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A Comparison of Pic -Based Strategies for Robotic Bass Playing

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***Abstract*—The Faculty of Engineering at Victoria University of Wellington has constructed a robotic bass guitar player, Bassbot. A critical feature of such a robot is the plucking mechanism. Three mechanisms were made, two using stepper motors of differing sizes and one using two pull type solenoids. These were compared based on metrics of speed and consistency. There was trade-offs between the systems, with the most consistent being the slowest and the fastest system being the least consistent. To expand the abilities of the robot, a height adjusting cam was added to one of the stepper motors to allow dynamic playing.**

Keywords- Bass Guitar, Robotic Instruments, Plucking Mechanisms, Optimisation

I. INTRODUCTION

Only a small number of robotic stringed instruments have been constructed worldwide. Many of these devices have been criticised for sounding unnatural. The Faculty of ngineering at Victoria University of ellington see s to remedy this by creating a novel robotic bass guitar design. The eventual goal is to incorporate this automated bass guitar into a large robotic orchestra that is being developed in association with the New ealand School of Music.

An e tremely important aspect of any robotic stringed instrument is the method by which the string is pluc ed or stroked). To the authors' best knowledge, a quantitative analysis of their pluc ing mechanisms has either not been done or has not been published.

The aim of this paper is to compare three pluc ing mechanisms based on speed and consistency of pluc s. These metrics were chosen due to their importance and ease of measurement compared to more sub ective terms such as tone and performance value.

Initially a pic that will be able to combine the desirable aspects of speed whilst still producing a natural sound needs to be chosen. Variables to be considered include the thic ness of the pic and the method by which the pic is applied to the string. This pic will be used as the benchmar on all three pluc ing systems.

A comparison of the three pluc ing mechanisms is presented considering their relevant costs speed and consistency of performance. The tests are all run on the BassBot platform using a custom optical pic up and a standard 0.110" bass string.

II. BACKGROUND

Robotic instruments have been an area e plored by artists engineers and scientists for the last century. The earliest e ample of an automatically played musical instrument is Fourneaux's "Pianista" player piano from 1863 1 . Player pianos were commercially successfully until the onset of the great depression in 1929. Since then music reproduction means such as records and CDs have been preferred ma ing robotic instruments less commercially attractive.

Hobbyist musical robot pro ects have recently become more common with microcontrollers such as the Arduino 2 ma ing embedded programming more accessible. However these pro ects are normally simply thrown together without uantitative results being researched or published.

Two prominent robotic guitars include Eric Singer's GuitarBot 3 shown in Figure 1 a and MMIs Poly-tangent Automatic multi- Monochord PAM 4 shown in Figure 1 b . These instruments implement two different types of pluc ing systems.

GuitarBot uses a rotational system driven by a geared servo motor which turns a bloc with four pic s mounted to it. PAM uses an opposing solenoid system that pulls a pic across the guitar string. Both systems were trialled and analysed as discussed in this report with an additional system that improves on both systems with the ability to control the dynamic component of the string pluc .

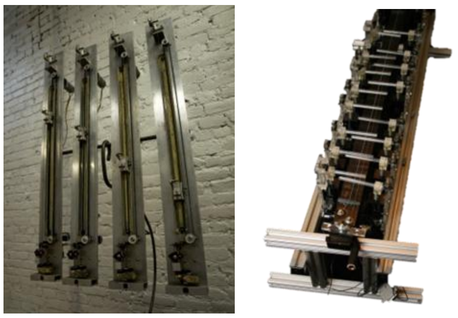

Figure 1 a Lemurs GuitarBot 3 b MMIs PAM 4

III. T ST RIG

To test various pluc ing techni ues a test bench Figure 2 was constructed. A galvanised steel frame was used to ensure rigidity with a sheet of plywood riveted on top. The plywood allows aluminium brac ets to be attached simply with woodscrews. Motors solenoids and pic ups have been attached to these brac ets allowing easy construction and modification. Stainless steel U shaped brac ets were placed at each end to elevate the string one with a notch to hold the string and the other with a machine head allowing the string to be tuned.

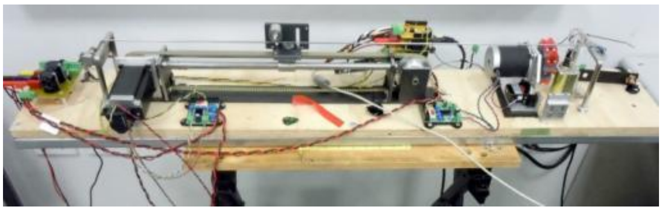

Figure 2 BassBot Test Bench

Initially a standard magnetic bass guitar pic up was used to convert the string's vibrations into an electrical signal. However this sensor suffered from interference from the motors even when a mu-metal shield is used. To solve this problem an optical pic up 5 is incorporated Figure 4 a . This is made from an infrared L D and photo-transistor. The string is placed between the optical pair casting a shadow on the receiver. The changing shadow from the vibrating string creates an electrical signal that corresponds to the vibrating fre uency of the string.

Commands were sent to the pluc ing mechanisms using the MIDI protocol 6 . A custom MIDI controller was implemented on an Arduino UNO microcontroller development board with shields PCBs designed with headers to plug onto the Arduino board made for driving the mechanisms Figure 4 b .

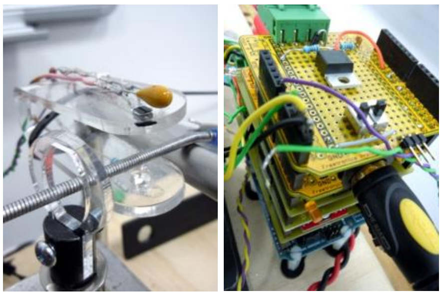

Figure 3 a Optical pic up b Arduino + Shield

The concurrent time based audio programming language ChucK was used to perform analysis. This program can output MIDI commands and record the resulting waveforms from the pic up. These wav files are then analysed in Matlab to retrieve data such as ma imum notes per second and the RMS power of specific responses.

IV. PLUCKING M CHANISMS

Three pluc ing mechanisms are investigated. For the purpose of this document they will be referred to as small stepper large stepper and solenoid system. The small stepper system is based on Eric Singer's GuitarBot's pick wheels while the solenoid system is very similar to pressive Machines PAM. The large stepper is a modified version of the pic wheel with the addition of MIDI *velocity* controlled height allowing dynamic control.

The pluc ing mechanisms were evaluated on two main criteria ma speed and consistency of stri es. The faster the system the better as the mechanical system should not limit the musician controlling the robot but rather be able to respond adequately. The world's fastest guitarist can play at 600 beats per minute or 23.5 notes per second nps 7 and thus is the benchmar for the pluc ing systems.

Consistency is also important delivering a repeatable volume pluc . To test consistency a sample of 100 pluc s was ta en 10 seconds apart on each system with the RMS power of each pluc with 2 s of decay time being recorded. To compare the systems the standard deviation was ta en of the 100 pluc s. The units for this are arbitrary with no meaning of their own but providing a means of comparison.

The large stepper system also has its dynamic range measured relating the RMS power of its pluc s against the height of the mechanism.

A. Pick selection

Initially a guitar pic had to be chosen for use with the pic ing systems. Seven Dunlop pic s were compared 0.5mm 0.6mm 0.88mm 2mm stiff Torte pic s and 0.46mm 0.88mm and 1mm fle ible Nylon pic s.

Thic er pic s give a much deeper sound due to a larger fundamental than the thinner pic s of the same material. Higher harmonics are heard easier with the thinner pic s as the fundamental is not as dominant. As tone is sub ective with different tones preferred by different genres of music or individual musicians this metric was not given the same priority as speed when comparing the pic s.

One pic was placed on the small stepper system at a time and the ma imum speed that the stepper motor could turn while pluc ing a string at a set height si teen times without slipping was recorded Figure 4 . It can be observed that the nylon pic s can be played at a higher speed than their Torte counterparts. This is due to the fle ibility of the nylon allowing the pic to push past the string while offering less resistance than the stiffer Torte pic s.

hile the 0.46 nylon pic can pluc the fastest at 13 notes per second nps it does not stri e the string with a defined attac [1]. As it is fle ible it simply bends past the string not giving a defined attac sound. This attac portion of a pluc is important from a musical standpoint as it clearly defines the start of the note.

[1] Attac : The initial run-up of level from nil to pea

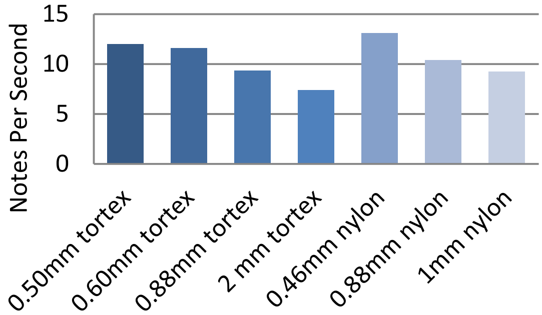

Figure 4 Pic   speed comparison

The more rigid 0.5mm Torte   pic   gave a much more defined attac   and a louder sustain while only being slightly slower   12 nps . These two pic s were placed on the stepper motor and played after each other. Their response is shown in Figure 5. Due to the stronger response and high speed the 0.5mm Torte   pic   was used on all the pluc ing mechanisms.

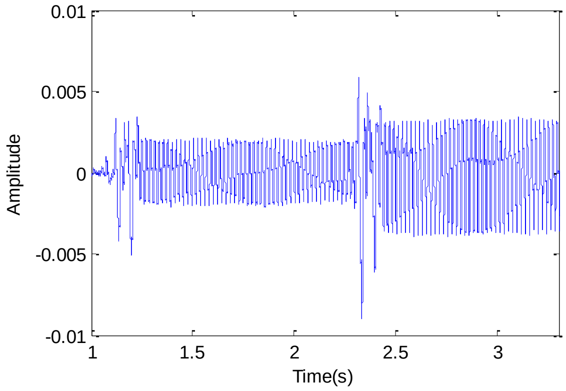

Figure 5 0.46mm Nylon and 0.5mm Torte

B. Small Stepper System

The small stepper system consists of a Mercury Motor SM-42B G011-25   N MA   17 motor being driven by the   asyDriver stepper motor driver   8   attached to a height ad ustable L-brac et shown in Figure 6. An aluminium bloc   with four 0.5mm Torte   pic s is mounted onto the shaft of the motor giving it a pluc ing rate of 4 pluc s per shaft rotation in a configuration similar to Eric Singer's GuitarBot   3 .

This system is the second most e pensive with the motor costing   15 and the motor driver board costing   13.

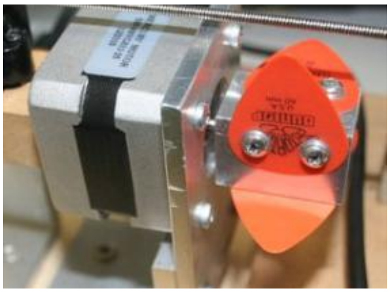

Figure 6 Small Stepper Pluc ing System

1) Speed

The small stepper motor in its current configuration is the slowest of the three systems at 12nps. This could however easily be doubled by using an eight-pic   wheel as used by the large stepper system although the mechanism can only play when the tip of the pic   is pushed across the string due to low tor ue. If the motor is set too high raising the pic   then the system slips.

2) Consistency

The small stepper motor is the most consistent that is consecutive pluc s have similar amplitude and decay. The 100 pluc   test has a mean of 0.0148 and a standard deviation of 0.0027.

C. Solenoid System

The second system developed is a solenoid push-pull configuration similar to EMMI's PAM robot   4 Figure 7 . This consists of two Solen 121 18711 pull-type solenoids opposing one another driven at 24V by IRLD024 N-channel MOSF   Ts controlled by the Arduino.

The guitar pic   is mounted to a T brac et which is attached to the solenoid plungers. To stop the plungers rotating a slotted piece of acrylic is attached above the solenoids to guide the pic   brac et. The solenoids are attached to L brac ets which in turn are attached to a brac et that allows ad ustment for the height of the solenoids and the separation between them.

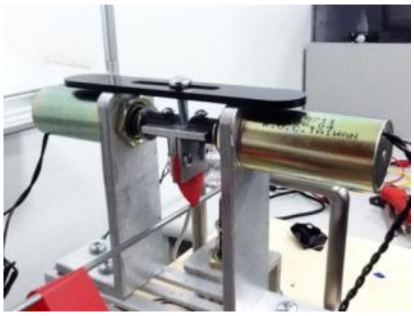

Figure 7 Solenoid System

The solenoid system is the cheapest to build with the solenoids costing   5 each and no special driver board re uired rather two   0.50 MOSF   Ts are all that is re uired. Parts for this system total   11.

1) Speed

The solenoid system performed well in terms of speed reaching a ma imum of 20 nps. The solenoids were moved to different positions as the force of a solenoid is inversely proportional to the stro e[2] s uared   9   and the ma imum speed was recorded   Figure 8 . As can be seen the ma imum speed is indeed a   uadratic response with the limits being set at one end by the pic   brac et not having enough space to move over the string. At the far end of the curve the movement was limited by the solenoid plungers falling out of the solenoid casings.

[2] Stro e: Distance between end-stop and plunger end

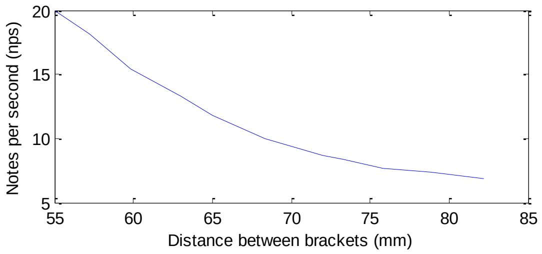

Figure 8 NPS vs. Distance between two brac ets

2) *Consistency*

If every second pluc is observed the solenoid system is very consistent. However for an un nown reason the system prefers to go one way more than the other. To try and fi this problem a metal plate was added to the T-brac et sandwiching the pic . Solenoids were swapped the pic brac et assembly was turned and the P M to the stronger side was reduced to even the system out. The results of these tests are shown in Figure 9.

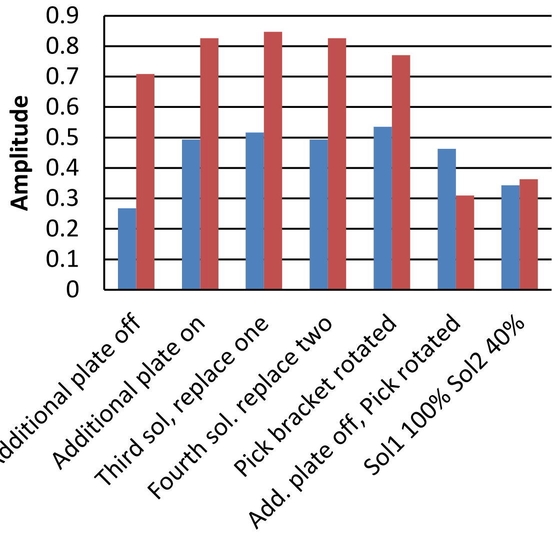

Figure 9 balancing the solenoid system

It can be seen that the additional plate did help the situation although it did not completely fi it. Rotating the pic brac et and swapping the solenoids with spare ones had little to no effect. Slowing down the predominant side did balance the system with detriment to the overall speed of the system.

The final system with the plate on and 100 P M on each solenoid had a RMS Power mean of 0.0443 and standard deviation of 0.0099 in the 100 pluc test.

D. *Large Stepper System*

The solenoid system and small stepper system were both found lac ing in their performance. The solenoids are inconsistent between alternative pluc s and the small stepper system is slow. A system Figure 10 was set up that combines the consistency of the small stepper system with the speed of the solenoid system.

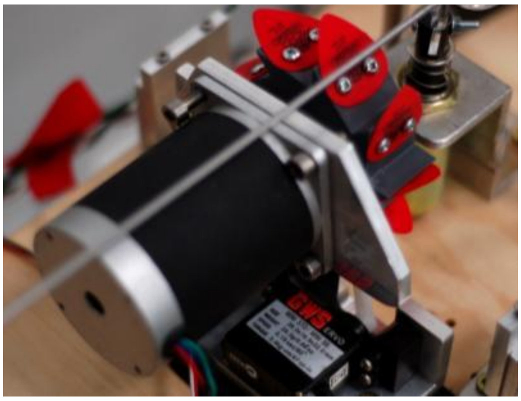

Figure 10 Large Stepper System

This consists of a N MA-23 57B G621 stepper motor driven by a STMicroelectronics L6208PD stepper motor driver evaluation board. This motor can deliver significantly more tor ue than the smaller stepper 12.5 g-cm as compared to 2.3 g-cm. This allows the system to drive more than ust the tip of the pic across the string without slipping as the small stepper is prone to.

This is the most e pensive system to build. It consists of a 33 stepper motor a 15 servo motor a 60 stepper motor driver and is the most complicated brac et to manufacture.

1) *Speed*

 ight pic s were mounted to further increase the speed of the system as compared to the smaller system. The pic s were mounted on a 45 degree angle to give a sliding effect closer to how a human plays as opposed to pushing perpendicularly through the string.

Using the 0.5mm Torte   pic s the large stepper system can rotate at 3.125 rps or 25 nps without slipping. This is over twice that of the smaller stepper and 25   greater than the solenoid system.

2) *Consistency*

The large stepper motor has a similar consistency to the solenoids although it is not as uniform. This is mainly due to the servo not holding the stepper motor at an e act height but rather pulsing up and down small amounts uic ly. ach pic is also at a slightly different position which contributes a variance in each of the eight pluc s. The RMS power plotted against 100 puc s is shown in Figure 11.

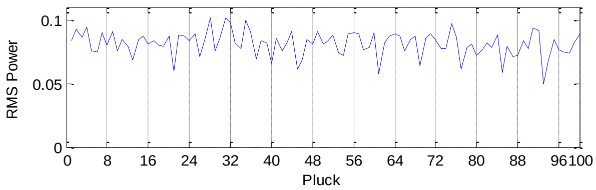

Figure 11 RMS power vs. pluc s

The 100 pluc test has a mean of 0.0812 and a standard deviation of 0.0097 meaning that the consistency of this system is statistically similar to the solenoid system.

3) Dynamics

One of the areas not e plored in past pluc ing mechanisms is the ability to ad ust the height for pluc ing dynamics. This is useful as a recurring problem in robotic instruments is that they sound li e robots. The guitar needs to be able to play loud and uiet notes to better emulate a human playing style thus making the robot’s music sound natural, rather than ”mechanical”.

To test the servo mechanism the large stepper motor system was sent eight pluc instructions ten times per degree of height. ight pluc s were needed to account for any differences between the positioning of the pic wheel. This set of pluc s was repeated ten times so an average could be ta en and then the stepper motor was lifted one degree by the servo and repeated. The RMS power value of each set of eight pluc s were averaged and plotted against the normalised height of the stepper motor

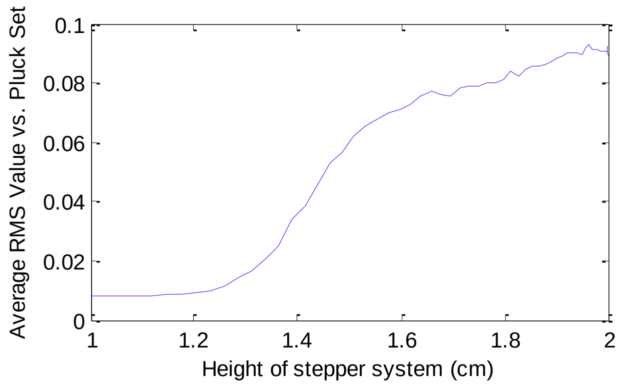

Figure 12 Average RMS value vs. Pluc Set

The figure above shows a linear region where the output increases smoothly with the servo height between 1.3 cm and 1.6 cm. Above 1.6cm the string is being hit so hard that the string is being overdriven and the system cannot consistently pluc it. Below 1.3 cm the string is not actually being touched rather the mechanical coupling of the motor with the test bench base is e citing the string.

V. R SULTS

As e pected the large stepper motor was the fastest system at 25 notes per second Figure 13 and is also faster than the world record holder ohn Taylor at 23.5 nps. The solenoid system comes close at 20 nps and the small stepper system is behind at only 12 nps.

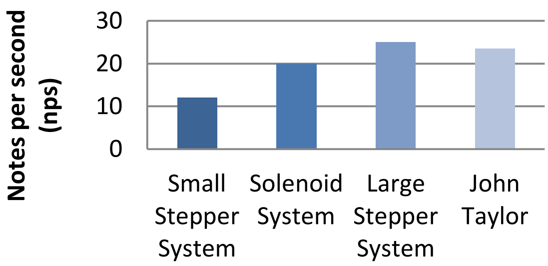

Figure 13 Speed summary

The smaller stepper motor is the most consistent of the three systems with a standard deviation of 0.0027. The solenoid and large stepper systems are very similar with standard deviations of 0.0099 and 0.0097 respectively. This is shown in Figure 14.

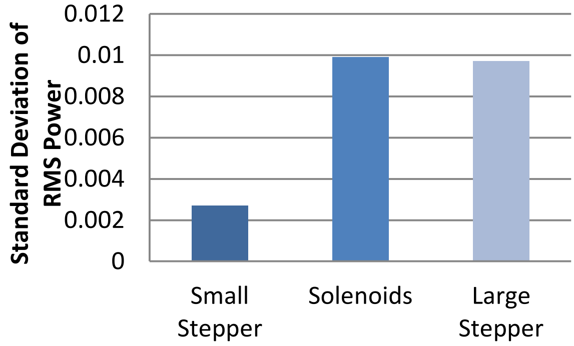

Figure 14 Standard Deviation of the three systems

VI. FUTUR IMPROV M NTS

This study has focussed on pluc ing mechanisms using guitar pic s only. A future improvement could include using different techni ues such as hitting with a drum stic bowing electromagnets -Bow bouncing and using rubber or glass wheels. These would give different responses to the guitar pic s allowing the robot to have a greater tonal range.

The systems could be further improved by using an optimisation algorithm such as genetic algorithms or similar to find optimum speeds and forces to apply to the string.

The solenoid system e cels in its cost:performance ratio. A system that uses a servo to raise one of the servo brac ets with the other brac et on a hinge as depicted in Figure 15 would allow dynamic control without the hefty price tag of the large stepper system.

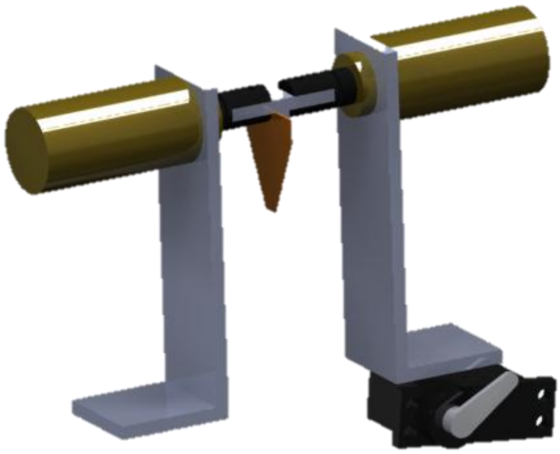

Figure 15 Solenoid system with dynamic control

VII. SUMMAR AND CONCLUSIONS

Two mechanisms were built and tested testing two different techni ues rotating pic wheels and alternating pull-type solenoids. A third system using a stepper motor was built that operated faster than either of them and had a wide range of dynamic control provided by a servo which is an aspect not covered by previous designs.

The 0.50 mm Torte pic was chosen as a benchmar for its high speed while still being able to ma e a standard pluc ing sound. It was found that the small stepper system with the more fle ible nylon pic s on was able to turn faster than with the Torte counterparts but made less of an impression on the string.

A system was made that can play faster than any human with the large stepper system consistently playing at 25 nps. The Solenoid system was not far behind at 20 nps. This could be further improved if a smaller pic brac et was used allowing the solenoids to be placed closer together. The small stepper system however fell short at 12 nps.

Consistency was measured by ta ing a sample of 100 pluc s RMS power and finding the mean and standard deviation. It was shown that the smaller stepper had the most consistent pluc .

The solenoid system was more predictable as there are two separate cycles in its pluc ing range. very second pluc was consistent with itself but there was a large amount of disparity between consecutive pluc s. The larger stepper with eight pic s had less disparity between each pluc but as there was a larger number there is more chance for a pic to be slightly out of alignment thus reducing the overall consistency.

All three systems have their strengths and wea nesses. If consistency is deemed the most important aspect then the small stepper motor e cels when high speed is not important. If high speed simplicity and low cost are important the solenoids e cel at the cost of consistency between alternative pluc s. If cost is not as important but dynamics and high speed are desired then the large stepper motor is preferred although it has a similar consistency of pluc s as the solenoid system.

The large stepper system is chosen as the main pluc ing mechanism on Victoria University's BassBot as the dynamic control allows for a much more musical e perience as compared to the more static mechanisms.

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