The Robotic Taishogoto: A New Plug 'n Play Desktop Performance Instrument

Jason Long
Tokyo University of the Arts
12-8 Ueno Koen
Tokyo, Japan
djkinetix@gmail.com

ABSTRACT

This paper describes the Robotic Taishogoto, a new robotic musical instrument for performance, musical installations, and educational purposes. The primary goals of its creation are to provide an easy to use, cost effective, compact and integrated acoustic instrument which is fully automated and controllable via standard MIDI commands. This paper describes the technical details of its design and implementation including the mechanics, electronics and firmware. It also outlines various control methodologies and use cases for the instrument.

Keywords

Musical Robotics, Japanese Instruments, Robotic Performance, Music Technology, Taishogoto

1. INTRODUCTION

Though the field of musical robotics has enjoyed accelerated development over the last few decades, in part due to increases in power, affordability and accessibility of microcontroller technology, there are a number of obstacles that prevent the area from gaining the ubiquity of fields such as electronic music. With very few commercial products available, many students in the field have turned to the creation of their own unique instruments and while this can be artistically rewarding and sonically diverse, most of these instruments are also complex, requiring a significant investment of space and time to set up and learn. Cost of parts and access to the required machinery are also significant factors which prevent many potential robot musicians from realizing possible designs. This Robotic Taishogoto design tries to address these problems by presenting a new instrument that was built using tools commonly found in university workshops and local maker spaces, easily obtainable and affordable materials, and is created by retrofitting electronics inside an already existing instrument. To reduce necessary setup time and learning curve in a similar way to the Karmetik Notomoton outlined in [3], the Robotic Taishogoto is fully integrated, requiring only a standard power cable and USB or MIDI connection from the intended controller or sequencer. It also features a magnetic pickup with volume and tone controls for amplification.

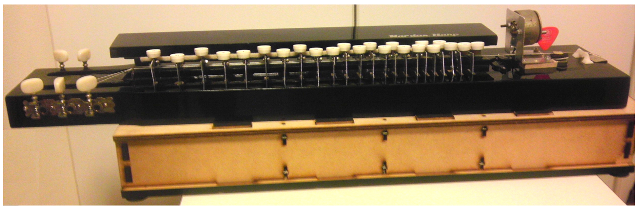

Figure 1: The Robotic Taishogoto

1.1 The Taishogoto

The taishogoto, also sometimes called the Nagoya harp, is a form of fretted Japanese zither instrument. It generally has five strings, three tuned to the same note, one tuned an octave lower, and the other tuned two octaves lower. Above each fret is a lever which resembles a type-writer key, which when pressed, will fret the first four strings at that note leaving the lowest string open. In order to allow it to be played in various keys without retuning, the open string in this particular instrument was removed. The taishogoto is traditionally played by strumming the strings with a pick in the right hand, and using the left hand to control the notes with the keys. Unlike most string-based instruments such as guitars, the taishogoto already has a fretting mechanism built-in, making it an ideal candidate for automation.

2. DESIGN

While to the author's knowledge this is the first example of a robotic taishogoto, there are a number of aspects of other instrument designs that have aided in its invention. There are four main sections of the physical design, the enclosure, the picking mechanism, the array of fretting components, and the damper. Each will be discussed in turn below.

2.1 The Enclosure

After some preliminary experiments with solenoids that are small enough to fit inside the original instrument, it was found that they were nowhere near strong enough to pull down the levers with enough force to successfully fret the strings. Noting that mounting the solenoids above the instrument would obstruct an audience's view of it and prevent manual playing of the instrument, it was then decided to expand the area underneath the instrument with an enclosure that could house the twenty three solenoids for the notes, the damper solenoid, the power supply and all of the control electronics.

The simple enclosure design as shown in the CAD drawings of Figure 2, was intended for laser-cut MDF wood, and the roof of the enclosure doubles as a mounting board for the solenoids.

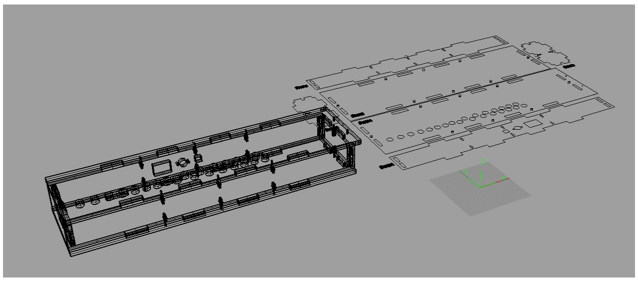

Figure 2: CAD design of the enclosure

2.2 The Picking Mechanism

There are a number of different solutions that have been invented to carry out the task of picking strings in automatic instruments. Trimpin's sketches of designs for his 'If VI was IX', 'JackBox' and 'KrautKontrol' installations as shown in [2], show a number of different motor and solenoid based methods of plucking a string. Eric Singer's GuitarBot in [6] uses an effective stepper-motor based mechanism, and Dr. Godfried Willem Raes's Expression Control in Automated Musical Instruments[1] makes mention of stepping motor, DC motor and rotary solenoid based methods. [7] gives an analysis of the cost and performance of a number of these techniques.

The relatively small form factor of the taishogoto and limited area in which to mount a picking mechanism means that the chosen method should be simple and compact, and the goals of this project dictate that it should also be cost-effective. After a double linear solenoid configuration was trialed and found not to satisfy these requirements because of size and mounting complexity, a rotary solenoid based method was used. The rotary solenoid was mounted near the sound hole with an aluminum bracket, and the pick was attached to the plate of the solenoid with another aluminum bracket as shown in Figure 3. The spring inside the device was adjusted so that the initial stroke, which is powered by the onset of a voltage, approximately matches the power of the return stroke which is powered by the return spring.

Some automated string instruments such as the MechBass in [4] implement velocity sensitivity in this mechanism by allowing adjustment of the height of the pick by way of servo motor or linear soft-shift solenoids. This taishogoto is relatively sensitive to small adjustments in pick height because the pick must travel through four strings of two different guages in a single stroke and in a position too low, the pick will occasionally be blocked by one of the strings. Automated height adjustment would be a welcome addition in the future of the instrument though, as in its current form, the higher notes tend to suffer from reduced loudness due to the fact that they are closer to the pick and are forcing the string position lower. Pick selection also influences this balance, so a relatively thin pick of 0.60mm was chosen for its flexibility, making the pick less likely to be stopped by the strings if the height is set low.

2.3 The Damper

The damper mechanism is comparatively simple consisting of a single small tubular push-type solenoid mounted near the bridge of the instrument under the strings. It has a felt pad attached to its plunger which is pressed against the strings at will to silence them. Rather than using a servo motor like the MechBass [4] which allows varying degrees of pressure applied to the strings, a solenoid was chosen due to its speed and quiet action, allowing very quick dampened notes. The strength of the dampening was optimized using a fixed power resistor to limit the current applied, as too strong a push generates bending noise from the strings, and too weak a push will not silence the strings quickly enough. The opposite end of the plunger rests on a soft surface inside the instrument to prevent clicking upon release of the damper.

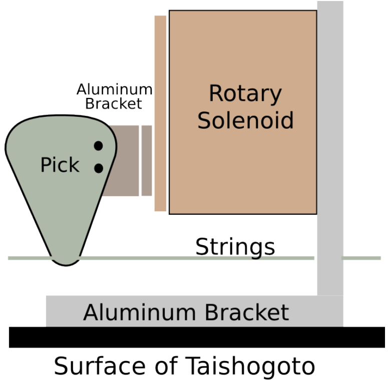

Figure 3: The picking mechanism

2.4 The Fretters

Not only were the fretting solenoids too large to fit inside the original instrument, they were also too large to be positioned in a single row underneath the levers and had to be positioned in a staggered arrangement as can be seen by the line of circles on the enclosure design in Figure 2.

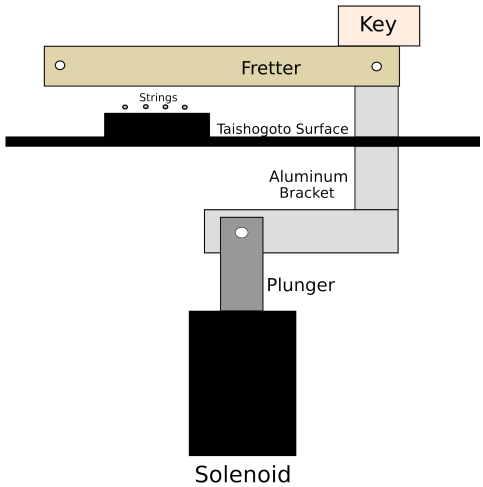

Figure 4: A side view of the fretting mechanism

Though each solenoid plunger is placed in line with each lever in one axis, for most of the notes there is still displacement on the other. To connect the plungers and the levers, a set of 23 aluminum brackets were created by hand, in various shapes to accommodate for this displacement and the shape of the instrument. To account for the rotational aspect of the movement of the levers, the brackets had to be attached in a way as to allow both the solenoid side and the lever side to rotate slightly, though this mechanical movement created a noticeable and distracting metallic noise. To overcome this, rubber rings were added to separate the brackets from the levers. Though the pressing of the levers naturally generates some noise that is a part of the sound of the instrument, the abrupt nature of the solenoid movement, accelerating as it reaches the end of its stroke is

[1]`http://logosfoundation.org/g_texts/expression-control.html`

the opposite of how human players play a note and creates another extraneous clicking noise at the point of contact between the levers and their own mounting pole. To reduce this noise, a very thin layer of soft tape was added at this point of contact. Pulsewidth modulation of the control signals to the solenoids may seem to be the natural solution to the abrupt solenoid movement, but as Dr. Godfried Willem Raes states "The trouble with PWM [...] is that it causes audible artifacts from the solenoids. If you try to overcome these by setting the fundamental frequency way above audio, however, you will run into trouble with the dissipation and the electromagnetic radiation (EMC)."[2]

3. ELECTRONICS

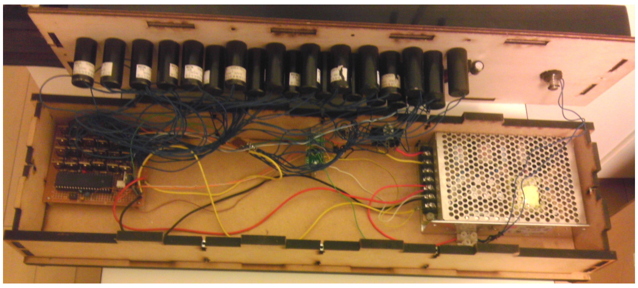

Figure 5: Inside the Robotic Taishogoto

3.1 The Power Subsystem

The power supply for the robot taishogoto had to fulfill a number of requirements. Firstly, it had to fit in a relatively small area inside the enclosure, secondly, it had to provide enough current to drive the total of twenty five solenoids and all of the control circuitry, and thirdly it had to provide the appropriate voltages for each of these sets of electronics. The above pictured switched-mode power supply was chosen because it provides both a regulated 5 volt supply for the logic level electronics and a 24 volt supply for the solenoids. At certain current loads, it also emitted a very high-pitched, penetrating tone which was eliminated by taking it apart and applying hot glue to the inductor inside.

Though there are twenty five solenoids in total, twenty three of them are along the fretboard, and since it is a monophonic instrument, almost never three, rarely two, and in most cases just one fretboard solenoid will be activated at any one time during operation. The damper solenoid needs much less power than the fretboard solenoids to achieve its purpose so a power resistor reduces its current requirements. These solenoids were controlled using the left schematic shown in Figure 6.

The picking rotary solenoid will have an average duty cycle of fifty percent as it will be charged between every second note. The power used and heat generated by this situation is improved upon by implementing a pulse and hold configuration as shown in Figure 6's right schematic which was used in the Logos Foundation player pianos. It works by sending an initial short pulse at the higher current for the attack and subsequently switches to a longer hold signal which need only deliver enough current to keep the solenoid in place for a length of time before release.

Though in some cases it may be beneficial to apply a higher than rated voltage to a solenoid to achieve greater power, since all of the solenoids in this instrument have the potential to be charged for many seconds at a time, it is prudent to stick to their 24 volt rating to prevent overheating and damage.

[2]http://logosfoundation.org/g_texts/expression-control.html

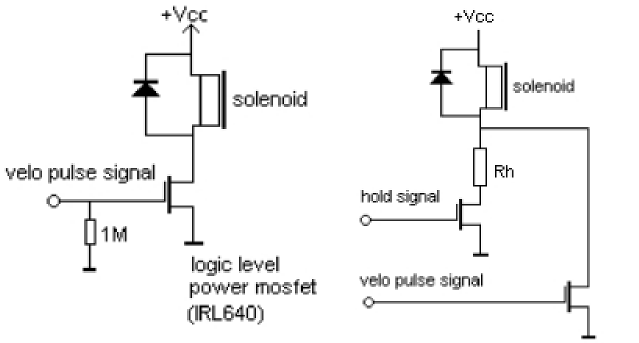

Figure 6: Fretting solenoid circuit (left) and picking solenoid circuit (right) Credit : Dr. Godfried-Willem Raes

3.2 Control Electronics

For this instrument, the AVR Atmega644p chip was chosen as the main microcontroller because of its easy-to-integrate 40 pin DIP form factor, 2 UART peripherals, 32 GPIO pins which are more than required for the number of solenoids used, its low cost, and its compatibility with the convenient Arduino[3] programming environment by way of the Sanguino[4] board definitions. The Atmega8u2 microcontroller was also mounted on a separate surface-mount breakout board dedicated to USB-MIDI communications and was loaded with the open source HIDUINO firmware, which is outlined in [1], recompiled to use an appropriate USB-MIDI device name.

Even though the Atmega644p features dual UART peripherals and can accommodate simultaneous MIDI signals coming from both the USB board and the MIDI input, because of the fact that there would be no need to use both of these inputs at the same time, both of the connections were routed to a single UART RX pin on the master chip as shown in Figure 7. Taking away the requirement for the firmware to poll both UARTs delivers a slight performance increase and makes the firmware smaller and simpler.

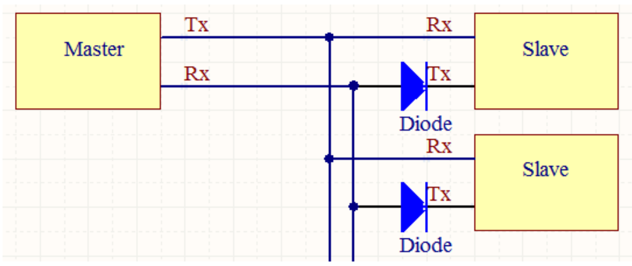

Figure 7: MIDI signal mixing schematic

3.2.1 *Pickup*

Separate from the power and control circuits, the instrument was also retrofitted with a specialized taishogoto pickup which is mounted in the sound-hole, and a circuit which includes volume and tone controls and a 3.5mm TS phono jack audio output on the rear of the instrument.

[3]http://arduino.cc/
[4]http://sanguino.cc/

4. CONTROL STRATEGIES

Many automatic instruments require just one mechanical action per musical message received, but the robotic taishogoto is somewhat more involved. There are a number of control strategies ranging from completely manual, to highly automatic. A manual operation strategy would mean that each action on the instrument would be triggered by its own MIDI message, with individual control over the fretting, picking and dampening mechanisms. This method is clearly the most powerful, as it allows any manner of playing that the instrument is capable of, but it would be rendered highly difficult to undertake a live performance, and quite laborious to compose music with it.

A highly automatic configuration would use as few MIDI messages as possible to operate the instrument. For example, a single note-on command would first fret the string of the desired note, then activate the picking mechanism while taking note of its position, and wait for the corresponding note-off command which would raise the damper and the fretter to stop the note. This method would let a musician quickly plug in the instrument for the first time and be able to play intelligible music with ease. On the other hand, this configuration has a lot less flexibility to create more detailed compositions, lacking the ability to independently control the damper, the pick, the fretters, and their time relationships.

One possible method would be to write a number of different configurations and allow switching between them via program change messages, though instead of that, the following configuration has been created which sits in between the two extremes outlined above to attempt to be practical for both compositional and live performance purposes.

The range of note-on messages which correspond to the keys of the instrument, all trigger the desired note to be fretted, and the strings are plucked soon after. The subsequent note-offs then release the fret. There is one exception in that the lowest note plays the open strings with no fretting. Playing this lowest note while holding down another note allows the player to repeat the same note without the interruption of raising the lever between notes.

While keeping the convenience and playability of this automatic control, manual control capabilities are included using sustain pedal and expression pedal continuous controllers, the former withholding note-offs from the fretboard and the latter withholding the pick commands from newly played notes. Independent control of the dampener is also implemented by note-on and note-off signals from the note one semitone lower than the lowest of the instrument.

5. PERFORMANCE CONSIDERATIONS

A slight inconsistency was observed in the picking mechanism where, although both directions of movement produce similar volume levels, there is a small timing difference between the directions. This would become noticeable when a line of evenly spaced notes were programmed in a sequence and the timing of the resulting realization would be somewhat swung. To fix this, a slight delay was added in the firmware to the quicker direction to create an even level of latency. For tight synchronization with other instruments, it is possible then to use the standard delay compensation features of MIDI sequencing software.

Even with this extra latency added, there is a delay of less than 50 milliseconds from when a control message is sent until the note is sounded. While this does not compare particularly favorably with most virtual instruments for example, it is more than playable and responsive enough for both compositional purposes and live performance settings.

While there are certainly some performance techniques which are not realizable on this instrument such as dynamic control and picking individual strings of the set, it also makes possible many different sounds and musical passages that are not possible by playing in the traditional method. For example, very quick scales, arpeggios and large jumps are easily achieved. Quick, consistent picking and equally fast, precision-timed damping are also made possible. As with almost all musical robots, the fields of real-time algorithmic composition, interactive performance and usage in installations are also opened up to the sound of this instrument through automation.

6. CONCLUSION

The Robotic Taishogoto is a new robotic musical instrument which has proven itself in performances in concerts, interactive musical installations, and in educational workshops. The use of rapid fabrication techniques and low cost materials, along with simple circuits derived from open hardware resources, and both pre-compiled and highly abstracted firmware from open-source software resources, allow the construction of instruments such as this to be created by students and musicians without engineering training in order to pursue their interests in the musical robotics field. It is hoped that the details of this instrument's design and construction presented in this paper will inspire more musicians to undertake musical robotics projects and contribute to the wider field of research.

7. REFERENCES

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