# Swivel 2: A Systems Overview and Evaluation of a New Mechatronic Slide Guitar

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***Abstract*—The Faculty of Engineering at Victoria University of Wellington, in collaboration with the New Zealand School of Music, has constructed a six-stringed modular robotic slide guitar player, Swivel 2. This paper presents a systems overview of the instrument, focusing on the fretting mechanism, picking mechanism, electronics, and usage scenarios. A history of mechatronic guitar and string instruments is provided, as is a detailed explanation of the authors' motivations for building Swivel 2.**

## I. Introduction

### A. Expressivity in Musical Robotics

Musical robotics is a burgeoning field, with increasing exposure both in the academic and popular press. A survey of the state of the art [1] in musical robotics reveals that many systems are mechanically quite simple, resulting in automated musical instruments with a limited range of musical expressivity. While such expressively-limited systems can be found in many subdisciplines of musical robotics, including percussion, keyboard-based instruments, and wind instruments, this paper focuses on recent advances in monochord zither design. It is the goal of the authors to enhance the expressive potential of mechatronic guitars by building systems that afford composers and musicians greater control over the instrument's pitch and dynamic response.

This paper opens with a brief history of automated music before focusing more specifically on related works in the field of mechatronic stringed instrument design. Additionally, key contributions of other workers pursuing the goal of robotic musicianship will be presented. Following the exposition of related works, the authors' prior mechatronic string instruments will be presented. The primary goal of this paper is to compare the performance of Swivel 2, a new mechatronic slide guitar shown in Figure 1, with the authors' prior instruments. After a systems overview of Swivel 2, with a focus on the string picking, pitch-shifting, and string damping subsystems, along with a brief discussion of the system's electronics, Swivel 2's pitch shifting performance is tested. The pitch shifting performance is then compared with that of Swivel 1.0 and MechBass, two of the authors' prior works. The paper closes with a discussion of applications and usage scenarios of mechatronic guitar systems.

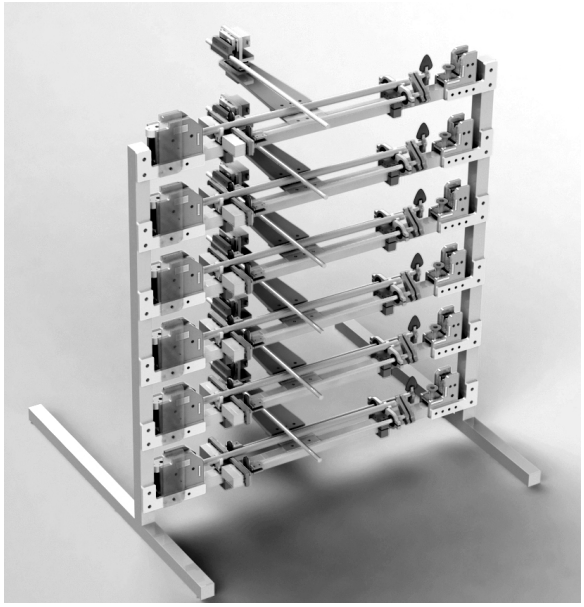

Fig. 1. A Rendering of Swivel 2, Complete with Six String Modules

### B. A History of Mechatronic Stringed Instruments

Inventors of automated musical instruments have been interested in picked-string automata since the 19th Century: such mechanically-sequenced, pneumatically-actuated banjo and violin-playing instruments abounded in the 19th Century [2]. These instruments represented a high degree of mechanical complexity for their time, but lacked the ability to engage in dynamic variation, pitch-bend effects, or any type of on-the-fly variances in the pre-selected tune. Such automated string instruments appeared near the end of a thousand-year tradition wherein inventors strove for musical reproduction through augmented instruments. These augmented instruments, including Renaissance-era self-playing pipe organs, 18th-century musical boxes, and, perhaps earliest, a water organ developed by the Banu Masu brothers in 9th Century Baghdad, are explored in depth in [2].

The advent of the phonograph and loudspeaker, described

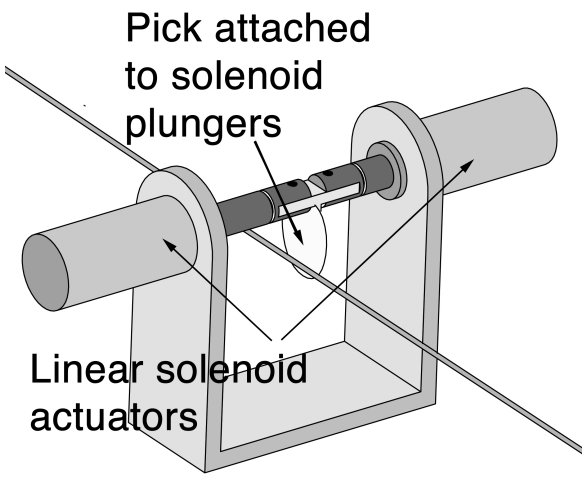


Fig. 2. An Illustration of a Solenoid-Based String Plucking Assembly

in [3], put an end to innovation in self-playing instruments for much of the 20th Century. The 1970s, though, saw a resurgence in interest in automated musical instruments, primarily by artist/engineers such as Trimpin [4] and Godfried-Willem Raes [5]. These artists used mechatronic techniques to provide their automated instruments with the ability to play computer-programmed sequences and respond to sensor input. Current work in musical robotics focuses largely on human-robot interaction, as exemplified in [6] and [7].

In the 1990s, several notable mechatronic guitars were built: one of the earliest was built in the early 1990s by Nicolas Anatol Baginsky for his Three Sirens robotic band (discussed more in [1]. The system, dubbed Aglaopheme, is a multi-stringed robot guitarist featuring a linear-motion pitch shifting mechanism. Mechatronic music pioneer Trimpin began building automated guitars during the late 1990s: his *KrautKontrol* and *If VI Were IX* installations, finished in the early 2000s, feature solenoid-actuated guitars with added vibrato functionality [8]. Another notable robotic guitar is Eric Singer's GuitarBot [9], a four-stringed slide guitar that accompanied guitarist Pat Metheny on his 2010 Orchestrion tour.

An examination of existent mechatronic guitars reveals several common methods of accomplishing string picking and pitch shifting (henceforth referred to as fretting). There are two primary means by which strings are picked in existing systems: double-solenoid string picking and pickwheel-based approaches. Double solenoid string picking involves two coaxially-mounted linear solenoid actuators with a pick mounted between their plungers, as shown in Figure 2. Upon actuation of one of the solenoids, the pick is moved across the string. Pickwheel-based systems use a series of radially-mounted picks attached to a motor, and were utilised on MechBass and described in detail in [10].

There are two main methods for fretting the string: fixed-position solenoid arrays and linear motion-based approaches. Fixed position solenoid arrays, like the type illustrated in Figure 3, consist of push-type linear solenoid actuators mounted at each fret along the guitar's neck. When actuated, the solenoids push the string down, pinching it against the nearest fret and changing the string's pitch. This method, while allowing for rapid transitions between notes, does not allow for such expressivity-increasing techniques as pitch bends or slide effects. Linear motion approaches, exemplified by GuitarBot [9], consist of a linear stage mounted adjacent to the guitar's string. The belt-driven or leadscrew-driven system moves a trolley with attached slide along the string. This approach to fretting, while resulting in latency between fretting events, allows for pitch bends, alternative tunings, and slide transitions between notes.

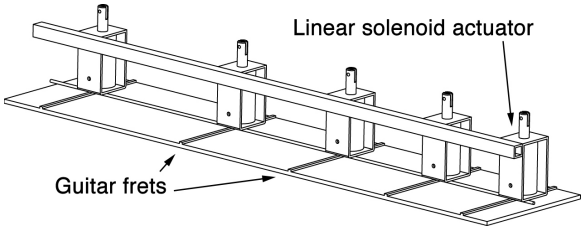


Fig. 3. An Illustration of a Fixed Position Solenoid Fretting Array

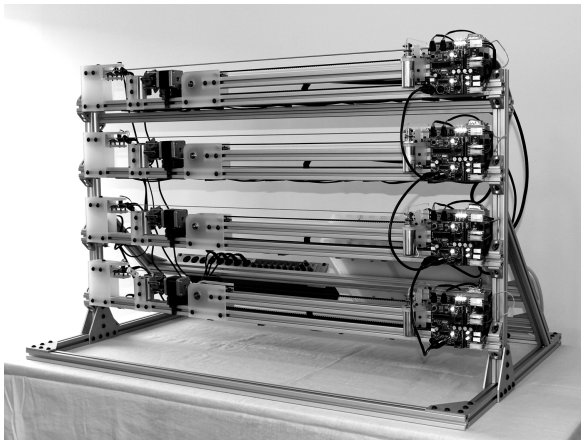

Fig. 4. MechBass, built by James McVay [10]

## II. Prior Work: Swivel 1.0 and MechBass

The authors' prior works, Swivel 1.0 and MechBass, were two mechatronic instruments designed with a focus on speed, precision, and accuracy in fretting. After an overview of both systems, the lessons learnt from more than a year of applications-based testing will be discussed.

### A. Brief Overview

MechBass is a modular mechatronic bass guitar, discussed in more detail in [10]. It features a belt-driven linear motion fretting assembly as well as a pickwheel-based note picking system. MechBass uses NEMA-23 and NEMA-17 stepper motors throughout, and has the ability to clamp and release the string. Figure 4 shows MechBass, complete with four modular string systems. Swivel 1.0, shown in Figure 5, was developed concurrently with MechBass with the intention of evaluating a

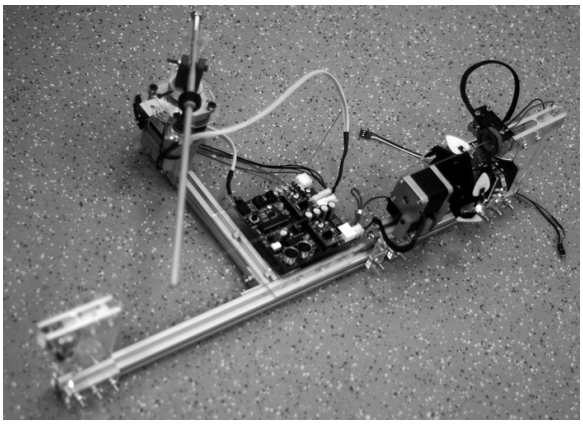

Fig. 5. Swivel 1.0

novel rotary motion-based fretting system. The rotary motion system consisted of NEMA-23 stepper motor which held a rod, called a fretter arm, capable of being rotated across the string. Upon reaching the desired position along the string, a linear solenoid actuator mounted on the fretter arm clamps the arm against the string, resulting in a change of the string's pitch.

Swivel 1.0 and MechBass use similar electronics, described in depth in [11]. Both Swivel 1.0 and MechBass use an optical pickup to input the strings' vibrations to a host computer or loudspeaker; the optical pickup was chosen as a means of avoiding electromagnetic interference from the proximally-mounted stepper motors and DC servos.

Swivel 1.0 and MechBass have been extensively used in performance and demonstration contexts. MechBass has been used heavily as an engineering recruitment outreach tool. Swivel 1.0 has been used in live performance contexts.

### B. Research Conclusions from Swivel 1.0 and MechBass

MechBass and Swivel 1.0 were compared and contrasted, the results of which can be viewd in [11]. While MechBass outperformed Swivel 1.0 in many early evaluations, the novelty and potential increase in simplicity in Swivel 1.0's design led the authors to pursue subsequent work on Swivel 1.0's configuration.

Microstepping on Swivel 1.0 allowed for high-precision fretting and good repeatability, further discussed in [11]. At high microstepping settings, however, fretting speed was considerably slower than at lower-resoluation settings. A revised PCB assembly was proposed, allowing for on-the-fly selectable microstepping settings. However, the actuator's bulk and expense, coupled with the relatively complicated driving circuitry present with Swivel 1.0's stepper motors, resulted in the desire to revise the actuation systems of Swivel 1.0, opting for lower-cost, lighter, and simpler-to-drive RC servo modules.

Additionally, a desire to build a system more "gig-friendly" and portable than the heavy and bulky MechBass further motivated the construction of the new lighter-weight Swivel 2, discussed and evaluated below.

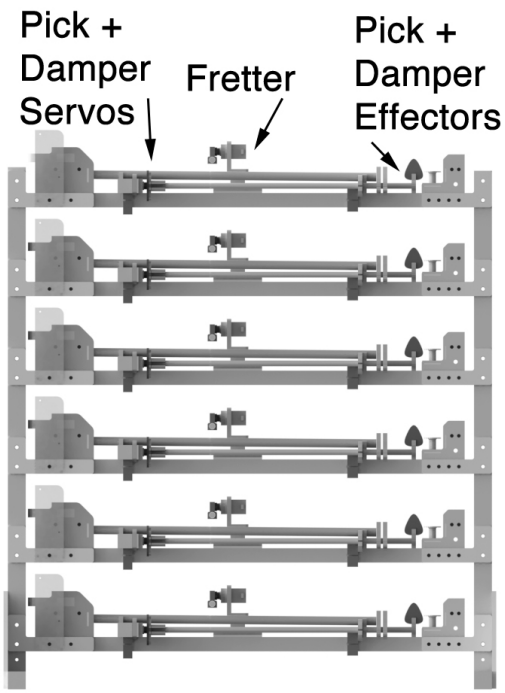


Fig. 6. A Front-View Rendering of Swivel 2

## III. Swivel 2

This section introduces Swivel 2, a new mechatronic slide guitar with six individual string modules, as shown in Figure 6. Swivel 2, unlike MechBass and Swivel 1.0, uses RC-style DC servos for all actuations. As stated in section II-B, the large stepper motors used in Swivel 1.0 and MechBass were judged to be too expensive, bulky, and heavy for Swivel 2, a system designed with portability and low cost as primary goals. After a brief discussion of the authors' motivations for building Swivel 2, a systems overview will be presented.

### A. Motivations

A key motivation in building Swivel 2 was to create a mechatronic instrument capable of high speed, accurate, and precise fretting action with the ability to perform portamento (pitch bend) effects. Such capabilities would afford composers the ability to create chords and melodic patterns difficult or impossible to accomplish with human-played guitars.

Swivel 2, conceived of as a guitar accompaniment to the lower-pitched MechBass, would provide the authors' percussion-centered Machine Orchestra [12] with melodic and harmonic content. Additionally, Swivel 2 was designed to further evaluate the fitness of rotary motion-based fretting techniques against the linear motion system used on MechBass.

### B. String Picking

String picking is simplified from Swivel 1.0: instead of a rotary pick wheel with numerous picks attached, Swivel 2 uses a single pick which performs Treciprocally: alternating

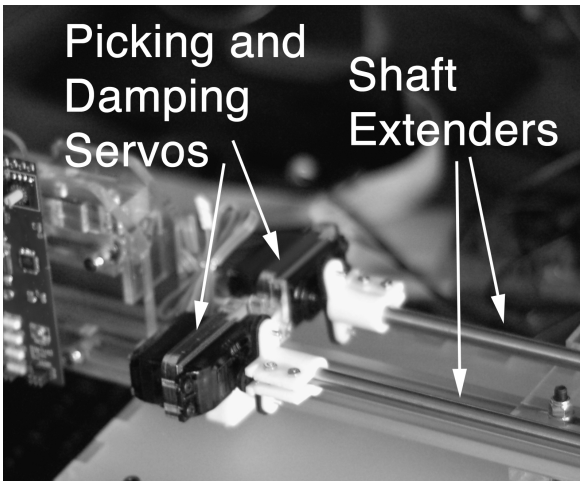


Fig. 7. Swivel 2's Picking and Damping Servos and Shaft Extenders

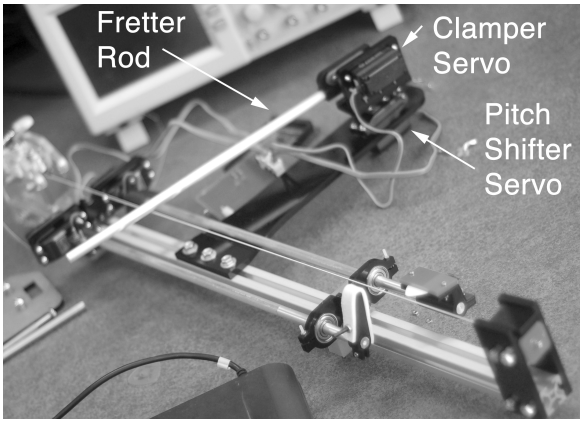


Fig. 8. Swivel 2's Fretting System

pick instructions send it back and forth across the string. The reasons for the simplified picking system are twofold: firstly, standard RC-type servos are incapable of full rotations, necessitating reciprocating action. Secondly, a single picking mechanism is lighter, less expensive, and less bulky than a custom-machined pick wheel as used in [13].

The string picking system consists of a single standard-sized RC servo whose driveshaft is connected to a bearing-supported shaft extender, shown in Figure 7. The use of the shaft extender allows for the picking servo to be mounted far from Swivel's magnetic pickup, out of electromagnetic interference range. Upon receiving an instruction to conduct a pick event, the picking servo rotates through an arc whose size varies depending on the guitar pick's thickness: thicker picks deform less upon contact with the string and therefore require a smaller arc than thinner picks. The pick servos' mounting compared to the pick position is illustrated in Figure 6.

### C. String Fretting

String fretting, the act of changing the string's vibratory length by positioning a movable fret at varying positions along the string, is accomplished on Swivel 2 through the use of two

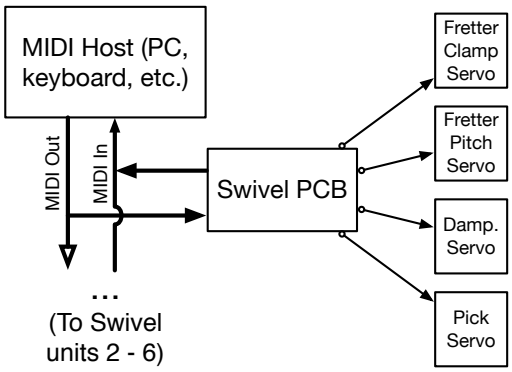


Fig. 9. Swivel 2's MIDI In/Out Bus and Actuator Connections

RC-type servos: a pitch shifter servo and a clamper servo, depicted in Figure 8. Attached to the pitch shifter servo is the fretter, an aluminium rod that functions similarly to a slide on a traditional slide guitar. The pitch shifter servo is attached perpendicularly to the fretter servo, which raises and lowers the fretter against the string. If forced against the string with sufficient pressure, the string will vibrate between the fretter and the bridge, resulting in a changed pitch.

### D. String Damping

String damping is accomplished similarly to string picking: a padded damper end effector is attached to an extender shaft which is in turn connected to a standard size RC-type servo. Figure 7 shows the damper servo, which, like the picker servo, is positioned as far as possible from the interference-sensitive magnetic pickup. Upon actuation, the damper moves against the string, deadening any string vibrations. Variable damper pressure can be applied, allowing composers to determine the rapidity with which string vibrations diminish.

## IV. Swivel 2 Electronics and Software

Swivel 2 is a modular mechatronic instrument: like MechBass, each string unit is discrete and can be used independently of the others. An individual unit is shown in Figure 10. The separate modules are on a serial communications bus, illustrated in Figure 9 using the MIDI protocol, a popular protocol for electronic musical instruments. The following subsections will discuss Swivel 2's electronics, string pickup, and MIDI signal interpretation.

### A. Swivel Board

The Swivel Board is a custom PCB assembly and is used in each of the Swivel 2 units. The Swivel Board contains a microcontroller, voltage regulation circuitry, and MIDI input and output. The microcontroller receives and interprets incoming MIDI messages, converting them to variable duty cycle waveforms as inputs to the servo actuators. Additionally, each board features a 16-position rotary switch, allowing for MIDI channel allocation without the need to reprogram the microcontroller's firmware (a problem encountered in the MechBass electronics).

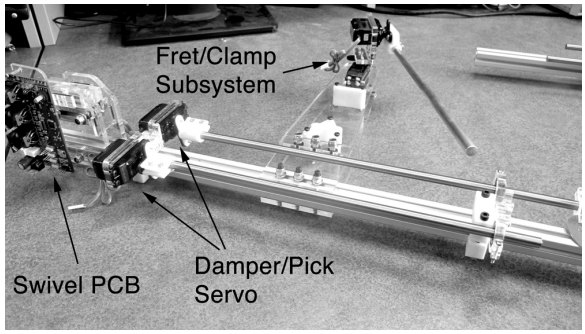


Fig. 10. One of Swivel 2's Modular String Units

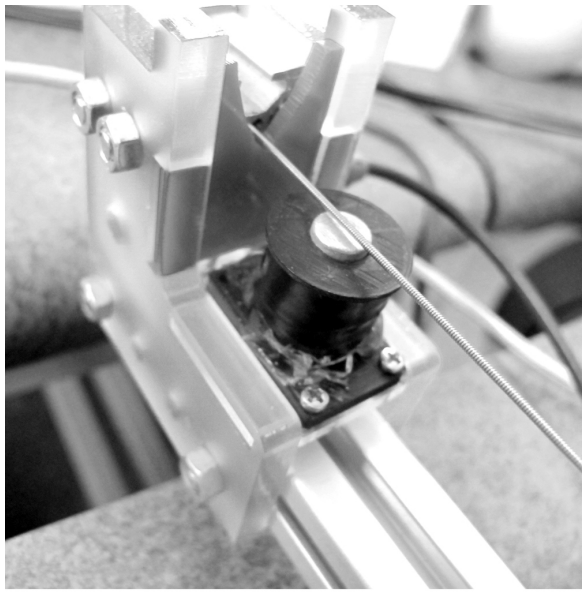

Fig. 11. Swivel 2's Magnetic Pickup

### B. String Pickup

Swivel 2 uses a traditional-style guitar pickup: a permanent magnet about which a coil of enameled wire is wrapped, shown in Figure 11. The pickup used on Swivel 2 differs from those used in [10] and [11]: while the optical pickups previously developed performed suitably, they require more precise positioning than does the magnetic pickup used on Swivel 2.

### C. MIDI Commands

Table I shows the MIDI commands processed by each of the Swivel 2 modules. MIDI messages are typically broadcast from a host PC running either consumer audio software such as Ableton Live or custom software, typically written in the ChucK audio programming language [14]. Each module is assigned a different channel. Upon receiving a MIDI message, the microcontroller evaluates whether it corresponds to its selected channel. If so, it determines the message type and behaves accordingly. Each of the RC servo actuators expects a variable duty cycle waveform, which is generated by the microcontroller and output to the servo's data input.

TABLE I
SWIVEL 2 ACTUATOR ACTIONS AND THEIR CORRESPONDING MIDI COMMANDS AND RANGES.

| Action | MIDI Message | Range |
|---|---|---|
| Fret (Shift Pitch) | Pitchbend | 790 positions |
| Clamp | Control Change 8 | 30 positions |
| Pick | Control Change 7 | 40 positions |
| Damp | Control Change 9 | 10 positions |

## V. EVALUATION

Swivel 2's performance was evaluated and compared with that of Swivel 1.0 and MechBass. Of particular interest was fretting performance, including fretting speed and fretter pitch consistency. The following subsections detail the evaluations and present evaluation conclusions.

### A. Fretting Speed

The ability for a mechatronic guitar instrument to rapidly change pitch in a repeatable fashion is paramount to the instrument's overall usability. The slow performance of Swivel 1.0 motivated the revisions present in Swivel 2. Fretting speed was measured by instructing a Swivel unit to play a single octave consisting of half of the string length. The time taken to move from a home position to a position one octave above that was timed and is reported below. Incoming audio was recorded to a PC and was analyzed in software with 1 ms resolution.

The average octave shift time of five pitch shift evaluations was 82 ms with a standard deviation of 1 ms.

In [10], the most rapid half-string octave shift on MechBass was found to be 360 ms. Swivel 2 is able to shift half the string length in 82 ms. This considerable speed increase is likely due to two main factors: the smaller size of Swivel 2 and the reduced angle through which Swivel 2's fretter servo needs to rotate to perform the pitch shift. Swivel 1.0, equipped with a microstepping stepper motor, has higher pitch resolution than Swivel 2. This will be addressed in future versions of Swivel with higher-resolution duty cycle generation as well as with a higher-resolution encoder-equipped fretter motor.

### B. Pitch Repeatability

To evaluate the pitch repeatability of Swivel 2, the fretter was sent from a random position to a given position. The string's frequency was then recorded and analyzed on an audio tuner with 1 Hz resolution. Five trials returned the same result: from each position, the fretter returned to the given position, with a frequency of 151 Hz. This repeatability is comparable to that of MechBass [10].

For applications requiring good pitch repeatability and high speed pitch shifting scenarios, the above evaluations show that the rotary action of Swivel 2 is an effective, lightweight, and low-cost solution.

## VI. Conclusion: Applications and Usage Scenarios

Swivel 2.0 was conceived of not only as a smaller, lighter, and cheaper counterpart to MechBass, but also as a musical mechatron capable of repeatable performance, affording composers a greater amount of expressive control than is typical to performance-oriented musical robots. The authors hope to use Swivel 2 in three main ways: as an onstage performance instrument (to join the array of instruments described in [12]), and as a sound sculpture, capable of performing long-duration musical compositions in a gallery setting, and as a demonstration tool for outreach to attract students to the engineering discipline.

As a research tool, Swivel's speed, modularity, and repeatability will allow for the deployment of robotic techniques novel to the subdiscipline of musical robotics. These techniques will be a major focus of the authors' future work on Swivel. In creating a new musical instrument endowed with parameters affording musical expressivity, a system capable of being meaningfully controlled with machine learning and artificial intelligence techniques has been built.

## Acknowledgment

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