic extensions of existing instruments.

Much recent work has focused on human interactions with musical robotics. Ajay Kapur, with his MahaDeviBot and other robots in his Machine Orchestra [10], improvises with North Indian classical instruments: his robots respond to his musical decisions in real time. Others are exploring this new paradigm of live interaction and improvisation: Gil Weinberg is a leader in this field, producing works such as Haile, a robotic drummer. "Haile has listening skills and can join and improvise with live players" [17]. More recently, Weinberg has created Shimon, a robotic marimba capable of improvisatory performance [7]. Weinberg uses many of these complex musical robots in interactive improvisations [16].

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Another worker contributing much to the field of performance oriented musical robotics is Roger Dannenberg, through works such as "McBlare" [3] and Carnegie Mellon's RobOrchestra. The works of Weinberg, Kapur, and artist Eric Singer [5], along with the innovative robotic systems from Koji Shibuya and colleagues from Waseda University (exemplified in [15]), point to a next generation of musical robotics: that of closed-loop systems capable of automatic calibration and feedback-based error correction.

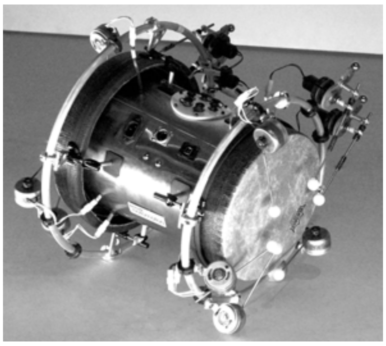

Figure 1: TrimpTrons and KalTrons on NotomotoN

[8] and [2]. Additionally, Nick Collins provides an introduction to autonomous mechatronic music systems in [2].

2.2 Robots in the Machine Orchestra

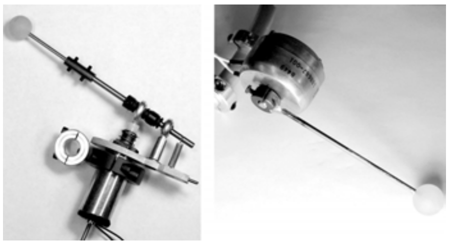

Figure 2: The two tested beaters: Linear-style Kaltron (left) and rotary-style TrimpTron (right).

Robotic percussion instruments have been a major part of our recent artistic output and research: through the Machine Orchestra [10], the authors regularly work with more than forty solenoid-driven robotic percussion instruments. The Machine Orchestra and related projects focus on human/robot interaction through musical performance and improvisation. Such interaction has been hindered by the solenoid-based drum strikers on the drums: the lack of predictable and consistent velocity response requires performers to be familiar with each individual variety of robotic drum beater and the beater's specific dynamic response. To address this problem, we have decided to create calibration, optimization, and closed-loop feedback systems to improve the dynamic responses of the drum strikers. To optimize the many existing drumming systems in the Machine Orchestra with a minimum of mechatronic augmentation, we chose to use the system described below in section 3.

3. EXPERIMENTAL SETUP

Figure 3 illustrates the signal flow in the solenoid optimization experimental setup. At the core of the test setup is a drum to which a piezo vibration sensor is attached. The sensor's signals are converted to MIDI information on an Alesis D4 drum module; the MIDI is then received on a PC via a Firewire audio interface. On the PC, signal processing

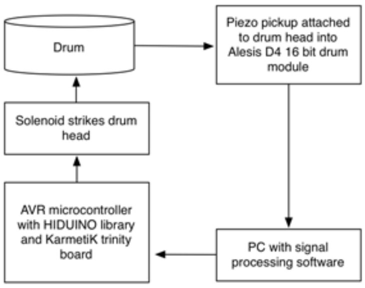

Figure 3: Optimization signal flow

software both conducts optimization routines and outputs MIDI events to a microcontroller which in turn controls a solenoid configured to strike the drum. The following subsections will examine the experimental substages in greater detail.

3.1 Input section

In order to receive input data from the drum, a piezo pickup system was chosen. A piezo pickup was attached to each drum head. The pickup's analog signal was converted to MIDI information in an Alesis D4 16 bit drum module and transmitted to a computer through a MIDI-enabled firewire audio interface. Early tests showed that differing placements of the piezo pickup could result in greatly varying dynamic ranges. Further, different drum heads could result in considerable variations in dynamic ranges. To compensate for this, signal processing software was written to automatically map the pickup's dynamic response regardless of piezo positioning or drum head type. This signal processing software, discussed more in section 3.2, greatly simplifies the signal input section, removing the need for highly precise piezo pickup positioning.

3.2 Signal processing section

The signal processing section of the calibration setup can be divided into three subsections: the scaling subsection, the calibration loop, and the MIDI transform routine. The scaling subsection determines the dynamic range of the input section and piezo attached to the drumhead by outputting a range of 128 MIDI values and reading in the corresponding values. Since the ultimate goal of the calibration procedure is to achieve linear parity between the input and output values, the output values must be scaled such that the maximum output value does not exceed the maximum attainable input value (an important consideration due to the fact that an output value of less than 127 often results in the greatest corresponding input value). Outgoing 7-bit MIDI values are therefore scaled between zero and the maximum input value received.

After the correct scaling factor is applied to the outgoing values, the program enters the main calibration loop. A variety of search techniques were evaluated, each of which resulted in an optimized array wherein the output values are scaled to become linearly equivalent to the actual values produced by the solenoid drum beater.

The program enters the final stage of the signal processing section upon creation of a transform array: incoming MIDI values sent by performers are scaled such that the dynamic response of the solenoid drum beater matches more closely the desired linear output velocity specified by the performer.

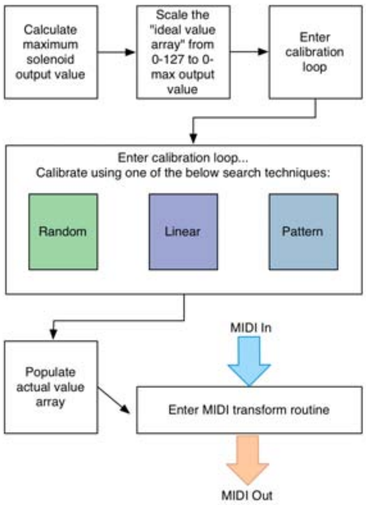

Figure 4: MIDI calibration signal flow

3.3 Output section

The output stage is the final stage in the calibration signal flow. In the output stage, transformed MIDI values are sent to a microcontroller-based solenoid driver. The microcontroller is an AVR microcontroller using the HIDUINO library [4] which allows for driverless USB connectivity. The solenoid drum beater's velocity is controlled via an interrupt-driven chopper drive output to a power MOSFET. The MOSFET switches a drum beater equipped with a 24V solenoid. The tested solenoids are shown in figure 2. More information about the solenoids can be found in [9] and [11]. The output section is identical to that currently used in the KarmetiK Machine Orchestra: in order to implement the new calibration software discussed in this paper, no firmware or hardware changes are needed.

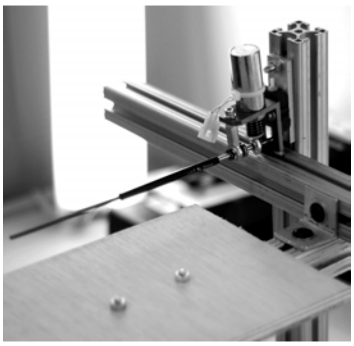

Figure 5: The experimental test setup, shown with a Trimpin Striker drum beater

4. EXPERIMENTS

To determine whether the lack of linearity in the dynamic response of solenoid-based percussion systems could be improved, experiments using different search techniques were conducted and their outputs analyzed. In the calibration software, a tolerance parameter was employed: notes within five velocity steps of the desired value (out of MIDI's 128 possible steps) were deemed acceptable in the below experiments. The fitness of a calibration method was based upon two criteria: whether an acceptable degree of linearity was obtained from the search technique and the amount of time required to optimize a system. The time required to optimize, shown in figure 8, is the average time of five separate calibration attempts. To allow the system to settle between output events, strikes were timed to repeat only every 1000 milliseconds. Tests were conducted with two types of beaters: one rotary-style beater (the TrimpTron) and one linear-pull beater (the KalTron, designed by Michael Darling). These two beater styles exemplify the majority of the drum beater varieties utilized in the Machine Orchestra.

4.1 Search routines

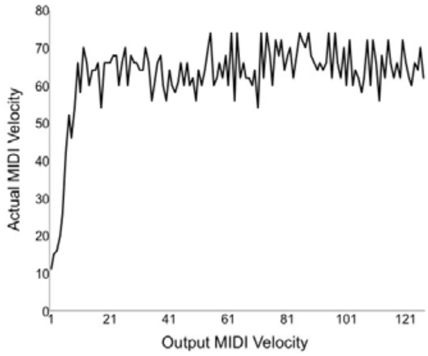

Figure 6: Uncalibrated MIDI input versus output velocity, illustrating the data's nonlinearity.

Prior to running any calibration routines, the system's open-loop response was recorded and in shown in Figure 6. The extreme nonlinearity of the response is visible, with the majority of the dynamic range present in the first ten output values. While Figure 6 (tested with a KalTron beater) shows the system's abrupt rise to a maximum value and subsequent stasis about the maximum, the system's desired response is a linear relationship between the input and output values.

To correct the system's nonlinearity through the use of calibration, the following techniques were implemented in the MIDI calibration signal flow. These techniques were chosen for their simplicity and ease of application. Future work will consist of further exploration of alternate search techniques.

4.1.1 Random Search

Random search routines, discussed in detail in [1], use numbers chosen at random to optimize a system. In this application of a random search routine a 7-bit MIDI output value is randomly chosen such that the sampling range does not change over time. The resulting value is sent to the mechatronic drum beater. Figure 8 shows the average time required to create an optimized solution to the system through the use of random search techniques.

4.1.2 Linear Search

With linear search, a 7-bit value was iteratively increased from zero until the output value most closely matched the value received by the MIDI input device. Values are increased in a linear manner as illustrated in Figure 7. This technique is described in more detail in [12]. The average time required to optimize the system through the use of linear search is shown in figure 8.

4.1.3 Pattern Search

The pattern search technique iteratively increased values from zero. As the output values approached the desired value, the step size was exponentially decreased. This technique is of limited application with low-resolution MIDI

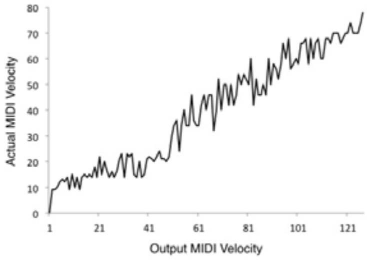

Figure 7: Output of a the system shown in Figure 6, this time calibrated with linear search

messages. Such an approach will likely return significantly improved results in future versions wherein a higher resolution communication protocol is employed (see section 5).

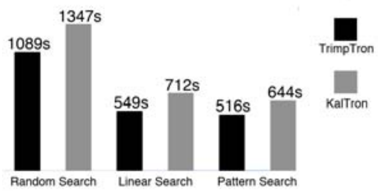

Figure 8: Test Type and Average Time to Optimize

4.2 Experimental Results

The results of the tests are shown in figure 8. Random search techniques were quite inefficient, requiring long times to optimize. Pattern-based searches were found to be the most efficient at rapid optimization, followed by linear search techniques. The TrimpTron rotary-style solenoid beaters optimized faster than the KalTron linear-to-rotary solenoid beaters, possible beacause of the TrimpTron's simpler design. As discussed in section 5, the relatively long times required to optimize the drum beater system should not be taken as an indication of inherent flaws in the concept of optimization of solenoid drum beaters: with improved search algorithms, the authors believe that faster optimization times are possible.

5. CONCLUSIONS AND FUTURE WORK

The work discussed in this paper represents the first stage in a series of projects intended to create more predictable robotic instruments through the use of closed loop systems. While the results presented in this paper display improvements over unaugmented systems, there are two primary avenues for improvement: a higher-resolution protocol than MIDI and real-time calibration techniques.

Additionally, a higher degree of optimization can likely be attained through the use of measurement techniques not based upon piezo pickups. Current work focuses on alternate methods of measurements through the use of encoders and potentiometers to provide real-time beater arm position.

Future work will explore the use of predictive techniques to analyze the system's current state if not at rest and send correspondingly correct values.

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