LEMUR's Musical Robots

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ABSTRACT

This paper describes new work and creations of LEMUR, a group of artists and technologists creating robotic musical instruments.

Keywords

Robotics, music, instruments, MIDI

INTRODUCTION

LEMUR, League of Electronic Musical Urban Robots, is a group of artists and technologists dedicated to producing robotic musical instruments. This paper describes LEMUR's motivations, instrument details, underlying technology and applications of the instruments.

MOTIVATIONS

LEMUR is motivated by a desire to create new ways to extend human musical capabilities. With our designs, we seek to augment the possibilities available to players and composers, not to replace human musicians. For example, robotic instruments can play in ways that humans can't or generally don't play. Some of these capabilities include speed, pitch and expression granularity, complex polyrhythms and extended duration playing.

In LEMUR designs, instrument musicality is of primary importance. We strive to create robots which *are* instruments, as opposed to robots which *play* existing instruments – that is, newly designed instruments which are robotically playable and controllable.

The instruments provide composers with an immediacy of feedback, similar to composing on synthesizers. However, as opposed to synthesizers, physical instruments resonate, project and interact with sound spaces in richer, more complex ways. Clearly, they have a more commanding physical presence as well.

THE INSTRUMENTS

LEMUR has created a diverse group of stringed and percussion robots, including GuitarBot, an electric slide-guitar-like instrument; TibetBot, which plays Tibetan singing bowls; !rBot (pronounced "chicker-bot"), which plays goat-hoof rattles; ForestBot, a shaker-based instrument; and ModBots, a series of modular percussion robots.

All instruments are controlled by custom developed MIDI hardware and software, based around PIC microcontrollers. Using MIDI, the instruments can be played individually or as an ensemble. They respond to MIDI commands in real-time and can be played live by humans from MIDI keyboards and other MIDI devices. They can also be played from computer via sequences or algorithmically generated improvisations. Use of standard MIDI commands allows the musician or composer to control the instrument using familiar tools with no additional computer or special software required.

GuitarBot

In designing GuitarBot, our goal was to create an electrified slide guitar that was versatile, responsive, capable of fast and slow playing, easy to control, with high-quality sound, modular and portable.

GuitarBot consists of four independent single-stringed slide guitar units. A PIC microcontroller on each unit receives MIDI commands and controls operation of the electromechanical components.

Each slide is controlled by a DC servo motor driving a pulley and belt that moves a sliding bridge. Positional feedback is accomplished by a potentiometer on the idler pulley. A proportional-integral-derivative (PID) algorithm running in firmware is responsible for servo positioning.

The pick mechanism consists of four guitar picks mounted on a block that rotates on a shaft. The shaft is also belt and pulley driven by a DC servo motor. Pick position feedback is accomplished using a photosensor reading dark and light patterns on a wheel at the end of the shaft.

A "clapper" solenoid is used as a damper which closes on the string and stops vibration when activated.

The units are independently tunable and have a 2-octave range with microtunable pitch resolution. The bridge can move from one end of the range to the other in under 1/4 second. Each unit also has a custom designed electromagnetic pickup.

The second model of GuitarBot, which is currently being designed, will feature an interchangeable picking system, allowing for different actuation systems that can easily be swapped in and out. Planned mechanisms include bouncing, bow-like action, rubber and glass wheels and electromagnetic excitation

GuitarBot is described in more detail in the paper *LEMUR GuitarBot: MIDI Robotic String Instrument*.

TibetBot

TibetBot is designed around three Tibetan singing bowls, with six robotic arms which strike the bowls to elicit a variety of tones. It is capable of creating both atonal rhythms as well as tonal droning soundscapes.

The singing bowl is a traditional instrument of the Mahayana and Tantric sects of Buddhism centered in Tibet. Each bowl produces two prominent tones – a high pitched ring and a low pitched drone – as well as numerous harmonic tones. Traditionally, bowls are constructed from seven different metals formed into a distinctive dome shape. The combination and density of these metals is what produces the distinct tonal quality of the instrument.

The singing bowl is normally a hand-held instrument, with a wooden mallet used to produce a ringing drone combining the high, low and harmonic tones depending of the area of the bowl struck.

For robotic implementation, we created six aluminum arms (two per bowl). One arm per bowl is raw aluminum bar, producing a high pitch tone when striking the bowl; the other arm has a soft rubber end, producing a low tone. The arms are controlled by solenoids, triggered by MIDI note commands.

A future design will augment the instrument with resonating tubes. A tube will be located over each bowl and may be moved closer or further from the bowl using robotic controls, shaping and filtering the sound of the bowl.

!rBot

!rBot is a mollusk-like structure made of leather, aluminum and steel. A mechanical system of cams and levers powered by two motors opens and closes !rBot's shell. As the shell opens, a platform holding a shaking percussive rattle protrudes from the robot's interior, receding again as the shell closes.

!rBot fuses traditional musical instruments with mechanical design. Inspired by the human mouth, the goal of !rBot was to develop a percussive instrument in which the release of sound could be shaped and modified by a malleable cavity. As the cavity opens and closes, it effectively acts like an analog filter, shaping the sound of the enclosed percussive instrument.

!rBot is an experiment in forms of mechanical motion and their relation to sound. The rhythmic drone produced by a set of Peruvian goat hoof maracas is dependent on movement of mechanical gears and oscillating cam systems. The sound achieved references both a history of human percussive instruments and the mechanized motion present in industrial machinery.

!rBot is designed to be modular. Its interior rattle can be replaced by other percussive instruments including bells, chimes, shakers or other types of maracas.

ForestBot

ForestBot consists of a collection of stalks which arc up from bases on the ground. Each stalk has an egg-shaped rattle mounted at the free end and a small aluminum armature affixed near the base. The armature supports a motor with an asymmetrical counterweight which, when spun by the motor, vibrates the entire stalk and thus causes the rattle to shake.

The stalks are in clusters, with 5 sharing a single base. The robot's five bases can be arranged such that a person interacting with it is entirely surrounded by the stalks, with the rattles dispersed in the air just above head level.

The rods are made of fiberglass, 10 feet long by 1/4” inch in diameter. A variety of dimensions and materials were auditioned in order to find one that would create a system with a slow and gentle fundamental movement when the rattles were attached. The rattles themselves are *Rhythm Tech Eggz* brand plastic egg shakers, epoxied to suction cups that allow them easily to be mounted to and removed from the rods.

Each armature consists of a custom-formed piece of aluminum approximately seven inches long that provides a mechanism for attaching to the rod; a simple mounting for the small DC motor; and a Delrin counterweight. After some experimentation with various counterweight shapes, we settled on a design in the form of a thickened checkmark.

A long rod, fixed at one end and free at the other, is a musical system analogous to the tine of a mbira, or thumb piano. It has a fundamental vibration frequency determined by the length and rigidity of the pole and the weight of the egg rattle at the end. In our system the fundamental frequency of the stalks is extremely low, expressing itself as a very slow waving back and forth at about .5Hz.

Like a musical string, the rod also vibrates at harmonics of its fundamental frequency. It is these harmonics that are excited when the counterweight near the base of the stalk is activated. Differing masses of counterweights and positions on the stalk yield different harmonic excitations. Furthermore, the system exhibits resonance and damping of vibrations at different motor speeds.

Although at present the rattles are all nearly identical, a variety of textures and responses are attainable by varying the motor speed, counterweight mass and armature position.

The original bases of ForestBot – fixed, non-articulating platforms – are currently being modified to allow for articulating X-Y angle control. The new bases enable us to control their angle to “play” the fundamental frequency of the rods, causing them to swing from side to side and front to back. This gives us the ability to choreograph both the sound and the motion of the robot and yields a compelling immersive experience.

ModBots

ModBots are miniature, modular instruments designed to affix to virtually any structure, thereby allow the composer musical control of anything from a battery of specially designed instruments to structural surfaces within pre-existing architectural space. With an emphasis on simplicity, each ModBot design usually consists of only one electromechanical actuator (a rotary motor or linear solenoid) which responds to varying degrees of supply voltage regulated by a microcontroller. This single-actuator design philosophy demands that all mechanical movement within the instrument be subordinated to the physical capabilities of the lone motor or solenoid employed. While this may sound like a limitation, such use of mechanical design (as opposed to more “intelligent” electronic design) brings a reliability, mechanical consistency and modularity that would otherwise not be possible.

Each device can be fitted with a variety of mounting harnesses and is connected to the brain (box containing the microcontroller, control circuitry and power supply) via a single run of cable. Thus, the microcontroller administers the appropriate voltage to hit, shake, scrape, bow, spin or pluck sound from any sonorous object with the precision one would expect from digital control.

HammerBots (the ModBot beater device) for example, can be fitted with any striking device to play loud or soft with a speed and consistency unavailable to human percussionists.

SpinnerBots apply friction to a circumference in much the same way rubbing one's finger on the rim of a wine glass causes the glass to 'sing'. Though usually fitted with round telephone bells, SpinnerBots can also make metal tubing "sing" with a rotary bowing action.

RecoBots use a high-performance servo to scrape back an forth along an attached surface with precise control over the position and speed of the scraper. Most commonly, RecoBots scrape the sides of springs lightly stretched over a resonator.

SistrumBots use a solenoids to pull a set of jingles back and forth and allow precise control of tambourine-like shaking sounds.

VibroBots consist of eccentrically loaded motors which, when activated, shake at frequencies too fast to be rhythmic and too slow to be a pitch.

A general bowing device, the BowBot is a bow-wheel lowered to a surface by means of a centrifugal clutch which engages when the motor is driven. BowBots can be used to bow strings, sheets of metal or nearly anything that responds to constant friction.

PluckBots agitate a surface in the same way that a bassist plays pizzicato. PluckBots are used to play steel tongues, wires and strings.

Because of their small size, versatile mounting capability and minimal cabling required for installation, ModBots can be configured in limitless arrangements. In addition to use in custom instrument designs, ModBots have brought MIDI capability to such places as museum stairwells, steel hulled ships and the sculptural work of other artists.

APPLICATIONS

LEMUR robots have been featured in a wide variety of applications, including automated and interactive musical installations and in performance of live, generated and sequenced musical works. They have performed as solo instruments and in combinations as a robotic ensemble, as well as interactively in conjunction with human musicians. As tools in the hands of composers, players and interaction designers, they provide compelling new means of musical expression.

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More information on LEMUR is available at http://lemurbots.org.

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Figure 1: GuitarBot

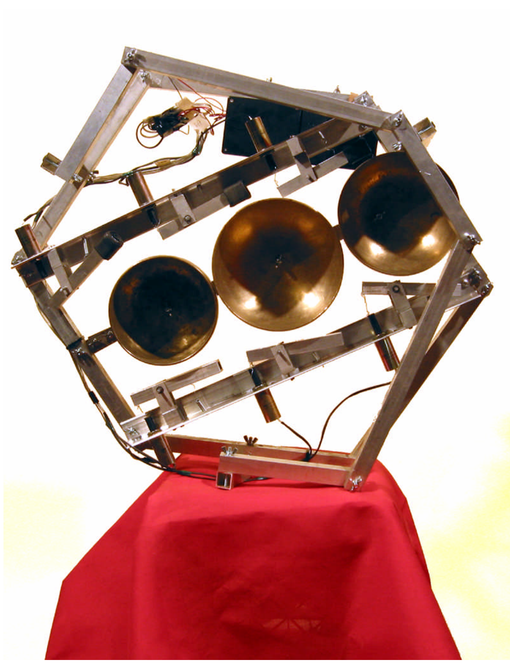

Figure 2: TibetBot

Figure 3: !rBot

Figure 4: Observers viewing ForestBot

Figure 5: Several ModBots in installation