The JoyStyx: A Quartet of Embedded Acoustic Instruments

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ABSTRACT

The JoyStyx Quartet is a series of four embedded acoustic instruments. Each of these instruments is a five-voice granular synthesizer which processes a different sound source to give each a unique timbre and range. The performer interacts with these voices individually with five joysticks positioned to lay under the performer's fingertips.

The JoyStyx uses a custom-designed printed circuit board. This board provides the joystick layout and connects them to an Arduino Micro, which serializes the ten analog X/Y position values and the five digital button presses. This data controls the granular and spatial parameters of a Pure Data patch running on a Raspberry Pi 2.

The nature of the JoyStyx construction causes the frequency response to be coloured by the materials and their geometry, leading to a unique timbre. This endows the instrument with a more "analog" or "natural" sound, despite relying on computer-based algorithms. In concert, the quartet performance with the JoyStyx may potentially be the first performance ever with a quartet of Embedded Acoustic Instruments.

Author Keywords

Embedded acoustic instrument, raspberry pi, acoustic resonance, pcb design, granular, timbre, Satellite CCRMA

ACM Classification

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing, C.3 [Special-Purpose and Application-based Systems] Real-time and embedded systems, and H.5.2 [Information Interfaces and Presentation] User Interfaces

1. INTRODUCTION

The JoyStyx is an embedded acoustic instrument. These instruments are designed to allow custom hardware interfaces to be connected to software instruments running on embedded Linux boards [11]. The sounds generated are then amplified and sent to speaker drivers connected to a digitally fabricated body. This houses the instrument's electronics and provides for a unique sound-filtering and radiation pattern, depending on the particulars of the materials and geometry. Figure 1 illustrates this concept [1].

NIME'17, May 15-19, 2017, Aalborg University Copenhagen, Denmark.

Related prior work includes the D-Box (a hackable embedded acoustic instrument) [11] as well as earlier works such as Tristan Perich's 1-Bit Symphony (in some sense an embedded instrument) [6] and instruments that Jeff Snyder made for his DMA project [9].

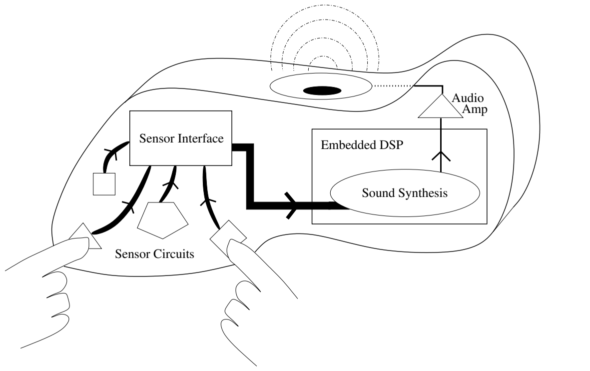

Figure 1: The concept of an embedded acoustic instrument.

2. DESIGN OF THE JOYSTYX

Performers interact with the JoyStyx by placing the fingers of their right hand on the five joystick pads.[1] A custom-designed circuit board was created in Fritzing [4] which arranges the joysticks so they fit comfortably under the performer's fingertips, see Figure 2. This circuit board also connects joysticks to an Arduino Micro, where the X and Y positions of these joysticks are sampled and serialized and then sent to a Pure Data patch running on the Raspberry Pi.

Figure 2: Custom-designed printed circuit board.

Each joystick controls a granular synthesis module [7] pro-

[1] At McGill University, Ivan Franco is refining an embedded instrument design that incorporates hand-wired joysticks.

cessing a unique soundfile spaced a perfect fourth apart.[2] Moving the joystick forward or backward gradually pitch-shifts the resulting sound up or down a whole-step respectively. Moving the joystick left or right scrubs the playback window through the soundfile. These movements also spatialize the resulting sound, moving it in the direction of the joystick by controlling the gain of three separate speaker drivers attached to the front and side faces. The joystick in neutral position gives a gain of zero to all drivers and increases the gain as it is moved away from center. Pressing down on the joystick splits the signal into a series of delay lines, allowing for additional timbral and delay effect options.

For optimum acoustics the JoyStyx body was designed to resemble a studio monitor. It is a simple cuboid shape with the inner volume optimized for the 3.5-inch driver used for the instrument's lower frequencies. These inner dimensions follow a 1 : 1.14 : 1.39 ratio to minimize any overlapping resonance frequencies. Simple bracings were attached to the face joints to add durability and rigidity [10]. Advancing from some of our previous instruments [2], the JoyStyx uses solid spruce rather than plywood. This change made the instrument much lighter and allowed the faces to vibrate more freely, giving the instrument a more individual timbre. The JoyStyx also has the speaker drivers mounted on the inside of the faces and takes advantage of grill covers to extend the instrument's lifespan.

Directionality is achieved with three 2.5-inch speaker drivers attached to the front and side faces of the instrument. The sounds generated by the granular modules are sent through a high-pass filter and directed to the speakers with the joysticks. Pushing a joystick forward increases the signal to the front channel, to the side increases the signal to the respective side speaker, and pulling back on the joystick distributes the sound evenly between the two side speakers. All of the remaining bass frequencies are low-pass filtered to the bottom 3.5-inch driver.

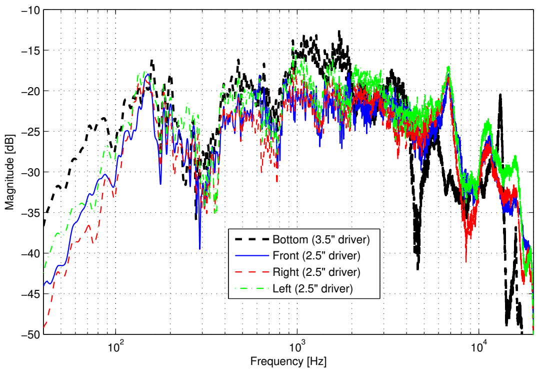

Figure 3: On-axis magnitude response of the four loudspeaker drivers, each of which is installed in a different side. (Note: These magnitude responses have been smoothed slightly in the frequency domain to make it easier to compare their properties.)

Bass ports were 3D-printed to boost the bottom end of the 3.5-inch driver. These ports were designed to a target resonance frequency of 60Hz, which is the bottom of the driver's range. The initial test dimensions for the ports were obtained using an online resonator calculator [5]. This tool accepts input values for the quantity, shape, and radius of the desired ports; as well as the volume of the body and target frequency of the resonator; and calculates the resonator length required. The desired effect is to boost the bottom end of the instrument's range and according to initial measurements, see Section 3, the tool appears to be accurate and effective.

3. MEASUREMENTS

To get an idea of the instrument's tone colour, we took measurements of its acoustic resonance. Using a long sine sweep as the input signal, we took measurements of each driver individually with the reference microphone on-axis 32-inches away from the instrument. Figure 3 shows the four responses plotted together. The magnitude response is plotted logarithmically with respect to frequency. Predictably, the smaller 2.5-inch driver gives a smoother response in the mid and high-end range, while the 3.5-inch driver shows more power in the low-end of the range.

We also took this opportunity to assess the effectiveness of the bass ports. By plugging the ports, we were able to get an idea of how the instrument would respond without the bass ports. Figure 4 shows a comparison of the front speaker driver's response with an open port vs with it plugged. We see an overall boost to the low-end frequency response, with a noticeable jump of nearly 3dB in the 60-80Hz range, as we had aimed for.

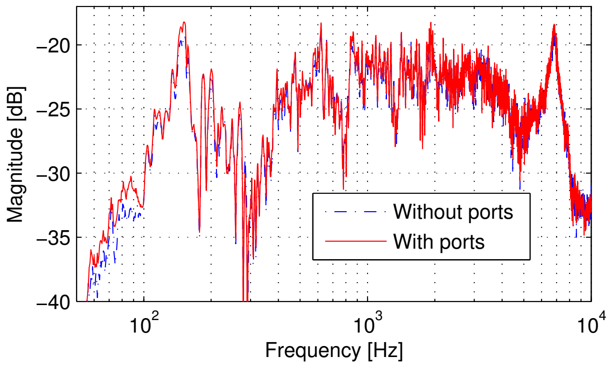

Figure 4: Unsmoothed magnitude response of the front without and with bass ports.

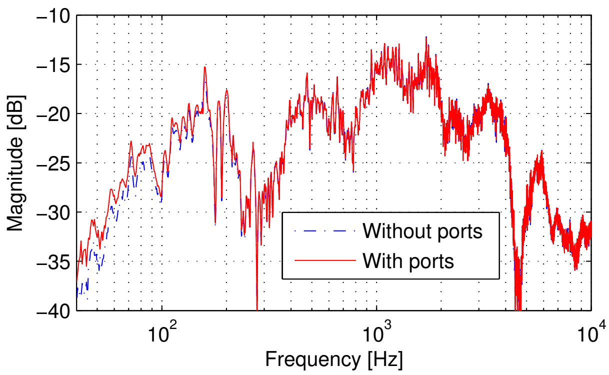

Figure 5: Unsmoothed magnitude response of the bottom.

Figure 5 shows the comparison of the 3.5-inch bottom driver in the same fashion. Again, we observe an overall increase in amplitude in the low frequencies and, again, we see a significant increase in the 60-80Hz range, as anticipated. This demonstrates that the bass ports have a predictable,

[2]The DIRTI musical instruments, with their granular approach, are a particular inspiration for the authors [8].

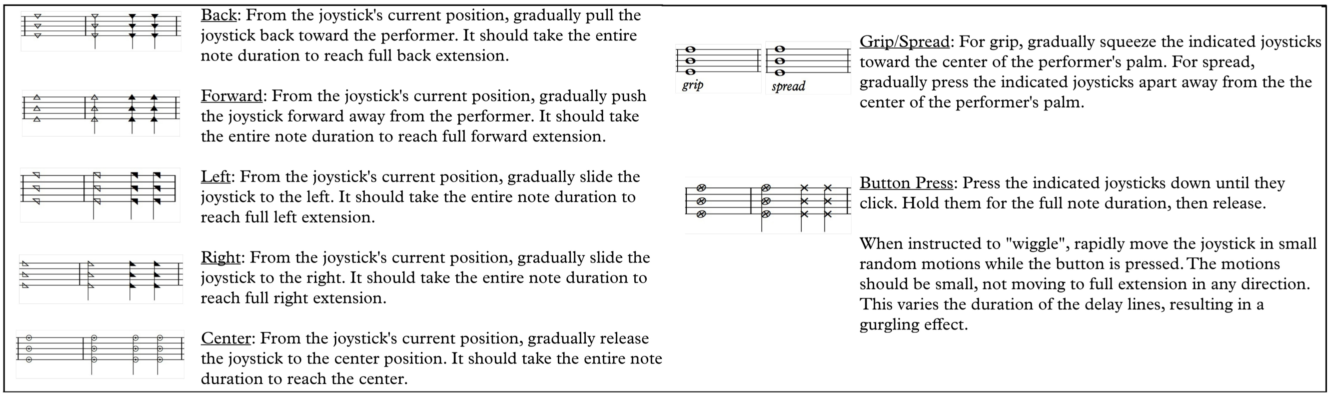

Figure 6: This key explains how to interpret the notation used for *Granular Quartet*. The written notes represent performance instructions rather than pitch content. Five staff lines each represent a joystick, notes written on the bottom line indicate actions performed on the thumb's joystick and those on the top line performed on the pinky's joystick. All actions should be slow and smooth.

controllable, and beneficial effect on the final sound of the instrument.

The magnitude response plots (see Figures 3, 4 and 5 – 10^2 indicates 100Hz, 10^3 indicates 1000Hz, and 10^4 indicates 10kHz) are plotted logarithmically with respect to frequency.

4. GRANULAR QUARTET

Granular Quartet is the first piece composed for an ensemble of the JoyStyx concept. Each of the four instruments has a separate sound source. Each instrument uses samples from either flute, oboe, bassoon, or bass clarinet. The use of different instruments gives the ensemble a wider range, from around 65Hz in the lowest bassoon note to around 1.5kHz in the highest flute note. The ability to gradually glissando between these notes, combined with the variety of smooth and buzzy timbres in the selected instruments, allows for a wonderfully complex spectrum of possible textures. The JoyStyx quartet can be seen in Figure 7

The piece is structured as a slow moving fugue. The subject and counter-subject ideas move gradually, allowing the subtle granular changes in each instrument to overlap in a slowly evolving, ambient cloud. It follows an ABA' form with the A-section demonstrating the instrument's ability to smoothly and subtly manipulate the soundfile while the B-section timbrally develops the subject by sending it through the delay lines with the button presses.

Figure 7: Four different editions of the JoyStyx instrument.

Granular Quartet was written specifically for the JoyStyx instrument and revealed some interesting challenges, specifically in notation. Whereas the Textural Crossfader [2] was able to use a simple grand staff, notating five separate controls–each able to move smoothly in two-dimensions and capable of two different button states–is a lot of information to mark down using traditional musical notation. This piece used a system of note-heads that used directional arrows to show the direction of movement for the joystick, see Figure 6. Each joystick was mapped to its own line on a standard five-line staff with traditional rhythmic durations informing the performer how long each movement should take.

Performers initially interpreted the instructions to be complex; however, compared to other music notation systems (for example, for extended techniques), it was actually quite simple. Merely, the challenge for performers was that it was an entirely new experience. Nonetheless, *Granular Quartet* was successfully performed at the LaTex 2016 Conference at the University of Texas at Austin on November 5, 2016, as well as the Laptop Orchestra of Louisiana Concert on November 14, 2016, in what may have been the first performances ever of a quartet of embedded acoustic instruments, see Figure 8. Future developments on the instrument will explore further notation options, see Section 5.

5. ADDITIONAL FUTURE DESIGN CONSIDERATIONS

The JoyStyx interface is currently being used to explore more complex mappings for future compositions using machine learning. It has been updated to run on the Raspberry Pi 3 board and uses the Wekinator platform [3], created by Rebecca Fiebrink, to train and store the learned models. The Pure Data patch sends the serialized Arduino data to Wekinator to be interpreted. The user trains a number of grips and hand-shapes that Wekinator then models. While Wekinator is running, the current joystick data is compared to these models and a weight for each model is sent back to Pure Data.

In Pure Data, a custom preset handler was designed to work with Wekinator. The user can find an ideal sound for each of the trained models and store those presets in Pd. The parameters of these presets are then interpolated based on the received weights of each model.

Currently, we are working on a system for interpolating between these presets in a less linear way. We hope to allocate positions for each of the presets in an n-dimensional space to allow for customized vectors between them.

This machine learning platform would open up a new compositional strategy for the interface. Rather than notating each action for each joystick individually, the composer could define a finite series of shapes or gestures and create a simple notation system for moving between them

Figure 8: *Granular Quartet* being performed live in concert.

over time.

Other considerations include material comparisons. We will be fabricating a few different versions of the JoyStyx that will be identical to the current model except for the use of other types of wood or acrylic for the instrument's body. We will then measure the acoustic resonance of each instrument to compare the characteristics of each material. In addition to this, we will be taking inspiration from traditional instrument luthiers and exploring more complex internal bracings to improve upon the simple edge reinforcements being used currently.

6. CONCLUSIONS

In designing the JoyStyx, we experimented with expanding the Embedded Acoustic Instrument platform beyond the standard stereo format by exploring 3.1 format of three directional channels and a low-frequency channel. We explored polyphonic and spatial interaction using a new custom-designed interface. We also discovered that, with a little fine-tuning, bass ports can have a desirable effect on the final acoustic character of the embedded instrument.

Historically seen, the concept of Embedded Acoustic Instruments has some novelty. In this light, the advancements made with the JoyStyx instruments are intriguing to discover. The nature of their construction causes the frequency response to be colored by the materials and their geometry, leading to a unique timbre, endowing the instruments with a more analog or natural sound, despite relying on computer-based algorithms. In concert, the quartet performance with the JoyStyx may potentially be the first performance ever of a quartet of Embedded Acoustic Instruments.

7. REFERENCES

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