Dipole Instruments for Sketching in Hardware with Embedded Acoustics

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ABSTRACT

Sketching in hardware with embedded acoustics can be challenging due to the newness of the technology and the complexity of realizing completed instruments. Following a brief review of established iterative design practices in computer music, the author provides some tips for sketching in hardware with embedded technology using Satellite CCRMA. The tips are exemplified through a series of "dipole instruments," which radiate sound approximately like dipole acoustic sources at low frequencies.

1. INTRODUCTION

1.1 Iterative Design in Computer Music

Iterative design is a simple but powerful design process. In this cyclic process, one redesigns a preexisting design, implements a working prototype, evaluates it, and repeats as depicted in Figure 1 [1, 2, 3, 4].

Iterative design has a history in the field of computer music [3]. For example, this kind of thinking has historically permeated the design of real-time computer music sound synthesis languages, which allow a sound synthesizer to be heard while it is being developed. This allows a developer to iteratively design sound synthesizer modules rapidly and efficiently. The Max [1] and pd programming languages allow sound synthesizers not only to be heard while they are being programmed, but also their state variables can be viewed using simulated oscilloscopes and other tools to promote rapid iteration.

In other computer music programming languages such as SuperCollider, ChucK, etc., rapid iteration not only allows one to arrive at a prespecified result more rapidly, it also allows one to discover new sounds, music, and ideas, which can further help in designing future musical sound. Perhaps today, as the distinction between composing music and designing instruments (or even "composing instruments" [7, 8]) becomes more blurred, it may seem acceptable, at times, to apply the design process of iterative design to any and all of these activities: designing instruments, composing music, and composing instruments.

[1] Regarding the Max sound synthesis programming language, the chief architect David Zicarelli has in fact stated that the language philosophy was motived by Joel Chadabe's concept of interactive composing [5, 6].

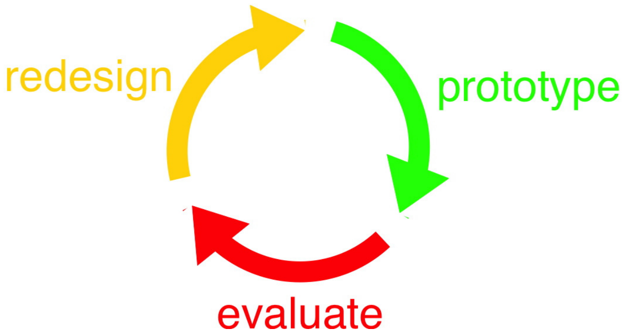

Figure 1. Cyclic representation of iterative design.

1.2 Iterative Design in Hardware

In contrast to the case with software, iterative design with hardware can be more challenging because it takes longer to realize a hardware prototype. For this reason, the *redesign* stage is especially important. The author recommends using copious sketching [9, 10, 11] during the redesign stage to try to complete a hardware design in as few hardware iterations as possible.

Some recently evolving hardware platforms have made iterative design with hardware somewhat easier, to the extent that even *sketching in hardware* has become more viable. Currently relevant hardware platforms include Arduino [12], Raspberry Pi, BeagleBone [13], Bela [14], and Satellite CCRMA [15].

1.3 Embedded Acoustic Instruments

Sketching in hardware can also be applied to the design of Embedded Acoustic Instruments. The concept of an Embedded Acoustic Instrument is depicted in Figure 2, which illustrates a sensor interface connected to an embedded sound synthesizer to an audio amplifier to a loudspeaker. These elements are all housed within a single enclosure.

This self-contained property means that Embedded Acoustic Instruments can be easier to maintain over time because their software is contained in the hardware, so it never needs to be updated to keep it working [16, 15]. Embedded Acoustic Instruments may also tend to facilitate performance practices becoming more highly developed, as it is more convenient to practice playing music with Embedded Acoustic Instruments — no wrestling with copious numbers of cables is necessary — after being powered up, they automatically become ready for making music.

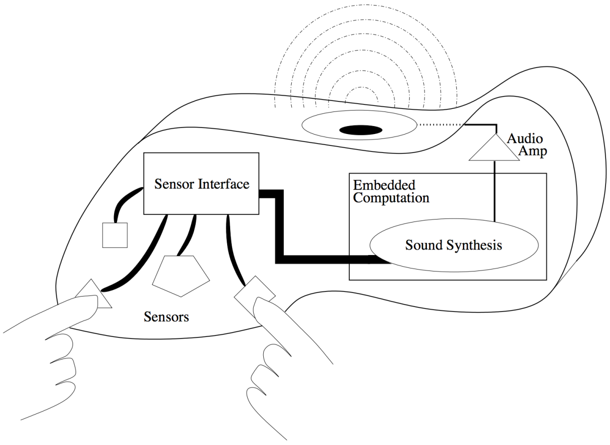

Figure 2. Concept of an Embedded Acoustic Instrument.

Figure 3. An example dipole instrument (loudspeaker has diameter , 12" (30.5cm)) that can balance upright by itself on a table (electronics hidden underneath the black acrylic plate).

2. DIPOLE INSTRUMENTS FOR SKETCHING IN HARDWARE

2.1 Theory

This work proposes the creation of *dipole instruments* to facilitate the sketching in hardware of Embedded Acoustic Instruments. Whereas many prior Embedded Acoustic Instruments have been mostly acoustically sealed, which can help enhance the low-frequency response [17], dipole instruments are *not* acoustically sealed. This makes it much easier to prototype with them because the electronics can be easily accessed, changed, reappropriated, etc.

Designers should, however, be aware that dipole instruments do not radiate sound as efficiently at low frequencies. For example, compared to a baffled loudspeaker, an unbaffled loudspeaker will radiate sound at 6dB/octave less than a baffled loudspeaker at low frequencies [17].

2.2 Practice

However, the author believes that a dipole instrument can still be so convenient for sketching in hardware that it can nonetheless be an attractive design option. The decrease in low-frequency response can for example be compensated for by using a more powerful loudspeaker, such as shown in Figure 3. Consequently, for making dipole instruments, the author recommends to **use a large woofer and attach all electronics to a single plate of material attached to the woofer.**

Because the acoustic design is open, the electronics can easily be accessed from all sides. That means if any aspect of the electronics needs to be tweaked, it can be easily reached and adjusted. (This is in contrast to a closed acoustic design where, if an electrical component needs to be adjusted, it might be hard to reach it depending on how the acoustic box can be opened and where the component is located.)

When oriented horizontally, the instrument radiates sound both upward and downward but not very much to the sides. At low frequencies, this radiation pattern is considered to be similar to the *dipole* shape as illustrated in Figure 4 [17].

If the woofer is heavy enough, then the instrument can balance itself upright on a table as shown in Figure 3. Moreover, sketching in hardware becomes easy. For example, the instrument can be stood up on a table as shown in Figure 5 to expose the electronics for easy access while prototyping.

In addition, it is recommended to **consider using USB or other USB-MIDI-based controller components since they can facilitate trying out new ideas and rapidly getting around the iterative design loop.**

In the example of the presently considered instrument, a FireFader USB-based controller was incorporated into the instrument [18]. This required only a simple 12V power connection and USB cable using pre-made cables, which is faster for prototyping than making custom cables, soldering them, etc.

Furthermore, it is a good idea to **maintain a library of commonly needed hardware components.** In this case, if a designer suddenly has a good idea, it might be possible to gather up the components needed to rapidly prototype and evaluate again. Otherwise, it can be necessary to mail-order hardware components and wait for potentially long shipping times, before one can go around the iterative design loop again (see Figure 1).

Finally, the author has found that, when prototyping Embedded Acoustic Instruments, it can be helpful to **be prepared to use ground-loop isolators.** When interconnecting significant numbers of boards, it can be possible to form ground loops, which negatively affect audio quality. If ground-loop isolators are on hand (especially ground-loop isolators that are inserted into 1/8" (3.18mm) cables), then if 60 Hz or 50 Hz hum is heard, it can often rapidly be eliminated by introducing an ground-loop isolator into the signal path.

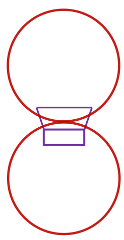

Figure 4. A *dipole* (also known as figure-of-eight) radiation pattern, which is similar to the radiation pattern produced by an upward-pointing unbaffled loudspeaker at low frequencies.

Figure 5. This example dipole instrument can stand up on a table exposing the electronics, which makes it easy to work on it.

Figure 6. The dipole instrument can be held in the lap for live performance.

2.3 Example Dipole Instrument for Playing Chua's Circuit

This paper is highlighting one particular dipole instrument that lends itself well to sketching in hardware. This instrument can also be held in the lap and cradled as shown in Figure 6, and in this sense the instrument bears some resemblance to the Cellomobo [19].

The present dipole instrument was designed for the purpose of playing Chua's circuit in real time [20, 21]. For this purpose, a SoftPot touch strip adjusted the time-step of the circuit simulation, providing for a pitch control that could rapidly be adjusted. In performance, this was adjusted by the performer's right hand as shown in Figure 6. Concurrently, the performer's left hand used the FireFader USB controller to haptically interact with the Chua's circuit simulation.

While much of the audio signal processing was calculated at a sampling rate of 44.1kHz, Chua's circuit was simulated at a higher sampling rate. The Raspberry Pi 2 used to build the instrument was capable of simulating Chua's circuit at 8x oversampling. This was sufficient for the low kinds of notes suggested by the size and cello or bass-like orientation of the instrument; however, even higher oversampling rates would be needed for realizing alto or soprano versions of this instrument.

From time to time, the performer's right hand could further adjust five potentiometers. These parameters were used to adjust the C_1, inductance, and R parameters of the circuit, as well as to scale the overall time-step (e.g. pitch) of the instrument simulation [20], either as a fine adjustment or a very wide-ranging adjustment.

By implementing the simulation using the "limited" version of Chua's nonlinear resistor, it was possible to achieve a simulation that was stable over the entire range of available parameter values. However, the dynamic of the circuit tended to sometimes be a little bit too constant for musical use. Therefore, it was decided to use set the example parameters such that that the circuit tended to operate near the edge of self-oscillations. As demonstrated in the following video, the performer adjusted the circuit parameters with the aim of exploring bifurcations and staying near the edge of chaos: `https://goo.gl/XPu9H9`

2.4 Other Dipole Instruments

The author made an additional pair of dipole instruments. As shown in Figures 7 and 8, each of these instruments had a mid-sized loudspeaker on the left and the right. Quite conveniently, these speakers provided the performer with a stereo pair, which was very useful for monitoring sound during live performance.

However, these instruments turned out to be considerably harder to prototype with. These designs were based around the idea of having two plates of laser-cut material – one for the top plate and one for the lower parallel plate, which connected the speakers together. This made the instruments mechanically more robust, but the speakers were glued to the lower plate, as there was no strong mechanical alternative — however, this led to a design in which it is difficult to replace either of the loudspeakers or back plate if any of these parts breaks. Therefore, the author believes this design is not as useful for sketching in hardware as the one shown in Figure 3; however, they are still presented here for additional consideration and comparison.

Figure 7 shows an instrument designed for playing the Peter de Jong chaotic map, as given by
`http://paulbourke.net/fractals/peterdejong`

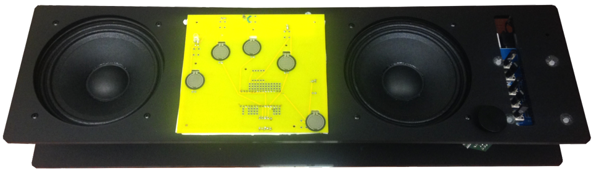

Figure 7. A dipole instrument for playing the Peter De Jong chaotic map as connected to a pair of digital waveguides [22].

Figure 8. A dipole instrument for playing a pair of coupled circle maps [23, 24] as connected to a pair of digital waveguides [22].

when coupled to a pair of digital waveguides [22]. An electroacoustic miniature composed for this instrument can be found in audio and score formats at the following links: `goo.gl/hGkt9F` and `goo.gl/1U5rge`

Figure 8 shows a second dipole instrument which was used for playing a pair of coupled circle maps as coupled to a pair of digital waveguides [22, 23, 24]. The audio and score of an electroacoustic miniature composed for this instrument are available at `goo.gl/DQkHZR` and `goo.gl/txKPPF`

3. RESULTS

Depending on the selected parameters, the Chua's circuit could tend to produce a fairly simple periodic waveform. However, as far as physical modeling goes, the tone was quite complex for a low-order system — the nonlinearity included in it caused significant amounts of energy to be placed in a whole series of higher partials. This tone was musical enough, but similar tones could be more easily produced using other sound synthesis techniques.

With this instrument, however, it was quite interesting to adjust the circuit parameters so as to cause bifurcations in the sound. This enabled the exploration of a complex timbre space that had some intuitive sounding if mysterious origins in the circuit parameter adjustments. Therefore, from the sketching in hardware perspective, it made sense to expose the circuit parameters by way of potentiometer knobs to facilitate gradual exploration of timbre spaces. The touch strip enabled the rapid adjustment of the simulation time step. While in nonlinear systems parameter adjustments can be mysterious, the time-step adjustment had a clear and direct influence on perceived pitches, so it was useful to expose this directly for rapid adjustment.

In contrast, the other dipole instruments realized using chaotic maps connected to digital waveguides, as shown in Figures 7 and 8, had an even brighter sound [22]. This was because of the inclusion of the digital waveguides [22], which simulate oscillations all the way up to the Nyquist frequency [25]. The brighter sound of these instruments suited the smaller size of the embedded speakers well. The controls enabled precise adjustment of the model parameters for real-time performance, even if they were not quite as intuitive as the haptic control of the former instrument.

Overall, the focus on sketching in hardware allowed for various design changes to be made, enabling each of the instruments under development to grow into an acoustically viable [26] and performable musical instrument. This was only possible due to the modularity of the approach.

4. CONCLUSIONS

It is hoped that the general design tips provided in this paper may help practitioners, aiding them in sketching in hardware with Embedded Acoustic Instruments. The instruments presented provide some additional specific insights into exploring bifurcations and the edge of chaos [22]. Each instrument turned out to be useful for controlling a different chaos-based sound synthesizer.

Generally speaking, it is hoped that continuing practice with Embedded Acoustic Instruments will provide more ideas about how to enhance music performance, which will eventually be re-considered in the development of future platforms for making Embedded Acoustic Instruments, as the process of iterative design evolves further.

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