El-Lamellophone - An Open Framework for Low-cost, DIY, Autonomous Lemellophone Based Hyperinstruments

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ABSTRACT

The El-Lamellophone (El-La) is a Lamellophone hyperinstrument incorporating electronic sensors and integrated DSP. An embedded Linux micro-computer supplants the laptop. A piezo-electric pickup is mounted to the underside of the body of the instrument for direct audio acquisition providing a robust signal with little interference. The signal is used for electric sound-reinforcement, creative signal processing and audio analysis developed in Puredata (Pd). This signal inputs and outputs the micro-computer via stereo 1/8th inch phono jacks. Sensors provide gesture recognition affording the performer a broader, more dynamic range of ”musical human-computer interaction” (MHCI) over specific DSP functions. The instrument’s metal tines (conventionally used for plucking- traditional lamellophone sound production method) tines have been adapted to include capacitive touch in order to control a synthesizer. Initial investigations have been made into digitally-controlled electromagnetic actuation of the acoustic tines, aiming to allow performer control and sensation via both traditional Lamellophone techniques, as well as extended playing techniques that incorporate shared human/computer control of the resulting sound. The goal is to achieve this without compromising the traditional sound production methods of the acoustic instrument while leveraging inherent performance gestures with embedded continuous controller values essential to MHCI. The result is an intuitive, performer designed, hybrid electro-acoustic instrument, idiomatic computer interface, and robotic acoustic instrument in one framework.

Keywords

NIME, proceedings, LaTeX, template

1. INTRODUCTION

Lamellophones have a series of tines that are fixed at one end and free on the other. The musical tone is produced by depressing and releasing the free end with the thumb allowing the tine to freely vibrate. They are ideal instruments for augmentation being handheld, compact and ergonomic. The instruments design facilitates uninterrupted traditional playing while allowing the performer to engage various specific sensors with broad or minute arm/hand gestures or explicitly with the free fingers. The unused surface area of the body is ideal for intuitive sensor placement, while direct audio acquisition is simple and robust via a piezo transducer. Lamellophones are typically sheerly acoustic folk instruments, however, augmentations, such as ours, equip the instrument for contemporary settings where audio processing and sound reinforcement are commonplace as well as offering experimental, novel sound design and interactive multi-media performance practice capabilities.

Figure 1: El-la: Tines are capacitive touch sensors

Previous work in lamellophone hyperinstruments can be reviewed in [9]. Our design is meant to be adaptable, easily replicable [5], and open-source so that any lamellophone performer could render their own version with little engineering background. El-La utilizes relatively easily sourced, low-cost components drawing from Konono No. $1'$s [3] spirit of using salvaged electronic components to develop new electro-acoustic instruments, analog signal processing and amplification systems for their neo-traditional lamellophone based music.

The instrument in its native state is made from wood which is hand carved with an effigy at the top for ornamentation. The tines are mounted to the body in the conventional method with a bridge. Additionally, small metal rings have been added to the tines to create a desired sustaining buzz when the tines are plucked. This is typical of many

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traditional African instruments [4]- which is interesting that it is a type of acoustic distortion filter. The body has been carved out on the inside creating a resonant chamber. The instrument is tuned to a single diatonic scale. Since the instrument is non-western, and therefore doesn't conform to the tempered chromatic scale, the suggestion of the octave is only relative to each preceding note when ascending the scale. Meaning, the instrument is tuned by ear and not by mathematically uniformed spaced intervals. The exact frequencies of each tine can be reviewed in[9].

2. HARDWARE : SENSOR INTERFACE

El-La incorporates a capacitive touch sensor controller, a three-axis gyroscope, a force sensitive resistor (FSR), 6 switches, 2 rotary Potentiometers, a membrane slider potentiometer, an xy axis joystick, and LEDs for visual feedback. To facilitate easy sensor acquisition, all sensors interface with an Arduino Nano. The capacitive touch sensor controller interfaces with the Arduino using an I2C interface, while the IMU outputs all sensors processed by its onboard ATmega328 via a serial stream (UART). All other sensors (buttons, pots, joystick, and FSR) interface by way of the Arduino Nanos analog and digital inputs. The Nano plugs directly into and is powered by the Beaglebone and communicates via USB. The whole system is modular, easily removable and packs into a case for transport.

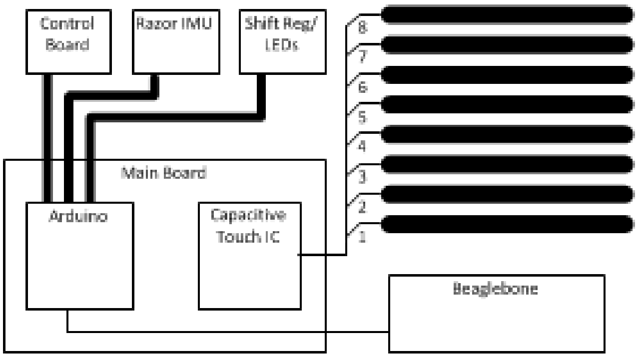

Figure 2: flow chart of modularity of componants

2.1 Piezo

A contact microphone, mounted on the body of the El-Lamellophone, is connected straight to the 1/8" audio jack of the Beaglebone board to acquire the audio signal. The signal is then processed in Pure Data.

2.2 Arduino and Sensors - HCI

The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.0) and works with a Mini-B USB cable [1].

2.2.1 *Switches, Pots, FSR, Joystick, Membrane*

The HCI components of the El-Lamellophone are strategically located so that they don't interfere with the performer's playability of the instrument in the conventional sense [8]. Six Pushbuttons and two (47k - the value chosen was arbitrary) rotary potentiometers are mounted on the upper back panel- accessed by the left and right index finger respectively. One Force Sensing Resistor (FSR) is located on the lower right front panel, below the tines, easily reachable by the right middle finger. The value of $2k\Omega$ was chosen for the resistor in series with the Force Sensitive Resistor (FSR) by connecting the FSR circuit to the gain CV of an analog synthesizer while viewing the output voltage on an oscilloscope. This value gave the best compromise between music expressiveness and full-scale reading on the oscilloscope. Also mounted on the back panel is one XY resistive analog joystick accessible by the left middle finger. On the side panel one SoftPot resistive membrane is mounted. The pushbuttons connect to the digital pins of the Arduino board, while the rest of the components connect to the analog pins.

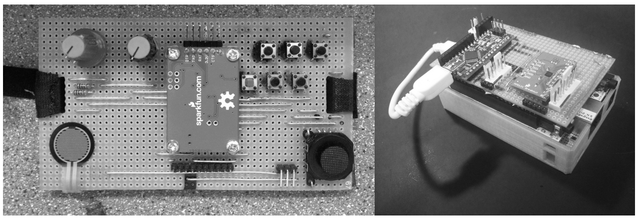

Figure 3: sensor interface (l) and Beaglebone (r)

2.2.2 *Capacitive Touch*

For this implementation we use 20 AWG wire soldered to the eight (8) tines on the El-Lamellaphone as electrodes. Each wire was then connected to the MPR121 Capacitive Touch Sensor Controller[2] from Freescale. This package is capable of controlling twelve (12) electrodes and interfaces via I^2C protocol. It also includes a three-level filtering process to eliminate any noise-induced detection. The maximum response time is 32 μsec and its output byte contains touch/release status for all tines. An advantage of this package is that it allows simultaneous touch detection of the eight tines- which in this case is used for polyphony.

2.2.3 *9DOF*

For the gyroscope implementation we use an InvenSense ITG-3200 three-axis (X (roll), Y (pitch) and Z (yaw)) gyroscope with I^2C interface. This small package ($4 \times 4 \times 0.9$ mm) digitally ouputs rotational data from any of the three sensed axes at a rate of 20 msec. In the current implementation the gyroscope is built into a 9DOF Razor Inertial Measurement Unit (IMU)[3] via I^2C protocol. The IMU's firmware scales the 16-bit output range of the gyroscope into a $[-180.00, 180.00]$ range for each axis and then transmits the rotational data to the host Arduino board via the serial ports **Tx** and **Rx**, at a baudrate of *56700 bps.* Figure 4 shows the direction of rotation of each of the sensing axes, in reference to the El Lamellophone. In the future we will use a cheaper platform for prototyping. This model was readily available at no cost so we chose to use it at the time. Lamellophone based gesture sensing using an IMU builds on previous work that was sketched using a Wiimote [9].

2.3 LEDs

A 10-segment LED bar graph is used to provide state and sensor feedback to the EL-lamellophone user. To economize the wiring footprint and then number of Arduino pins needed, two 8-bit Shift Registers are used to control the LED bar graph.

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[1] `http://arduino.cc/en/Main/ArduinoBoardNano`

[2] `http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=MPR121`

[3] `https://www.sparkfun.com/products/10736`

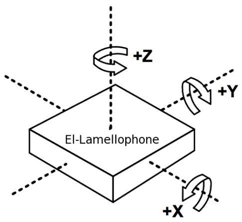

Figure 4: Axes of rotation of 9DOF

2.4 Firmware

The Arduino firmware is simple: each loop an output vector of floating point numbers is populated with the measurement from each sensor, and then sent to Pure Data using a serial connection. First, all analog sensors are read and stored in the first section of the vector. The Capacitive Touch Sensors states are stored in the next portion of the output vector. Finally the IMUs serial stream is parsed and stored at the end of the output vector. The output vector is now fully populated and ready to be transmitted to Pure Data. From the Arduinos perspective, transmission of the output vector to Pure Data is accomplished by writing the entire vector to the serial port one value at a time, with a newline character signifying the end of the vector.

3. HOST COMPUTER AND SOFTWARE

3.1 Beaglebone

Significant previous work has been done by the authors using this autonomous music computing platform featuring the Beaglebone. Technical specs (including the performance of the DSP latency) can be seen in [6], which was a previous autonomous hyperinstrument platform developed by the authors for the electric guitar.

3.2 Puredata

The DSP environment is built in Puredata (Pd). We chose Pd because it is free, widely supported, flexible, and robust. Serial data is received from the Arduino and then scaled and mapped to control specific effect parameters (delay length, feedback level, filter frequency, etc.). This simple prototyping system is robust but offers a lot of flexibility and potential. The sensor data can also provide an intuitive control interface for synthesis applications including controlling oscillator frequency, filter frequency/bandwidth, MIDI control/note attributes, and envelope values (attack, decay, sustain, release). This application allows El-la to be used as a versatile synthesizer controller while the lamellophone can still be played as usual all housed in one unit.

3.2.1 comport and sensor data parsing

All of the sensor data is transmitted to Puredata by way of a serial connection with the Arduino. The comport object provides a serial port interface within Puredata, making all sensor measurements available. The incoming ascii bytes are then converted to numerical values.

3.2.2 Audio Analysis for Control Data

Audio analysis of the input signal is accomplished to provide an amplitude envelope tracking system. RMS energy is thresholded to a usable range, and energy levels are displayed as they occur. This provides a simple means for visualizing the rise and fall of the total signal energy, and any further thresholding control can be added as needed. This data can be used to create dynamic, audio responsive control data for other devices.

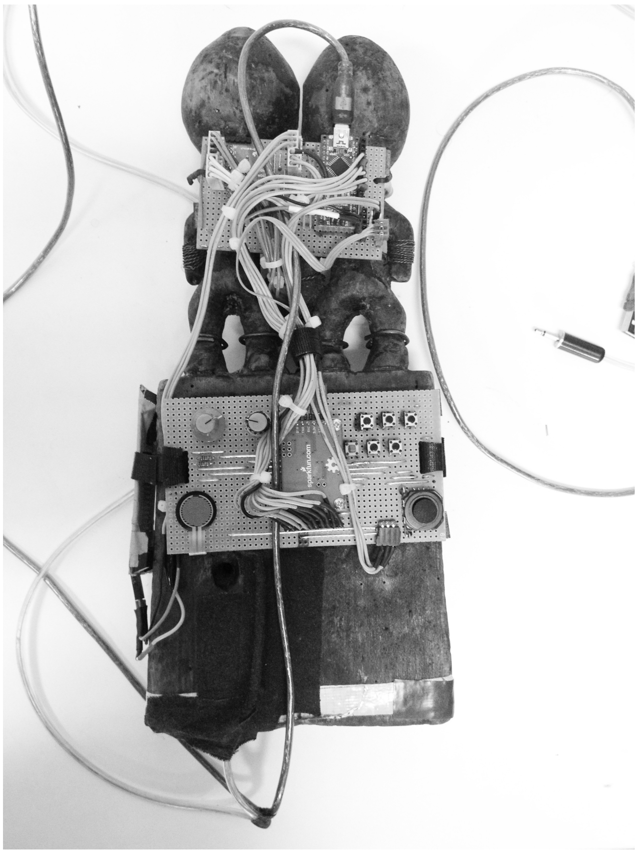

Figure 5: complete mounted system (velcro straps)

4. ACTUATION

A system for actuating the tines of the instrument electromagnetically has been developed, but not yet integrated into the existing instrument. This work is primarily based on prior art by Berdahl [1], McPherson [7], and Britt [2]. Mcphersons Techniques and Circuits for Electromagnetic Actuation outlines the possible methods that can be employed for this purpose, and our design derives from the "Force on a Ferromagnetic Object" section of the paper.

Britt [5] suggest that the complexity of the circuits used to drive both McPhersons and Berdahls electromagnetically enhanced pianos can be reduced when the system is driving an object without significant harmonic overtones. This is possible because a simpler amplifier that lacks a linear response can be used, a square wave input will produce a sine wave output on the physical vibrating body - the harmonic overtones of the input signal are ignored by the vibrating body. However, in that paper about electromagnetic actuation of a vibraphone, the large mass of the vibraphone bar necessitates a powerful amplifier. Luckily, the use of a polarized magnet affixed to the vibraphone allows for both positive and negative actuation of the bars, both attracting and repelling the bar. A +24V and -24V amplifier was used for that system, and a 3-state waveform that had a positive portion, a dead zone at GND, and a negative portion was used to avoid shoot-through on the power supply.

In addition to sharing the same inharmonic overtone property as vibraphone bars, the lamellophone tines have added advantages from their low mass and natural ferromagnetic properties, which allow for even greater simplification of this amplifier. The current amplifier design for EL-La uses a single-ended 12V supply driving a single MOSFET transistor with a freewheeling diode in parallel. This configura-

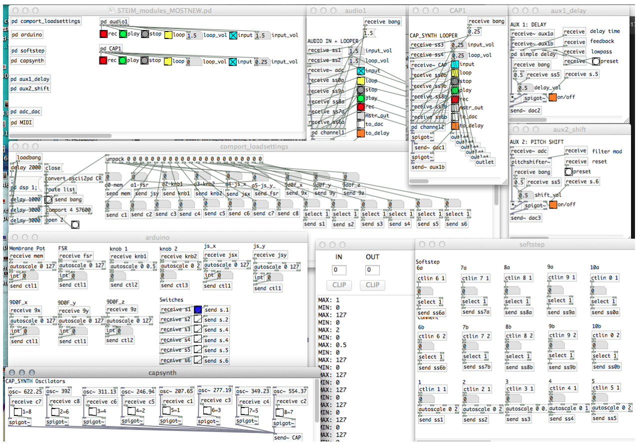

Figure 6: pd patch

tion is effective at driving the tines with a usable amplitude, is very low cost, and requires minimal heat-sinking. The most expensive element of the system is the electromagnets (footnote = part # ELMATU021020 from SolenoidCity.com, 28AWG), which cost $20 a piece in the quantities purchased for the project. The single-ended nature of the amplifier system also eliminates the need for the 3-state waveform required by the vibraphone bar, so a much simpler PWM output directly from a microcontroller pin can serve as the driving frequency for EL-La. Polyphony handling for the current system is an adaptation of the system used by the EM-Vibe, described in [2]. Generation of the multiple PWM waveforms is handled by a series of inexpensive microcontrollers communicating over I2C, a significant advantage in cost over the 8-channel audio interfaces used in the previous systems mentioned.

Some aspects of the current actuation system prevent easy integration into EL-La without compromising the performers ability to play the instrument normally. While the amplifier requires little-to-no heat-sinking, and the driver electronics are relatively compact, the magnets themselves are somewhat bulky, and require significant heat-sinking to avoid overheating. Ideally, the magnets would be positioned directly over the lamellophone tine, near the plucked end, but this configuration prevents normal playing technique. The actuation of the magnets also tends to cause the pitch of the tines to lower slightly, for reasons that havent yet been sufficiently explored by the authors. For these reasons, the current actuation system is a separate module from the rest of the EL-La, able to be actuated by the BeagleBone, but not part of the same lamellophone system held by the performer. In this case we can employ the various sensors, such as the capacitive touch interface via the tines on the performer′s instrument to control the actuation of the tines on the electro-magnetic lamellophone, for instance. Further, the signal from the actuated instrument can be acquired in the same format, using a piezo, amplified, and processed autonomously via its own Beaglebone audio processing system. The two Beaglebones can be networked and synced via ethernet or over a wireless connection using OSC.

5. CONCLUSIONS AND FUTURE WORK

The El-la framework has been tested and deployed in performance steadily over the past year. It has also been used extensively on an album exclusively featuring the instrument recorded at STEIM in Amsterdam during an Artist Residency surrounding El-la. The instrument proves to be stable, robust, and remains inspiring to the artist. Future work includes designing a PCB and proper housing for the interface and microcontroller that can easily mount onto the instrument, while remaining easily removable. A custom Lamellophone design needs to be explored to ascertain whether or not a proprietary version with embedded interface and controller would be more intuitive. A user study is planned to gain valuable feedback about the instrument's augmentations. Solar cells for power could potentially make the instrument truly autonomous and ready for deployment in the field where collaboration with traditional instrumentalists could be established, merging the innovation with a staple practice in order to forge new musical territory grounded in intrinsically socially binding and culturally meaningful music.

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