SWIVEL: ANALYSIS AND SYSTEMS OVERVIEW OF A NEW ROBOTIC GUITAR

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ABSTRACT

This paper describes the design, construction, analysis, and performance use of Swivel, a new robotic slide guitar system. The guitar makes use of novel robotic actuation techniques and affords composers and performers a high degree of control over the robotic instrument's dynamics and pitch content. In addition to a focus on Swivel's design and construction, a history of robotic guitars is provided.

1. INTRODUCTION

It has been a trend in many recent musical robotic systems to use mechatronic techniques to allow the instruments to have a greater range of control over musical parameters such as pitch and dynamic content. While many existing systems use simple single solenoid actuators to control musical events, Gil Weinberg, Ajay Kapur, Eric Singer, and the Waseda research group [6, 11, 12, 14], among others, have in recent years built instruments that extend musical robotics into a new realm of more precise control.

The greater degree of control in recent musical robots allows composers and performers more chances to express their musical intent than has previously been afforded by simpler systems. The work presented in this paper extends this trend in greater degrees of musical expressivity to robotic slide guitars: Swivel, a new robotic slide guitar, was designed with the intention of providing each of its subsystems with greater degrees of expressivity than have been found in prior robotic guitars. This greater degree of expressivity has resulted in new compositions and performances that utilize the robot's precision.

Swivel is composed of four subsystems: the string plucking mechanism, the string damping mechanism, the optical pickup, and the string fretting mechanism. A microcontroller-driven board controls each subsystem. The board receives MIDI events and translates them into actuator control messages. Each swivel robot is modular and can therefore be chained together to form a multi-stringed robot.

After a short history of robotic guitars, this paper focuses on the design, construction, and analysis of Swivel's subsystems. Following an evaluation of the robot, the paper closes with a brief description of a new live performance featuring the robot. It is hoped that the information provided in this paper will allow future workers to build and explore the musical affordances offered by highly expressive musical robots.

2. ROBOTIC MUSIC: RELATED WORK

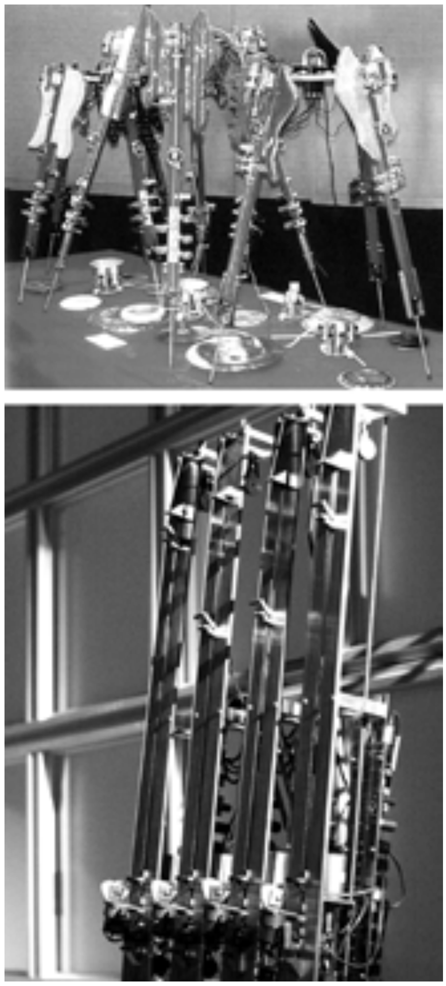

Figure 1. Trimpin's Krautkontrol (top) and Eric Singer's GuitarBot (bottom) [11].

Throughout the middle ages and Renaissance, inventers and musicians explored the design and use of automated musical instruments [4]. Often pneumatically or hydraulically actuated, these instruments typically featured musical events arranged on a pinned or punched barrel [3]. The Industrial Revolution saw automated music reach a technological and cultural peak, with advanced and precise instruments such as the Orchestrion and Pianola affording composers the ability to explore musical paradigms difficult or impossible to achieve with human players. The rise of acousmatic sound in the advent of the phonograph and, subsequently, the loudspeaker largely led to the demise of the increasingly complex automated instruments.

During the 1970's, artists created to the field of musical robotics by integrating the pre-loudspeaker automatic music techniques with contemporary electronics. These artists, including still-active workers Trimpin and Godfried-Willem Raes, found in musical robots a way to express computer music through media other than loudspeakers. This interest in utilizing computer music techniques with mechatronic apparatus is still active in contemporary musical roboticists who use state-of-the-art techniques to endow their machines with AI-driven musicianship [1].

While much musical robotic research focuses on percussive instruments such as drums and marimbas [5, 10], the past two decades have seen several notable robotic guitar systems. These instruments served as key inspirations to the new work described in this paper. William Baginsky's *The Three Sirens* ensemble uses a mechatronically-complex robot guitar, dubbed Aglaopheme, which plays music based on the output of an artificial neural network.

A second influential robotic guitar is GuitarBot, built by Singer in 2003. GuitarBot features four vertically mounted strings that remain in permanent contact with their sliding fretter. GuitarBot, shown in Figure 1, was most notably used in concert with guitarist Pat Metheny in 2010.

Groundbreaking sound sculptors Trimpin and Godfried-Willem Raes have also contributed to the subfield of robotic guitars: Trimpin's 2001 sculpture *Krautkontrol* features an array of solenoid-actuated guitars (shown in Figure 1) capable of floating bridge-mediated pitch bends [2]. The Logos Foundation, created by Godfried Willem Raes [7], built the Synchrochord monochord string instrument in 2012.

While existent robotic guitars have varying degrees of musical expressivity available to performers and composers, a goal in the design of Swivel was to create a system that affords artists high-resolution control over parameters such as pitch and loudness. The next section details the design, fabrication, and evaluation of these subassemblies.

3. SWIVEL: A SYSTEMS OVERVIEW

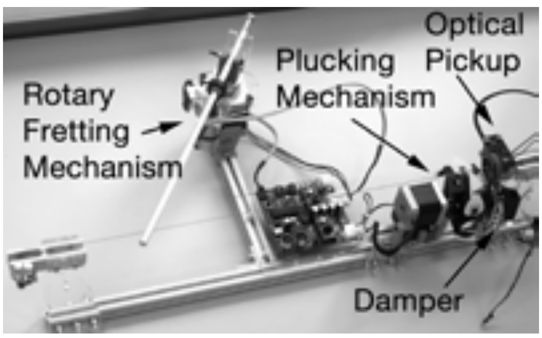

Figure 2. Swivel, with its sub-assemblies indicated.

The following subsections focus upon the design, implementation, and construction of Swivel's subassemblies. The mechanisms of action of each subassembly are discussed, and design and construction techniques are detailed.

3.1. Fretting Mechanism

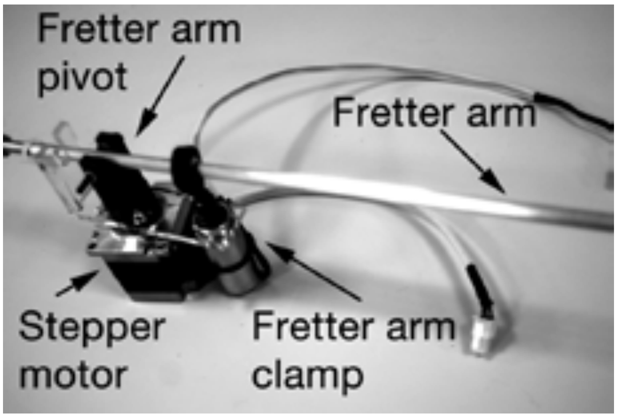

Figure 3. Swivel's fretting mechanism

Swivel's fretting assembly consists of a fretter arm, which is attached to a stepper motor via a pivot arm. The system is diagrammed in Figure 3. The stepper motor positions the fretter arm along the string; upon reaching the desired position, the solenoid-actuated fretter arm clamp brings the fretter arm into contact with the string. By eschewing traditional linear motion-based fretter systems in favor of a rotary mechanism, it was hoped that higher speed could be attained and simpler construction techniques be used. This rotary mechanism has been built using rapid prototyping techniques: 3D printing techniques were used to create the pivot arm.

3.2. Plucking Mechanism

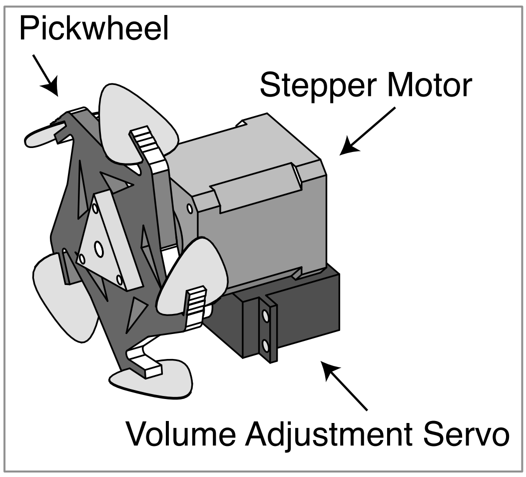

Figure 4. Swivel's plucking mechanism

A rotary plucking mechanism, diagrammed in Figure 4, is used for string actuation. Guitar picks are mounted radially around a laser cut acrylic clamp. The pick clamp is attached to the shaft of a stepper motor: upon actuation, the stepper motor rotates and brings the picks into contact with the string. To vary the power of the picking event, the stepper motor is attached to a servo-controlled cam. The cam raises and lowers the pick-wheel, allowing composers to choose the loudness of the picking event and provide audiences with a visual cue as the robot's loudness varies.

3.3. Damping Mechanism

A servo-based damping arm is employed to stop string vibrations; the damper functions by bringing a felt pad into contact with the string. Previous systems have used solenoid-based dampers with only two states: fully damped or undamped. Swivel employs a variable-position damper, allowing for different degrees of damping to be employed. The use of a variable damper instead of a simple bi-state damper allows composers and performers more control over the dynamic response of the robot.

3.4. Electronics, Pickup, and Communication

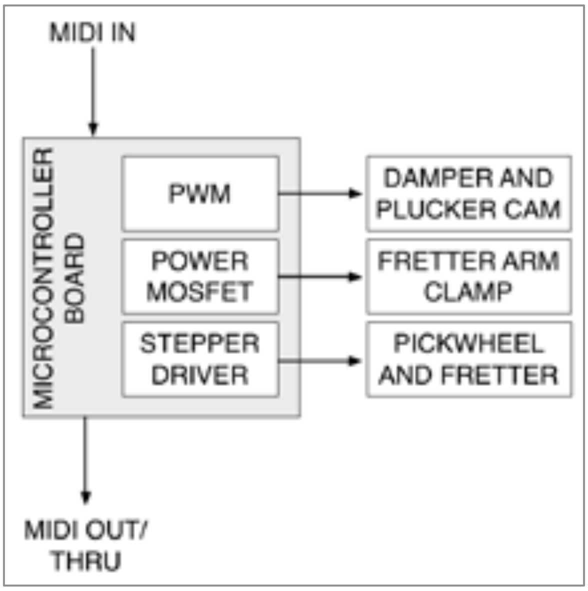

Figure 5. A block diagram of Swivel's control and communications electronics

Swivel communicates with a host PC via the MIDI protocol. Upon receipt of a MIDI message with noteOn information, Swivel's microcontroller converts the pitch information to instructions for the fretter stepper to step to a predefined point. Once the fretter is in position, the fretter clamp is actuated by a power MOSFET connected to a digital output pin on the board's microcontroller; concurrently, the plucker cam lifts the plucker stepper into a position corresponding to the MIDI event's velocity.

After the fretter is in contact with the string and the plucker raised to the predefined height, the plucker stepper actuates and brings a guitar pick into contact with the string. The string's vibrations are transmitted to the host computer and/or speakers by an optical pickup. Swivel's electronics are modular, allowing for multiple Swivel devices to be connected on a bus: each Swivel device could then be assigned a MIDI channel, allowing MIDI notes to be directed to each discrete string. Figure 5 shows a block diagram of Swivel's communications and actuator control electronics.

4. ANALYSIS AND EVALUATION

After the construction of Swivel, the fretter's performance was evaluated. The purpose of the evaluation was to determine the capabilities of each of the robot's components. An awareness of the system's inter-note speed, for example, will provide composers with knowledge of the musical limitations and abilities of Swivel. The subsequent subsections detail the evaluation of the fretting mechanism, a system unique to Swivel. See [13] and [9] for more detailed analysis of the damping and plucking mechanisms.

4.1. Analysing and Evaluating the Fretter

To find the resolution of Swivel's fretting mechanism, its step size at various microstepping resolutions was determined. Swivel uses a direct drive fretting mechanism: its stepper motor has a resolution of .9 degrees. The microcontroller board allows for multiple microstepping modes in addition to full stepping. Table 1 shows steps per revolution of the stepper motor at different microstepping settings.

Microstep Mode	Step Angle	Steps Per Revolution
Full Step	0.9 degree	400
1/2 Step	0.45 degree	800
1/4 Step	0.26 degree	1600
1/8 Step	0.11 degree	3200
1/16 Step	0.06 degree	6400

Table 1. Angles and steps per revolution for Swivel's microstepping modes.

To allow for accurate acceleration and deceleration with no slippage or missed steps, a stepper motor acceleration library is used on the microcontroller. The speed required to traverse the string is shown in Table 2.

Microstep Mode	Traverse Time	Steps Per String
Full Step	14.6 s	1050
1/2 Step	7.2 s	525
1/4 Step	3.7 s	263
1/8 Step	1.9 s	132
1/16 Step	1.0	66

Table 2. Time and number of steps required to traverse string at different microstepping settings.

From Tables 1 and 2, conclusions can be reached about Swivel's fretting capabilities: while full stepping allows for high-speed transitions between notes, its relatively low resolution results in low pitch accuracy. Increased degrees of microstepping result in slower note transition speeds but higher accuracy and the ability for increased microtonality between chromatic notes.

5. PERFORMANCE USE

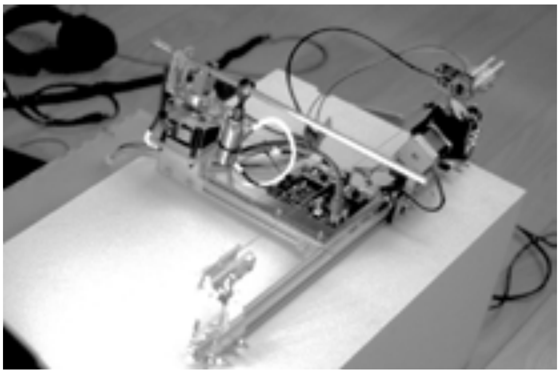

Figure 6. Swivel onstage during the performance of "Spatial String"

A musical composition was written to highlight Swivel's microstepping capabilities; the piece, called *Spatial String*, consisted of Swivel's output processed by digital audio effects and used as an input into a live diffusion performance system built by sonic artist Bridget Johnson. Using the fretting mechanism's high-precision 1/16 microstepping mode (which divides the string into 1050 steps), loops of microtonal content were played by the instrument and placed in space by the diffusion performance system.

The piece was performed at Wellington's Adam Art Gallery on October 25, 2012 to an audience which sat in close proximity to Swivel: the audience was clearly able to see the kinetic actions of the robot, shown in performance in Figure 7, and equate them with the diffusion system's sonic output. Swivel's first performance served as a testbed for the ease with which the robot could be used in a live context. It was found that the optical pickup system required extensive pre-performance calibration and will thus be simplified in future iterations of the system.

6. CONCLUSIONS AND FUTURE WORK

Swivel serves as a testbench for rotary motion string fretting, a novel technique previously unpublished. While Swivel's note transition times in microstepping mode are quite high, the speed with which notes can be fretted in full stepping mode highlights the promise of such fretting techniques. Future iterations of Swivel will use either selectable microstepping modes, which can be adjusted online, or a feedback-equipped DC servomechanism, allowing for closed-loop control and potentially higher fretting speeds. Qualitatively, it is felt that Swivel's highly kinetic modes of action provide audiences with a visually fulfilling experience wherein the robot's motions are quite pronounced. While the current generation of linear motion-based robotic guitars, such as [9], outperform Swivel in some aspects, the ease of assembly, low cost, and potential for future boosts in operating speed and precision warrant further work on rotary-motion slide guitars.

7. REFERENCES

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