An Analogue Interface for Musical Robots

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ABSTRACT

The majority of musical robotics performances, projects and installations utilise microcontroller hardware to digitally interface the robotic instruments with sequencer software and other musical controllers, often via a personal computer. While in many ways digital interfacing offers considerable power and flexibility, digital protocols, equipment and audio workstations often tend to suggest particular music-making work-flows and have resolution and timing limitations. This paper describes the creation of a hardware interface that allows direct communication between analogue synthesizer equipment and simple robotic musical instruments entirely in the analogue domain without the use of computers, microcontrollers or software of any kind. Several newly created musical robots of various designs are presented, together with a custom built hardware interface with circuitry that enables analogue synthesizers to interface with the robots without any digital intermediary. This enables novel methods of musical expression, creates new music-making workflows for composing and improvising with musical robots and takes advantage of the low latency and infinite resolution of analogue circuits.

Author Keywords

Analogue, Musical Robotics, Synthesizer, Interface, Servo, Solenoid, DC Motor, Stepper Motor, Control Voltage, Gate

ACM Classification

Categories and Subject Descriptors

H.5.2 [**Information Interfaces and Presentation**]: User Interfaces; J.5 [**Arts and Humanities**]: Performing Arts

1. INTRODUCTION

The field of musical robotics is concerned with creating music and sound-art using automated acoustic sound-objects, predominantly under computer control. Various digital protocols such as MIDI, OSC and custom solutions such as Tangle [6] are used to control these robotic instruments and interface them with electronic instruments and controllers. However, despite the variety of electronic musical instruments being produced with analogue control voltage (CV) interfacing options, there have so far been few solutions for utilizing the possibilities of these signals in conjunction with musical robotic devices directly. This paper describes the creation of a hardware interface that enables bi-directional communication between analogue synthesizer systems and several varieties of simple musical robot entirely in the analogue domain, enabling musicians and artists to take advantage of the benefits that CV-based systems offer, together with the acoustic sound and real-world visual feedback of musical robots.

First, brief backgrounds of musical robotics and analogue synthesizers are offered in order to place this research into context. The set of custom-built musical robots that are used with this system is then described, categorized by the devices' primary actuators. Following that, the hardware and functionality of the interface is detailed in sections. The paper will then conclude by presenting the results of experiments undertaken with the prototype, and outlining several improvements that are planned for the future.

2. BACKGROUND

Mechanical musical instruments have existed for over a millennium; one of the earliest recorded examples was the Banu Musa automatic water organ, which was described in the *Book of Ingenious Devices* in 850AD [11]. These types of devices did not become commonplace until the mass production of automated instruments such as orchestrions, player pianos and music boxes began in the late 19th century. [1] is a comprehensive reference of instruments created throughout this period.

The invention of the phonograph and the proliferation of loudspeaker technology in the early 20th century resulted in the popularity of automated musical instruments waning and production practically ceasing altogether. Despite this, composers such as Conlon Nancarrow continued to write music for automated instruments, utilising their ability to play music that would be difficult if not impossible for humans to perform. In the 1970s as transistors became more prevalent, a new breed of artists such as Trimpin and Godfried Willem Raes began to create new automated musical instruments, this time with precise computer control. In the 21st century, as microcontroller technology has become more affordable and easier to use, the field of musical robotics has grown significantly. [9] and [3] provide more detailed accounts of the history of musical robotics.

Analogue synthesizers have experienced a similar trajectory to that of musical automata, displaced by several decades. Though vacuum tube based synthesizers were produced earlier, the transistor ushered in an age of more affordable analogue synthesizers in the 1960s and 1970s created by pioneers such as Dave Smith, Robert Moog and Don Buchla. These instruments relied on various control voltage standards to communicate with each other. Advances in digital technology in the 1980s made new types of synthesis

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available while decreasing costs. Digital synthesizers such as the Yamaha DX7 did not require tuning, had the convenient ability to store and recall preset sounds and used the MIDI standard for communication. These capabilities, among other factors, made digital models very popular and the production of analogue synthesizers declined. In the 1990s, the shortcomings of many of the digital offerings were becoming understood, and a range of virtual analogue synthesizers (digital synthesizers that imitate analogue synthesizers) were brought to market. The 2000s and the 2010s have witnessed a resurgence in the popularity of analogue synthesizers and several companies such as Korg and Roland have delivered reissues of their analogue offerings as well as entirely new analogue products, complete with CV/Gate interfacing capabilities. Academic interest in analogue synthesis has also surged in recent years with projects such as Dahlstedt's Pencil Fields [2] and MIT's Patchwork project [7]. A detailed description of the advantages of CV/Gate is outside the scope of this paper; for more details, [14] is recommended reading on this subject.

Though the area of interfacing CV signals with sensors and actuators in the outside world is largely unexplored, the Sense, DC Motor, Servo and Solenoid modules produced by Bastl Instruments [1] are capable examples that seem to share the goals of the presented system.

Figure 1: The array of solenoid-based instruments used in this project. Top-left: Castanet, Top-right: Rotary solenoid-based striker, Mid-right: Linear solenoid-based striker, Bottom-left: Rattle Drums, Bottom-right: Egg Shakers.

3. THE ROBOTS

An ensemble of musical robots was created by the first author for the purposes of musical performances and installations. These robots utilise a variety of actuators, at several voltage levels and with differing methods of control. The categories of the robots are described below along with the control requirements of each variety.

3.1 Solenoid-based

The solenoid-based devices used are shown in Figure 1. The castanet and striking mechanisms perform optimally at 48 volts, and require short pulses of current to execute a strike, with springs returning the devices to their resting positions. This method of control resembles the *trigger* signals of analogue synthesizers. The construction and evaluation of several of these types of strikers is outlined in [4].

The instruments shown in the lower half of Figure 1 all use rotary solenoids and require separate on and off commands. This type of signal is analogous to synthesizer *gate* signals.

3.2 RC Servo-based

Many musical robots make use of servo motors to perform various operations. They may be used as strikers [13], fretters [10], or to apply friction as is the case for the robotic singing bowl shown on the left of Figure 2. Analogue servo motors require PWM control signals to operate, which are often generated by microcontrollers. In the interface presented however, a circuit based on the 555 timer IC is used to generate these pulses.

3.3 Stepper Motor

Robots such as the Mechbass robotic bass guitar [8] utilise stepper motors to achieve precise positioning of components of the instrument. In other cases, such as with the robotic ratchet shown on the right of Figure 2, less precise control can still produce interesting musical results. An A3967 IC built into the ratchet allows the motor to take individual steps with each pulse received.

Figure 2: Left: Robotic Singing-bowl, Right: Automated Ratchet.

3.4 DC Motor

Several artists such as Mo. H. Zareei have used DC motors in musical projects [15]. The speed of DC motors may be controlled by varying the voltage applied to them, or by simulating this by way of varying the width of pulses of current sent to the motors. This type of control can be compared with *CV* or *PWM* signals generated by synthesizers.

4. THE INTERFACE

In order to integrate these varying types of musical robot into an analogue synthesizer work-flow, the hardware interface pictured in Figure 3 was created. The top panel is divided into two sections, the red half for the high power connections to the musical robots, and the black half for

[1]http://www.bastl-instruments.com/modular/

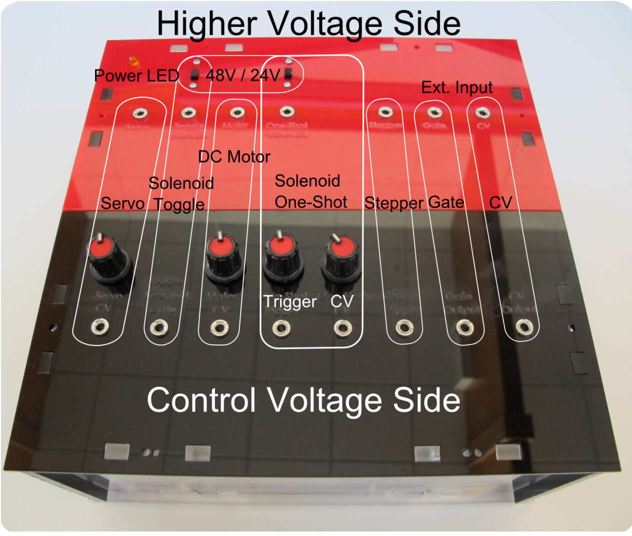

Figure 3: A prototype of the analogue synthesizer to musical robot interface.

interfacing with analogue hardware via CV/Gate signals. Red coloured patch cables are used for the high powered connections to aid in ensuring that they are never connected to synthesizer equipment, which would cause damage.

The functionality of the interface is also grouped vertically, with each socket of the low power section corresponding to the socket in the high power section directly opposite it. The details of each section of the interface will be described below, referring to Figure 3.

4.1 Servo Control

To control the position of a servo motor, a stream of pulses between 1 ms and 2 ms in length must be produced at a rate of approximately 50 Hz. Initially, a method which made use of the pulsewidth modulation capabilities of analogue oscillators was trialed, but was found to be ineffective due to the accuracy required of the pulsewidth and the fact that many analogue oscillators restrict the production of very thin pulses. Instead, a method which uses a 555 timer to generate the required pulses was chosen. When a CV is received, it is passed through the Servo CV potentiometer and the attenuated signal is subsequently used to modulate the width of the pulses produced by the 555 timer circuit. The 555 circuit outputs a PWM signal that is then sent together with ground and 5V connections via a TRS jack on the high power side of the unit to the servo to be controlled.

4.2 Solenoid Control

There are two types of solenoid control provided on the unit, toggle and one-shot. Toggle mode is useful for instruments that have separate on and off positions such as the rattle drums and egg shakers shown in Figure 1. The Toggle Solenoid Gate input on the interface is designed to receive a standard gate or other CV signal. Gate signals are passed through, and smoother signals are processed by a discrete transistor circuit to buffer and convert them into standard gate signals. This 2-state signal is then passed to the simple MOSFET circuit presented in [5] to control the solenoids.

One-shot mode is useful for instruments such as the castanet and striker units which require a short pulse of power to create a strike, and return to their resting positions by way of a spring. The One-Shot Trigger input on the interface is capable of receiving trigger, gate and CV signals and transforming them into short pulses to activate the instruments. It achieves this by using discrete transistors to buffer, invert and transform the incoming voltage into an inverted 5V gate, which acts as the trigger for a 555 timer running in a monostable configuration. The One Shot Trigger potentiometer sets the default pulsewidth of the 555 timer, which dictates the velocity of the resultant strike. A One-Shot CV input is also provided to modulate this velocity, and is attenuated by the One-Shot CV potentiometer. This can be thought of as emulating the functionality of the voltage controlled amplifiers (VCAs) of analogue synthesizers. The output of the monostable 555 timer is applied to a power MOSFET to control a solenoid in an identical way to the toggle circuit described above.

4.3 Motor Control

The speed of simple DC motors may be controlled by adjusting the voltage supplied to them, altering their musical results. The interface features a Motor CV input which is attenuated by the Motor CV potentiometer. Gate or CV signals are input and sent through an amplifier circuit which provides gain, buffers the signal and provides sufficient current to drive the motor.

4.4 Stepper Control

Though stepper motors are commonly controlled by microcontrollers, it is possible to control them via analogue means, and the process is simplified by utilizing an integrated circuit such as the A3967 Microstepping Driver. This device is able to utilise a gate signal to control the direction of rotation, and the rising edge of a trigger signal to advance the motor forward in individual steps.

The interface accepts a CV, gate or trigger signal at the Stepper Trigger input, and similar to the solenoid control circuits, buffers and quantizes the voltage into a gate signal before passing the output to the step input of the destination A3967. The robotic ratchet instrument shown on the right of Figure 2 works in only one direction and does not require a microstepping function, so these settings are hardwired inside the robot's enclosure. This allows a single TRS cable from the interface to provide the supply voltage and step control functions necessary to operate the robot.

4.5 Feedback from the Physical World

There are a number of projects which are based around connecting unconventional sources of voltages to analogue synthesizers in order to create interesting and expressive musical effects. These projects commonly utilize voltage outputs from light-dependent resistors (LDRs), infrared detectors and other sensors and in some cases these sensors are positioned to sense the motion of DC motors or other actuators such as in the Optical Tremolo described in [12]. This interface provides buffered CV and gate inputs for the purposes of safely connecting these types of devices to analogue synthesizers. This also enables the possibility of closed-loop feedback between musical robots and analogue synthesizers, an example configuration being a DC motor whose control signal is being modulated by the output of an LDR which is sensing the movement of that same motor.

4.6 Power Supply

Because this interface is designed to control several varieties of actuator, the power supply must also provide multiple levels of voltage to power the robots. The internal power supply is based around a multi-tapped transformer, bridge rectifiers and smoothing capacitors and provides unregulated power at 48V, 24V and 12V, and a regulated 5V supply. The 5V supply line provides power for the servo motor connection and acts as a reference for the gate circuits.

The 12V supply provides the power for the DC motor and stepper motor outputs. The solenoid outputs each feature a panel-mounted switch to utilize either the 48V or 24V power levels, depending on the requirements of the user.

5. LATENCY DISCUSSION

Though a musician may choose an analogue synthesizer to musical robot interface for subjective reasons such as making changes to their music-making work-flow, there also exist more tangible benefits to using such an interface. One difference is that while many digital systems use low resolution MIDI control parameters and some utilise higher resolutions, analogue systems such as this provide an effectively infinite resolution with which to make musical adjustments.

Another more objective benefit is the low latency operation of the interface compared with digital equivalents. [5] provides a method of evaluating the latency of musical robotic control systems by way of measuring the distance in time from when a control signal is sent and a signal is observed from a magnetic coil mounted in close proximity to the solenoid under control. In those tests utilising MIDI control, the average distance in time between a MIDI Note-On message being sent from a Digital Audio Workstation (DAW), being interpreted and forwarded via a microcontroller and the resulting signal being observed by the magnetic coil was 3.58 ms. This test was recreated by routing a square shaped output of an analogue low frequency oscillator (LFO) module to the One-Shot input of the interface, and having it control an Ushio rotary solenoid based striker, similar to the previous evaluations, with an electromagnetic pickup mounted in close-proximity. The output of the LFO and the electromagnetic coil were recorded concurrently at a sample rate of 44.1kHz in order to inspect the time difference in the signals. The result over 10 iterations was that the rising slope of the LFO corresponded with a rising slope of voltage in the electromagnetic coil on the same exact sample. This means that the latency was smaller than could be observed by this method of measurement, a significant improvement over the MIDI-based system.

6. FUTURE WORK

As the interface presented in this paper is the initial prototype, there are several areas planned for further development. One area is the issue surrounding using phono jacks for both the low and high power connections. Though this configuration provides convenience for advanced users, non-compatible sockets for the high power connections could provide a lower risk of incident for inexperienced users. While this has not been an issue thus far in practice, future improvements may also include PTC thermistors for overload protection or short-circuit detection circuitry. The possibility of providing CV controllable voltage sources for many of the outputs rather than set 48V and 24V is another area that is being investigated. Once a more widely applicable design is decided upon, creating an enclosure that is compatible with standard modular synthesizer systems such as Eurorack is also planned.

7. CONCLUSIONS

This paper has described the design and construction of a hardware interface that enables musicians to create music with musical robots in conjunction with hardware synthesizers entirely within the analogue realm. This extends the work-flow options and resolution and timing benefits of CV/gate control to the field of musical robotics and enables novel methods of musical performance, improvisation and composition. By outlining the functionality of each section of the unit, it is hoped that interested practitioners will be able to apply the described concepts in a combination relevant to their own musical requirements.

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