Proceedings of the 19th Sound and Music Computing Conference, June 5-12th, 2022, Saint-Étienne (France)

A Robotic Drummer with a Flexible Joint: the Effect of Passive Impedance on Drumming

Seyed Mojtaba Karbasi
RITMO Centre for Interdisciplinary Studies in Rhythm, Time and Motion
Department of Informatics
University of Oslo
mojtabak@ifi.uio.no

Alexander Refsum Jensenius
RITMO Centre for Interdisciplinary Studies in Rhythm, Time and Motion
Department of Musicology
University of Oslo
a.r.jensenius@imv.uio.no

Rolf Inge Godøy
RITMO Centre for Interdisciplinary Studies in Rhythm, Time and Motion
Department of Musicology
University of Oslo
r.i.godoy@imv.uio.no

Jim Torresen
RITMO Centre for Interdisciplinary Studies in Rhythm, Time and Motion
Department of Informatics
University of Oslo
jimtoer@ifi.uio.no

ABSTRACT

This paper introduces a drum robot with certain mechanical specifications and analyze its capabilities according to the drumming sound results when applied on a regular snare drum. The robot has two degrees of freedom, actuated by one quasi direct-drive servo motor. The gripper of the robot features a flexible joint with passive springs. We report on an experiment in which we have looked at the drum roll performance by the robot while changing a few control variables such as frequency and amplitude of the motion. Both single-stroke and double-stroke drum rolls can be performed by the robot by changing the control variables. The results of this experiment lay the groundwork for developing an intelligent algorithm for the robot to learn musical patterns by interacting with the drum.

1. INTRODUCTION

What can be expected from a drum robot? How can robots be used to create novel music? These questions have been pursued by researchers in the field of musical robotics in recent years, and we have seen robotic systems designed to perform music with different objectives achieving significant results [1, 2]. With the advancements in artificial intelligence and robotic systems, new capabilities have been explored in this field. One major aspect of musical robots that can lead to the emergence of creative results is the ability to learn skills autonomously. To make it feasible, it is important to make the robot utilize its potential and mechanical capabilities to play a musical instrument.

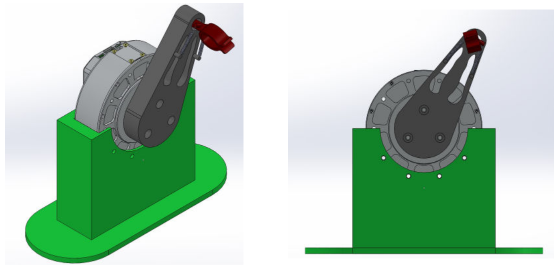
A main challenge when designing musical robots is to find the best sound-producing mechanism. Many musical

Figure 1: The robot prototype. The robot has two joints, one actuated by a servo motor and the other one contains passive springs to make the gripper flexible.

robots have been inspired by the way humans play instruments. However, the mechanical specifications of robots are completely different to the physical properties of the human body. Thus, almost all of the robotic arms designed to play drums contain a fixed gripper and they usually have less than three degrees of freedom. In comparison, a human arm has a much more complex mechanism, especially the hand and the fingers which hold the drumstick. A key question is whether a robot needs the same mechanical complexity to perform equally well as a human drummer? One can argue that if we want the complete capabilities of a human arm, we should consider the same mechanical attributes. However, for a specific task, like drumming, all of the physical complexity of the human arm may not be necessary. In fact, in the best case, a robot should perform most efficiently according to its mechanical characteristics, rather than just mimicking human musicians. For this purpose, it is important to utilize the maximum capabilities of a robotic system. This can be achieved by an analysis-by-synthesis approach for studying robotic drumming.

Human drummers learn by practicing how to use their hands' physical capabilities to perform efficiently. The

Figure 2: The drum robot playing a snare drum.



(a) (b)

Figure 3: The 3D design of the drum robot.

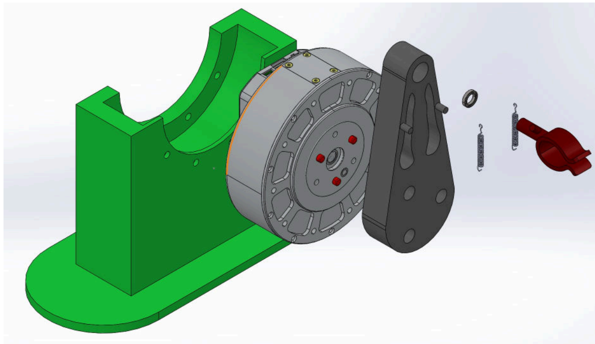


Figure 4: Each part of the robot used for prototyping the robot: base, servo motor, link, gripper, springs and ball bearing.

physical and mechanical constraints of the body shape the way a drummer learns the skills [3]. It is hard to build a robotic arm with the same mechanical properties as a human arm. A different approach, and the one taken in this paper, is to make a robot learn the necessary skills according to its physical constraints. In other words, when we have a robot with specific mechanical characteristics, it is expected that the robot should be able to learn the skills according to those constraints.

In this study, we introduce a drum robot which is designed and built using 3D-printing technology to play a snare drum (Figure 1). The robot has two degrees of freedom, with a passive flexible gripper and an actively controlled joint with a servo motor. In the paper, we present its design and construction and show how the flexible joint affects playing drum roll patterns. This can be seen as an analysis-by-synthesis approach to explore the drumming capabilities of the robot prototype.

2. RELATED WORKS

Several researchers have investigated the importance of mechanical actuation in drum robots. Hajian et al. developed a single-joint, variable stiffness robotic arm using pneumatic actuators in an agonist-antagonist arrangement [4]. Despite a successful demonstration of drum rolls, the authors acknowledge the slight possibility of their technology being implemented in practice due to servo delays in passive impedance control. Kim et al. use variable stiffness actuators (VSA) to reproduce single and double snare drum strokes, however, the device's utility is restricted by the VSAs' stiffness modification time [5]. Bretan et al. developed a robotic drumming prosthesis for an amputee drummer, controlled by electromyography (EMG) signals [6, 7]. Furthermore, Yang et al. used different actuation systems in order to achieve dynamic capabilities of the hand to perform multiple stroke drum rolls for the same robotic prosthesis [8]. They have also introduced a dynamical model that simulates the trajectory of the drumstick and estimates the control gains for a variety of natural bouncing patterns. A similar approach has been utilized in the Shimon robot, a robotic marimba player, to provide a wider dynamic range response compared to solenoid actuators [9].

Other types of actuators have been used in percussion robots in recent years. For instance, Van Rooyen et al. used voice coil actuators for a percussion robot [10]. Another actuation system based on transducer, proposed by Brown and Topel, is used for achieving nonlinear acoustic synthesis effect for a snare drum [11]. Each of these actuation techniques leads to achieving certain targets in percussion performance.

The main characteristic of the robot introduced in this work is the two-degree of freedom mechanism with a flexible gripper. This provides for a more complex robot-drum interaction than what has been explored in previous studies. However, adding this complexity also makes it more difficult to develop control strategies for desired drumming tasks. We have previously proposed an interactive learning algorithm for adjusting the joint impedance of a drum robot to perform double stroke drum rolls [12]. That algorithm was based on simulations of a two-degree of freedom robotic arm, comparable to the robot introduced in this paper. Our previous results were based on simulation, while in this paper we present results from a physical robot.

3. THE DRUM ROBOT SYSTEM

The design of the robot, including the mechanical design of the body, control and actuation, is based on the natural specifications of the drumming of human drummers. The details of the designed system are described in this section.

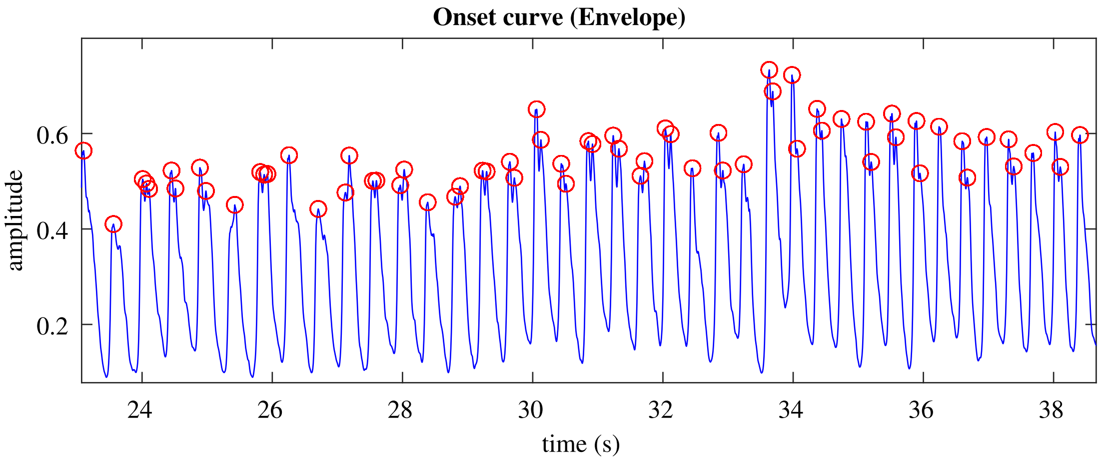


Figure 5: The amplitude envelope of a recorded drumming sound performed by the robot. The onset events are detected using the calculated envelope. The features used for analyzing the results are the relative amplitude of the detected events and time difference between consecutive beats.

3.1 Hardware

The robot hardware consists of 3D printed parts, passive springs and a quasi-direct drive servo motor (Figure 3). The design phase started by selecting a motor with the relevant characteristics for drumming: a Gyems RMD-X8. This motor is widely available in large quantities, relatively well documented and supported, and affordable at the time of writing of this paper. The RMD-X8 motor includes a gear ratio of 6:1 and CAN bus connectivity. It uses high resolution magnetic encoders and FOC drivers for working in different control modes such as position, velocity or torque control. This type of actuator is suitable for drumming tasks because of its ability to control torque as well as motion at high velocity (250rpm no-load speed). The torque control mode makes the robot capable of having impedance control of the arm. As we mentioned earlier, the mechanical impedance is an important property in drumming.

For building the arm, three main pieces were designed and 3D printed on a Fortus 250mc with ABSplus thermoplastic. The 3D model of the robot was designed using SolidWorks (Figure 4). We employed an iterative design strategy in which the model was continuously refined and tested until we had a prototype that was strong enough to handle the rebounding force during fast drumming while at the same time have a low enough weight to not limit the speed of the actuator.

The initial design of the gripper did not contain springs but a fixed gripper for the arm. As it turned out, the fixed gripper could not handle the rebounding forces in high-speed drumming. The result was numerous broken prototypes. This eventually led to adding flexibility to the gripper using a spring mechanism. The stiffness of the spring is a crucial parameter in the rebounding motion of the robot. With larger values of stiffness coefficient, the robot can play faster drum rolls. After some testing, we ended up with a spring with a stiffness coefficient of 25 N/m.

3.2 Software

The robot is controlled using an Arduino board, communicating with the motor via the CAN bus protocol. We developed a control library in C++ for performing drumming tasks using different control modes of the motor. In this study, a position-based control strategy is designed for the motor to track a sinusoidal trajectory with a desired frequency and amplitude to perform drum rolls with different frequencies and intensities.

4. EXPERIMENT DESIGN

For testing the physical capabilities of the robot, we designed an experiment to perform drum rolls. The purpose of the experiment was to find mappings between control variables of the robot motion and rhythmic features of the resulting drumming. This was based on extracting the *time difference* between consecutive beats played by the robot and their *relative amplitude*. These two features are essential in conveying the rhythm in drumming. The drum robot needs to play with precise timing and intensity in order to perform proper musical rhythms.

Control variable and parameters	Range
Amplitude of the motion	15-35 °
Frequency of the motion	1.5-5 *Hz*
Stiffness of the flexible joint	25 N/m
Controller frequency rate	300 *Hz*
Sound recording sampling rate	44100 *Hz*

Table 1: Value ranges of control variables and parameters used for the experiment.

We defined two variables in the control space: the frequency and amplitude of the robot's motion. We also defined two dimensions in the observation space: the time difference between consecutive attacks and their relative sound amplitude.

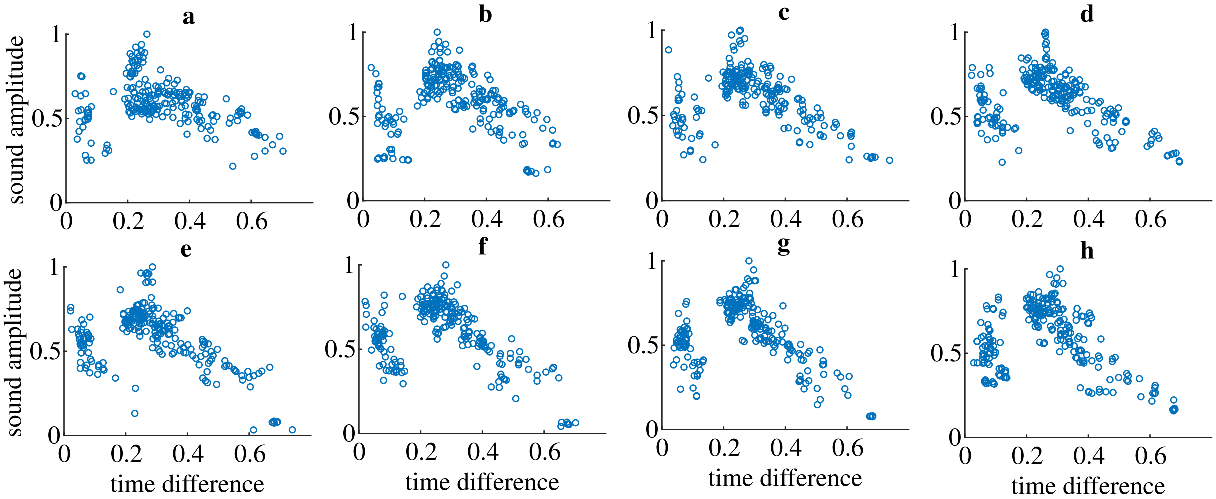


Figure 6: The extracted data points from the experiment in the observation space: time difference between consecutive notes (seconds) and relative sound amplitude. Each data set represents drum rolls with fixed amplitude of the motion and varying frequency between 1.5-5Hz and each data point represents a note played by the robot. Figure (a) has the smallest amplitude, and figure (h) has the largest amplitude.

The expimerntal settings are summarized in Table 1. For each experimental task, we used a fixed amplitude and increased the frequency of the motion within the range 1.5–5 Hz. We repeated the process for each amplitude value. The amplitude of the motion is defined by the angular range for the trajectory of the motor. The angular range of the amplitude of the motion varies between 15–35 °.

Sound features were extracted from the recorded sound files in Matlab using the MIR toolbox [13]. Onsets were detected using the amplitude envelope of the sound wave. A sample onset curve of the drumming sound is illustrated in Figure 5, showing the extracted events with red circles.

5. RESULTS AND DISCUSSION

As can be seen in the summary in Figure 6, similar patterns can be recognized in all of the recorded data sets. First, each data set consists of two distinguishable clusters. These clusters represent single stroke drum rolls (on the right side) and double stroke drum rolls (on the left side). This can more clearly be seen in Figure 7, which illustrates one data set (labeled (h) in Figure 6), in which single and double strokes are separated. Also in Figure 8, the impact of the changes in the frequency of the motion on the drumming motion can be observed.

Another general observation is the relationship between frequency and amplitude. By looking at the single strokes, we can see that when the frequency has been increased (smaller time differences), the sound amplitude also increases. It is natural to decrease the amplitude of the motion in faster drum rolls to maintain the same amplitude.

The data sets show how the observation space can be reached by changing the control variables. For instance, there are some “empty” areas in the observation space. This means that by adjusting the available control variables, performing a drum roll (with a specific frequency and amplitude) that resembles the empty areas is not feasible. In other words, the limitations and physical constraints of the robot determine the drumming result we can get by changing the control variables. This means that such an experimental approach can be used for the robot to explore feasible control possibilities to reach and recognize the reachable areas in the observation space. As mentioned before, the data can be used for learning algorithms that could find all the possible complex rhythmic patterns. This will allow the robot to utilize all its mechanical and physical potential.

6. CONCLUSION

In this paper, we presented a drum robot prototype and explored its ability to perform drum rolls. The main goal of the experiment was to investigate how drum robot performance is limited to its physical constraints. Furthermore, we are interested in exploring how a robot can find its optimum control parameters by performing at specific frequencies and amplitudes. The results are relevant for further iterations of the robot design and to develop algorithms for the robot to learn drumming tasks. There are some key points that can be discussed regarding the results:

- The passive spring used in the flexible joint limits the frequency of the double strokes. This means that for performing double strokes, the timing of the strokes is fixed regardless of the values of the frequency and amplitude. This issue can be solved by changing the trajectory offset or the point that the drumstick collides with the drum membrane. In this way, by adding an additional control variable, the feasible areas expand in the observation space for the robot, and the robot can perform with more variability.

- Having two degrees of freedom and being underactuated, the control of the robot becomes more challenging. The nonlinear behavior of the arm can not

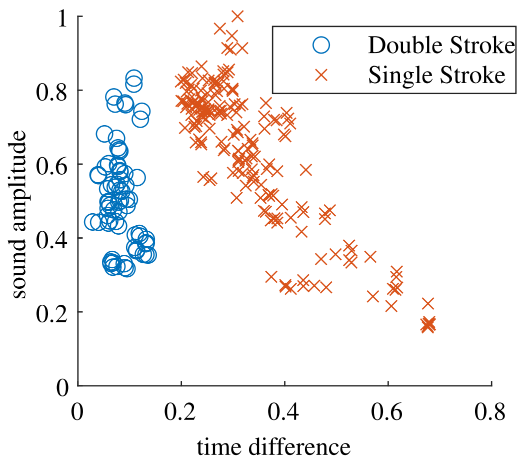


Figure 7: Single strokes and double strokes separated. The frequency of the double strokes is limited due to the presence of the passive spring in the gripper joint.

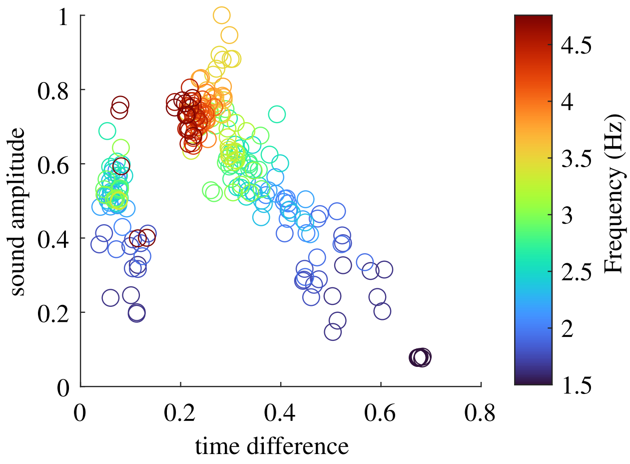


Figure 8: There is a direct relationship between the frequency of the motion and drumming features. The color of each point indicates the frequency of motion in the experiment.

be easily predicted. One way to develop satisfactory control parameters is by finding patterns in the drumming output. In addition to drum rolls, other complex rhythmic tasks can be explored by the robot without analyzing the dynamics of the robot and the drum. This model-free approach can be tried by using interactive intelligent algorithms like reinforcement learning to improve the creativity and efficiency of the drum robot. Some solutions might be completely different from how human drummers perform since the mechanics are different. Thus, it would be interesting to see the robot learn interactively.

In the future we will use machine learning methods to solve the nonlinear relationships between motion parameters of the robot and its drumming results. In particular, reinforcement learning has a big potential in training the control strategies of the robot. One important question when using reinforcement learning is how the objective for the robot can be defined, and how creative the behaviour can be. We will address both these questions in future studies.

Acknowledgments

This work is supported by the Research Council of Norway through its Centres of Excellence scheme, project number: 262762.

7. REFERENCES

[1] G. Weinberg and S. Driscoll, "Toward robotic musicianship," *Computer Music Journal*, pp. 28–45, 2006.

[2] M. Bretan and G. Weinberg, "A survey of robotic musicianship," *Communications of the ACM*, vol. 59, no. 5, pp. 100–109, 2016.

[3] R. I. Godøy, "Motor constraints shaping musical experience," *Music Theory Online*, vol. 24, no. 3, 2018.

[4] A. Z. Hajian, D. S. Sanchez, and R. D. Howe, "Drum roll: Increasing bandwidth through passive impedance modulation," in *Proceedings of International Conference on Robotics and Automation*, vol. 3. IEEE, 1997, pp. 2294–2299.

[5] Y. G. Kim, M. Garabini, J. Park, and A. Bicchi, "Drum stroke variation using variable stiffness actuators," in *2014 IEEE/RSJ International Conference on Intelligent Robots and Systems*. IEEE, 2014, pp. 3892–3897.

[6] M. Bretan, D. Gopinath, P. Mullins, and G. Weinberg, "A robotic prosthesis for an amputee drummer," *arXiv preprint arXiv:1612.04391*, 2016.

[7] D. Gopinath and G. Weinberg, "A generative physical model approach for enhancing the stroke palette for robotic drummers," *Robotics and autonomous systems*, vol. 86, pp. 207–215, 2016.

[8] N. Yang, R. Sha, R. Sankaranarayanan, Q. Sun, and G. Weinberg, "Drumming arm: an upper-limb prosthetic system to restore grip control for a transradial amputee drummer," in *2021 IEEE International Conference on Robotics and Automation (ICRA)*. IEEE, 2021, pp. 10 317–10 323.

[9] N. Yang, R. Savery, R. Sankaranarayanan, L. Zahray, and G. Weinberg, "Mechatronics-driven musical expressivity for robotic percussionists," *arXiv preprint arXiv:2007.14850*, 2020.

[10] R. Van Rooyen, A. Schloss, and G. Tzanetakis, "Voice coil actuators for percussion robotics." in *NIME*, 2017, pp. 1–6.

[11] H. M. Brown and S. Topel, "Drmmr: An augmented percussion implement." in *NIME*, 2019, pp. 116–121.

[12] S. M. Karbasi, R. I. Godøy, A. R. Jensenius, and J. Tørresen, "A learning method for stiffness control

of a drum robot for rebounding double strokes," in *2021 7th International Conference on Mechatronics and Robotics Engineering (ICMRE)*. IEEE, 2021, pp. 54–58.

[13] O. Lartillot and P. Toiviainen, "A matlab toolbox for musical feature extraction from audio," in *International conference on digital audio effects*, vol. 237. Bordeaux, 2007, p. 244.