A Methodology for Evaluating Robotic Striking Mechanisms for Musical Contexts

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ABSTRACT

This paper presents a methodology for evaluating the performance of several types of striking mechanism commonly utilized in musical robotic percussion systems. The goal is to take steps towards standardizing methods of comparing the attributes of a range of devices to inform their design and application in various musical situations. A system for testing the latency, consistency, loudness and striking speed of these mechanisms is described and the methods are demonstrated by subjecting several new robotic percussion mechanisms to these tests. An analysis of the results of the evaluation is also presented and the advantages and disadvantages of each of the types of mechanism in various musical contexts is discussed.

Author Keywords

Musical Robotics, Solenoid, Percussion, Servo, Pneumatic

ACM Classification

H.5.5 [Information Systems] Sound and Music Computing—Methodologies and Techniques, H.5.5 [Information Systems] Sound and Music Computing—Signal Analysis, synthesis and processing.

1. INTRODUCTION

Musical robotics is a field which involves making use of electronic actuators under computer control to excite an array of real-world sound objects. In a survey of musical pieces, instruments, installations and other art-works created by musical roboticists, it is apparent that the large majority of works make use of robotic percussion mechanisms. These assemblies can exist as a component of larger instruments and are also frequently used as independent strikers, such as with Eric Singer's Modbots [8]. As there many ways to design a striking mechanism, choosing from a large range of possible actuators and deciding which designs and hardware to utilize in a musical robotic project is a non-trivial task. It is clear that a standardized method would prove beneficial to compare the capabilities of different approaches. It is hoped that presenting such a method of evaluation will enable the community of musical roboticists to test and compare the performance of their own creations and facilitate the establishment of a repository of performance metrics. This data will be of use to the field by informing the choice and design of robotic percussion mechanisms.

In order to place this research in context, the paper will begin with a history of automated percussion mechanisms followed by an explanation of the main categories into which most robotic percussion mechanisms fall. The construction of the mechanisms that were evaluated is then described and the specifics of the evaluation methodology are detailed. The various performance metrics that are collected are then presented and the results discussed. Finally, these results are used to make suggestions regarding the selection of actuators and robotic percussion mechanism design.

2. BACKGROUND

The history of automated musical apparatus spans over a thousand years and some of the earliest automated striking mechanisms were applied to church bells in carillons in the 1200s. Automated musical instruments saw the height of their popularity in the late 1800s and early 1900s. [6] provides a detailed account of the history of automated instruments.

The rise of the phonograph and the loudspeaker in the early 20th century led to a decline in the production of automated musical instruments, but in the 1960s and 1970s, as computer technology began to become more affordable and accessible, pioneering artists such as Godfried Willem Raes and Trimpin began to revive the concept with computer-controlled instruments. Examples of early electronically controlled musical machines include Trimpin's Automated Pottery Wheel Turntables [1] and Raes' Bellenorgel. A more detailed history may be found in [2].

3. PERCUSSION MECHANISM TYPES

Though most robotic percussion designs are project-specific, there are several categories into which they may be grouped. This grouping may conveniently be based upon actuator type, discussed below.

3.1 Solenoids

The most common type of actuator used in robotic percussion mechanisms is the solenoid. Solenoids are durable, relatively low cost, simple to drive, and generate relatively low levels of extraneous acoustic noise. The remainder of this subsection details linear and rotary solenoids.

When using linear solenoids for robotic percussion, the target instrument is either struck directly by a push-type solenoid's core (as is the case with Raes' <Vibi> automated vibraphone), or is attached to a beater which rotates about a pivot (as in [8]). For acoustically-quiet operation, linear solenoids should be mounted with suitable dampening.

In applications that utilize rotary solenoids, beaters may be attached to the rotary solenoid's external rod, or to its rotating plate.

While rotary solenoids are often more expensive than linear solenoids, they afford designers the ability to create mechanisms with few additional moving parts. This reduces overall mechanism cost. Rotary solenoids are notably used in Murphy's Nudge [7] and the KarmetiK NotomotoN [3].

To drive solenoids, most implementations make use of power transistors. With the recent availability of low-cost Power MOSFET devices, these have become the preferred driver device for most robotic percussion systems. MOSFETS are used in the evaluations in this paper: The circuit used in these evaluations is shown in Figure 1.

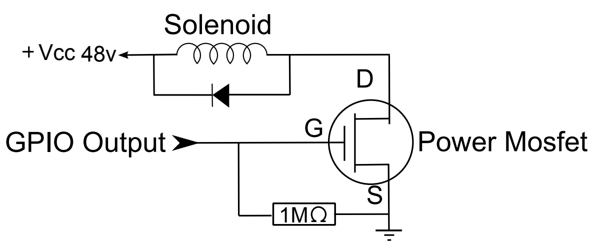

Figure 1: The circuit used to drive the solenoids

3.2 Pneumatics

While solenoids are the most common actuator for robotic percussion systems, pneumatic actuators are used by some notable projects, including Ken Caulkins' musical installations and the Zima Z-Machines.

The benefits of pneumatics are that they are powerful and durable, though they are also relatively expensive. There is a large variety of pneumatic actuators from which to choose, some of which provide longer travel than most solenoids. A drawback of pneumatic systems is that the air compressors and the exhaust lines often produce high noise levels.

3.3 Servos

Servos are electronic motors which are characterized by their ability to rotate to specific positions on command. They are used in several musical projects, including Talmudi, et Al.'s 'Drums v0.1' and Joakim Sand and Espen Stromme's 'Drum Machine.' Because of their ability to be positioned explicitly in software, they are able to be multifunctional, and can strike from various heights without the manual adjustments needed with other actuator types. However, servos generate a relatively high amount of acoustic noise and are generally less durable than pneumatic devices and solenoids.

4. TEST MECHANISM CONSTRUCTION

To compare the different types of mechanisms and demonstrate the evaluation methodology, seven mechanisms (shown in Figure 2) representative of popular musical robotic percussion systems are presented below. Further details on the construction of the B), C), D), and E) mechanisms may be found in [5]; the others are described below.

4.1 Rotary Solenoid Strikers

Two rotary solenoid strikers are shown in Figure 2. Both make use of aluminum mounting brackets to affix them to microphone stands and to mount input sockets. B) also uses a plate to affix a hollow 6 mm aluminum striking rod to the rotary solenoid's plate, whereas A)'s 3mm steel striking rod is welded to a shaft collar which is attached to the solenoid's rod.

A) uses a larger 48 mm Shindengen model, and B) uses a smaller 39 mm Ushio SP-B. Both are rated for 24 volts at a duty cycle of 100%. The devices are chosen as representative of those often used in robotic percussion applications. The SP-B is capable of 25 degrees of rotation, so a dampener is not required to limit its travel, and the Shindengen model has a 90 degree rotation, limited by a rubber stopper. Both of their internal springs are set to maximum tension.

4.2 Servo Strikers

An analog servo based striking mechanism is shown in Figure 2 G). The low-cost analog servo exhibited relatively poor performance with regards to latency, consistency, and loudness (detailed in [5]), so a digital servo-based mechanism has been built to establish whether a digital servo will be able to improve on these results. The new mechanism uses a Dynamixel AX-12 running at 1Mbps baud rate and maximum speed. The beaters, shown in Figure 2, consist of 6 mm rods attached to 24 mm diameter wooden balls.

4.3 Pneumatic Strikers

A novel pneumatic striking mechanism was designed to test the utility of magnetically coupled rod-less cylinders in robotic percussion applications. Since the previously constructed double-acting mechanism shown in Figure 2 E) lacked velocity control and was subject to strict height settings over the target, it was hoped that a new mechanism, equipped with a spring and configured for use in a single-acting arrangement would improve on these limitations.

The device has been built to closely resemble the linear solenoid with pivot mechanism shown in Figure 2 C), which itself is inspired by the Trimpin Hammer [4] and Kaltron [3] mechanisms. It is built around an SMC CY1B6H-40 magnetically coupled rod-less cylinder and in order to achieve a similar action to the other units for comparison, the carriage is fixed to the acrylic bracket and the cylinder barrel creates the actuation. Similar to Figure 2 C) and E), this design also features a 6 mm aluminum beater manipulated by two ball-joints and held in place by two shaft collars. Stoppers were not used for this device, as the actuator naturally limits its movement.

In testing, the internal cushioning feature of this actuator was found to greatly restrict its speed, causing it to exhibit unacceptably high latency and very low striking power. The result of this experiment shows that this actuator should not be recommended for percussion applications and is excluded from the results presented in the following section.

5. EVALUATION METHODOLOGY

This section details the specifics of the testing setup and provides information about the equipment used and how the measurements are made.

A Remo Fiberskyn frame-drum was used as the target for all of the tests. In order to measure the movement of the drum's membrane, a 35 mm diameter piezoelectric disc is affixed to the underside center of the drum's skin. The audio interface has sample rate of 44.1kHz and a bit-depth of 16 bits. All strikes occur 55 mm from the piezo disc. A sound-level meter is positioned 300 mm above the drum and is pointed at the center of the drum at a 45 degree angle. The meter is set to dBC mode.

To gain insight into the root causes of device latency, an electromagnetic pickup mounted near the solenoids and DC-motors is used to sense the onset of coil power-up. By viewing the pickup's output, the latency contributed by the electronics can be compared to the latency contributed by the actuators. This process is diagrammed in Figure 3.

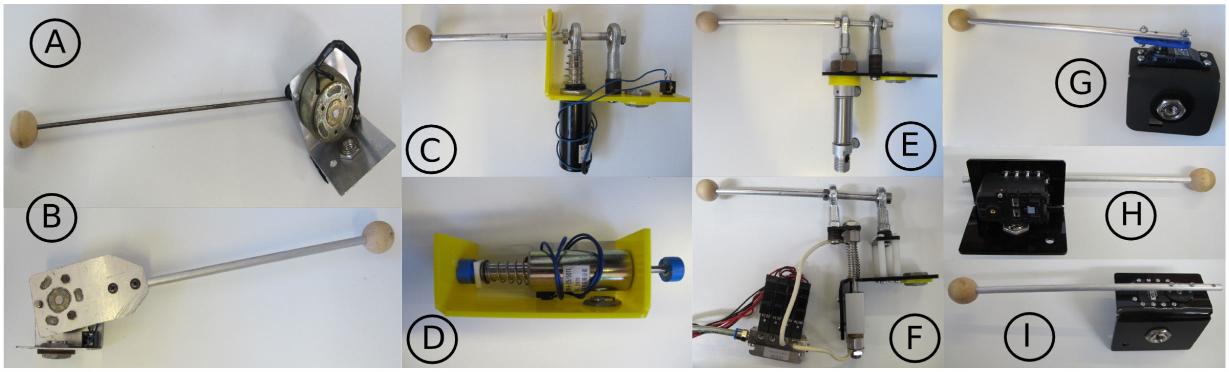

Figure 2: The collection of percussion mechanisms that were evaluated. A) Shindengen Large Rotary Solenoid Striker B) Ushio Small Rotary Solenoid Striker C) Linear Solenoid with Pivot D) Direct Linear Solenoid Striker E) Double-Acting Pneumatic Striker F) Magnetically Coupled Rod-less Pneumatic Striker G) Analog Servo Striker H) Digital Servo Striker back angle I) Digital Servo Striker front angle

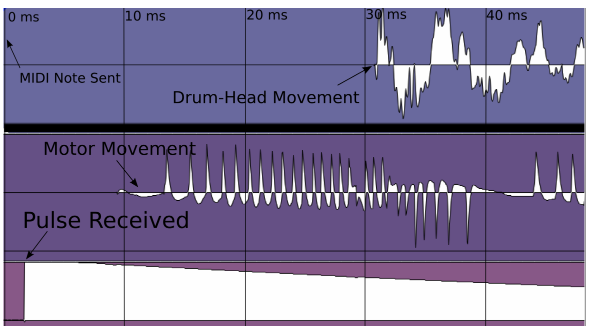

Figure 3: Measuring the system's latency

A 48 V driver box (using the circuit shown in Figure 1) is used to actuate the solenoid-based mechanisms. The analog servos receive 6 V and the digital servos, 9.6 V. The pneumatic devices receive 6 bar regulated air pressure.

5.1 The Evaluated Characteristics

The percussion mechanisms' Latency, maximum loudness, dynamic consistency, and maximum repetition rate were evaluated; methodology and results are shown below.

5.1.1 Latency

As shown in Figure 3, there are several components to the latency exhibited by robotic percussion mechanisms. The first value is the time between MIDI note transmission and the microcontroller receipt. In this testing setup the first latency value was an average of 1.69 ms with a standard deviation was 0.39 ms. The second component of latency is the time between microcontroller transmission and actuator receipt, as shown by an electromagnetic pulse observed by the pickup. For the solenoid mechanisms, this value was an average of 1.89ms with standard deviation 0.58ms. For the analog servo, this value was an average of 15.5 ms with standard deviation 1.8 ms. The final component of the latency is the time between actuator receipt and the beater making contact with the drum, and is related to the speed and height of the actuator. The total latency is the time between the original MIDI note being sent and the beater making contact with the drum. To obtain an average value, these total latency measurements were performed in sets of 10 strikes. The standard deviation of the average indicates the consistency of the latency.

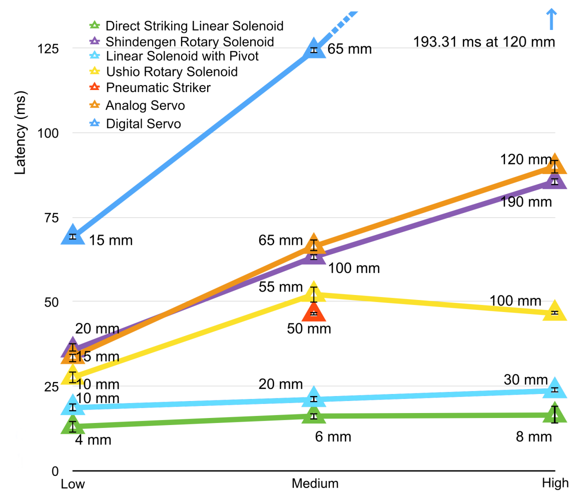

Figure 4: The latencies of the evaluated mechanisms

Each mechanism was tested at its low, medium, and high heights above the drum head. This allows for a more comprehensive view of its overall latency characteristics.

Figure 4 shows the results of the latency tests of the evaluated mechanisms. The Ushio Rotary Solenoid's middle position value is higher than its high position value because lower velocity notes were programmed for the middle position to prevent bouncing in the test setup.

5.1.2 Maximum Loudness

As maximum loudness varies across devices, the devices under test were positioned in order to maximize their loudness and the maximum values are shown in Figure 5.

5.1.3 Dynamic Consistency

To assess the extent to which the devices are able to strike at a consistent loudness, sets of 10, 1000 ms strike recordings were analyzed. RMS values are taken, and the average and standard deviation of these at varying heights are presented in Figure 6.

5.1.4 Maximum Repetition Rate

A maximum repetition rate for each mechanism was achieved by positioning the strikers near the drum and adjusting the

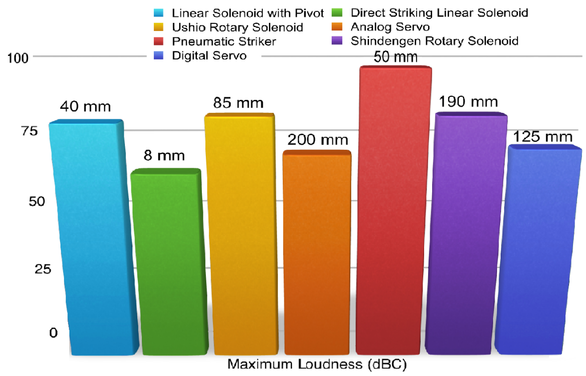

Figure 5: Maximum loudness values (dbC) of each striker with heights included

	Low	Medium	High
Linear Solenoid (Pivot)	3.5 (10 mm)	3.53 (20 mm)	4.25 (30 mm)
Linear Solenoid (Dir. Strike)	5.05 (4 mm)	7.12 (6 mm)	9.52 (8 mm)
Ushio Rotary Solenoid	4.34 (10 mm)	2.36 (55 mm)	1.44 (100 mm)
Shindengen Rotary Solenoid	6.99 (10 mm)	7.40 (100 mm)	3.22 (190 mm)
Analog Servo	4.34 (10 mm)	5.21 (65 mm)	6.08 (120 mm)
Digital Servo	2.93 (10 mm)	3.71 (65 mm)	3.16 (120 mm)
Pneumatic Striker	N/A	10.83 (50 mm)	N/A

Figure 6: Percentage standard deviations of the RMS Values of 10 strikes at various heights

MIDI control signals. During these tests, the strikers did not necessarily return to an at-rest position. To prevent damage to the drum from the pneumatic beater, a height of 50 mm was used for its test. The numbers of strikes per second were observed; the results are shown in Figure 7.

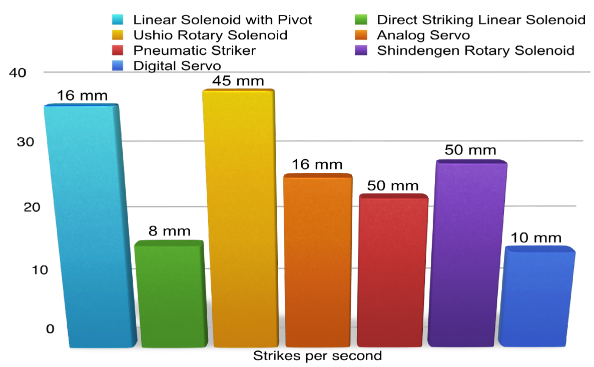

Figure 7: Maximum repetition rates achieved by each striker in strikes per second with heights

6. RESULTS

The results of these evaluations allow several observations to be made about their suitability for various musical contexts, and are described below.

The servos both received low scores for loudness and repetition rates and exhibited the highest tested latencies. While dynamically consistent, the digital servo exhibited especially high levels of latency. The analog servo exhibited lower latency but with lower consistency. Both produce much acoustic noise. These findings show that one should choose one of the other devices for robotic drum contexts.

The double-acting pneumatic device showed high loudness and latency consistency, but poor dynamic consistency. It is incapable of velocity control, produces much noise, and is expensive. Though further research is needed, preliminary testing of a new pneumatic striker indicates that magnetically coupled cylinders are unsuitable for percussion applications.

The smaller rotary solenoid exhibited good dynamic consistency and high repetition rates. The larger model showed similar latency, but worse dynamic consistency and repetition rates. It was also found to hit harder than the smaller model.

The direct striking linear solenoid scored the best in latency, but did not do well in other tests. The linear solenoid with pivot was shown to be a good general purpose unit with acceptable results in every characteristic measured.

7. CONCLUSIONS

This paper has presented a methodology for analyzing the performance of robotic striking mechanisms. In addition to already providing useful results, the methodology proposed can be used to evaluate other types of robotic percussion mechanisms. It is hoped that by sharing these methods, other creators of musical robotic works will use these evaluation techniques to create, test, compare, and share their robotic percussion devices. This will bring the field closer to a goal of establishing a repository of metrics to aid practitioners with musical robot designs.

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