The Siren Organ

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ABSTRACT

Sirens evoke images of alarm, public service, war, and forthcoming air raid. Outside of the music of Edgard Varése ([8], [9]), sirens have rarely been framed as musical instruments. By connecting air hoses to spinning disks with evenly-spaced perforations, the siren timbre is translated musically. Polyphony gives our instrument an organ-like personality: keys are mapped to different frequencies and the pressure applied to them determines volume. The siren organ can produce a large range of sounds both timbrally and dynamically. In addition to a siren timbre, the instrument produces similar sounds to a harmonica. Portability, robustness, and electronic stability are all areas for improvement.

Keywords

siren, organ, controllerism, modular, air compression, laser cutting, lathe

1. INTRODUCTION

The *siren organ* is an electro-acoustic wind instrument with the sound of a siren but playability of an organ. We built it to experiment with how acoustic sirens could be more musically oriented. Range of expression, minimal cost and construction overhead, and transparency in playability were our most important design requirements.

1.1 Motivation

The wide-sweeping glissando sound characteristic to a siren is one that only a few acoustic instruments can mimic, but over a shorter range. We desired a large range of control over the pitch change amount and speed.

Another of the main goals that we had was transparency: an instrument that gives performers the desire to play it because they are confident that they can, and that they know what it might sound like. For example, with timbre, even a physical understanding of complex harmonic motion and the vibrations of strings and columns of air does not inform the relative strength of those harmonics upon physical inspection. We sought out ways to more clearly demonstrate complex harmony via the patterns we cut into the siren disks.

Finally, we had five weeks to complete this instrument and worked with a small budget, making any custom materials with laser-cutters, lathe, and a mill, all designed in SolidWorks and Adobe Illustrator. Modern machine shops have opened up many possibilities for affordable instrument-making and this makes their documentation highly valuable.

1.2 Background

Pneumatic sirens are mechanical instruments producing very loud (>100 dB) sound. Their construction is typically considered in two parts: a *stator* and a *rotor* (also called a *chopper* or *siren disk*). The stator and the rotor have identical, equally-spaced openings and closings that look like fan blades. The rotor spins and its openings alternate between aligned with the stator (allowing airflow) and unaligned (no airflow). Voltage control varies the rotation speed of the rotor and creates the familiar wail of a siren.

The basic physics of our "siren organ" are trivial: an air stream is applied to a rotating disk with evenly-spaced holes. As the air flows over the holes, a repeating series of compressions and rarefactions create a periodic vibration that we hear as pitch. The shape of this oscillation is something close to a rectangular wave or pulse train, with the pulse width determined by the ratio of the diameter of the holes to the between-hole interval. The resultant pitch f_p is a function of the number of holes N and the speed of the rotating motor f_r (in rotations per second), by the simple relation $f_p = Nf_r$. So, a disk with 10 holes spinning at 50 rotations per second would have a frequency of 500Hz, close to a B4.

Bart Hopkin's documentation of the siren organ [4, 5] demonstrated iteration in musical siren design but more importantly showed that sirens can be built inexpensively. Following Hopkin's advice [5], we fixed the end of the blow tubes in holes in our siren disk stand and fabricated a wood nozzle for the opening of each tube to decrease the output diameter and focus the flow, greatly improving the signal-to-noise ratio (SNR) of the pitch. We found that there was a maximum limit to the size of the tube opening: 2 smaller openings had no aural effect on the SNR nor timbre from the larger.

Searching for toy sirens online (to no avail), we discovered a small number of 3D-printed models of plastic sirens. However, in each case they were constructed from gears that produced substantial noise. In general, the sirens available for purchase are meant for non-musical purposes and extremely loud (>120 dB). Many of these are leftover relics from the first World Wars and quite expensive collectible items.

1.3 Previous work

There are a small handful of "siren organs" in existence, the names of which are coincidental. John R. Pierce gives a nice example of a simple, homemade siren (no stator) in [7].

In 2004, Jean-François Laporte constructed a siren organ from "air compressors, pneumatic tubes, and boat horns" [6], culminating in his composition *Vertiges* [3].

Rene Bakker has done creative research in the siren domain, designing electromechanical "servosirens" and reinterpreting two old inventions: a 1915 patent filed by Dutch theologist Abraham Loman [2], which Bakker calls "an interpretation of the Loman siren organ," and the Helmholtz Doppelsiren [1]. Bakker's Loman siren organ is a very finished product. He rests a one-octave piano with knobs to control individual motor speeds atop a complex array of motorized sirens. The motorized buzz of the air compressor appears to be constant and substantial; however, the interface of the organ is remarkable. The documentation of his instrument is unfortunately lacking, so it is difficult to understand its full range of expression.

Finally, as mentioned above, Hopkin's handheld musical siren [5] sounded by air blown through a plastic straw inspired many ideas about the patterns for our siren disks.

2. CONSTRUCTION

The siren organ can be constructed using only materials from a hardware store, plus a small amount of electronics to apply voltage to a potentiometer. The instrument can be divided into three main components: (1) the air compressor, (2) the interface / controller, and (3) the siren disk.

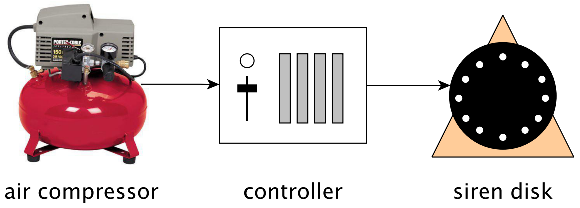

Figure 1: The three main components of the siren organ.

In prototyping, we started with a small (4") motor-driven disk with 4 concentric rings of holes, fixed to the stand by simply laser-cutting a small hole in the center of the disk and sticking it onto the shaft, to give us compact access to 4 voices per siren. Our "air compressor" was our mouth, delivering air to the spinning disk through a straw, and our controller only a 9V battery. In this phase, we achieved a surprisingly good SNR, once we realized that the motor could be pinched together to greatly reduce its hum. A second prototype multiplied the instrument into three separate disk-motor pairs, adding also three potentiometers and Arduinos. Here, we experimented with the disk design: minor chords, major chords, and different shapes of holes such as stars, triangles, and squares as well as their radii. We could not distinguish an effect these shapes had on the timbre, but the different radii had a clear impact on the overtone series, generating audibly stronger harmonics.[1] We laser cut a single stand for the three disks with screw mounts for the potentiometers (Fig. 2), but found this model too compact. Finally, we added the air compressor, and in order to stand up to it we shifted our focus to robustness.

[1]Interestingly, the minor chord and major chord design was also surprisingly similar, as if the integer ratio approximation (6:5) of a minor third was not close enough to reality ($2^{3/12} = 1.189$) to differentiate from that of a major third (5:4). Perhaps the lower frequencies have strong fourth harmonics, or there is some coupling that has an impact on larger ratios.

With the intent of performing together, we made three slightly different controller-disk-motor combinations. We refer to these as Controller 1, 2, and 3, final design pictured in Fig. 3, and likewise Disk 1, 2, and 3.

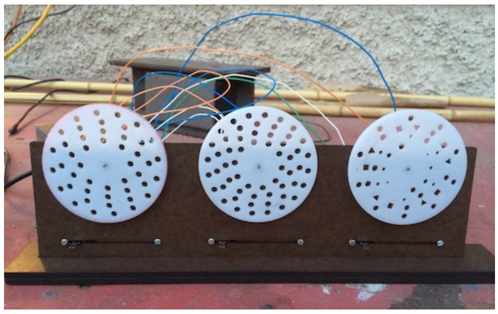

Figure 2: A later prototype of the siren organ.

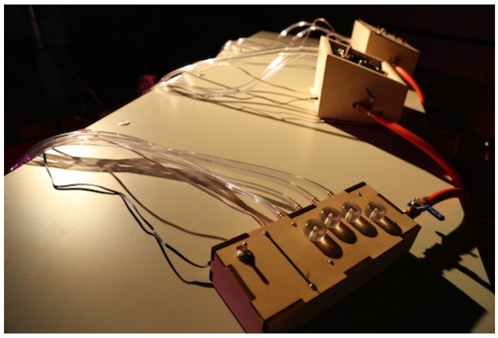

Figure 3: The final design of the siren organ.

2.1 Materials

We spent about $600 between the three of us constructing the siren organ, not including the air compressor or the access to such machines as a laser cutter and mill. The cost of the final design was about $450 of this expense. Research is always the most expensive phase of product design, so we found these costs reasonable. Close estimates of the quantities of materials are broken down in Table 1.

Table 1: Construction Materials

Item	Quantity
Plastic tubing (1/4" IID)	120'
Rubber tubing (3/8" IID)	15'
90° plastic barbs, threaded (1/4")	8
Plastic barbs, threaded (1/4")	8
Brass barbs, threaded (1/4")	4
Brass barbs, threaded (3/8")	3
Plastic barb-to-barb (1/4")	8
Birch for faceplates	2
Basswood for siren boxes	1
Blowguns	2
Ball valves	9
Acrylic for disks	3
Plumber's tape	1
3-way splitter	1
Power jacks	3
Arduino Nanos	3
Power supply	1
Switches	3
MOSFETs	6
Resistors	3
Motors (MD5-2445, 2.1A)	3
Potentiometers (faders)	3

2.2 Air compressor

The air compressor is a Porter Cable 150psi 6 gallon model. We regulated it down to about 30psi to work with the valves and tubing. In early prototypes, the disks were press-fit onto the motor shafts, but the disks would move up the shaft of the motor after continuous exposure to the pressurized air. Thus, we threaded both the shaft and the disk for a more secure fit.

We used a three-way brass splitter to supply air to our three organs with just one compressor. The stream is controlled by a "master" ball valve on the left side of each controller. Therefore, the air pressure can be limited differently for each controller. We had fun reaching over and turning each other up and (more often) down during performance.

2.3 Controller

Controller 1 (Fig. 4) was fashioned out of wood, plastic tubing, barbs, and 5 ball valves, plus the electronics. Controller 2 (Fig. 5) is similar to Controller 1, substituting 2 blowgun valves for 2 ball valves. The third controller (Fig. 6) is a custom set of lathe-turned buttons and a manifold of airways machined on a mill, all designed in SolidWorks. Each controller has a birch faceplate featuring holes and etchings made by a laser cutter.

Figure 4: Controller 1 with faceplate.

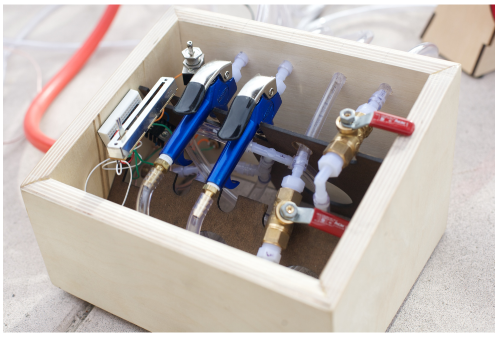

Figure 5: The exposed interior of Controller 2, housing two blow guns and two ball valves.

The inside of Controllers 1 & 2 supports the heavy blow guns and ball valves, and leaves space for the network of (unforgiving) plastic tubing. Barbs were fully inserted into the tubing to stand up to the strong air pressure.

Four holes and a power jack adorn the front of each controller, providing the output air flow and connection to the power supply. The power switch is in the top left corner of the faceplate. On the left, an Arduino Nano is glued to the interior of the controller. This connects the potentiometer to the voltage supplied to the rotating motor.

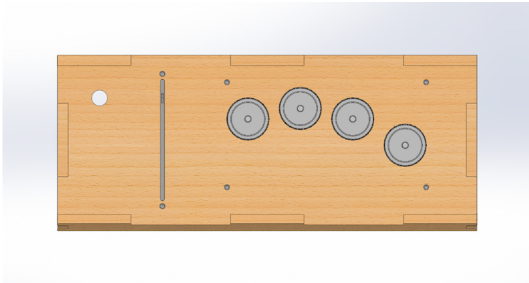

Figure 6: SolidWorks diagram of Controller 3.

2.4 Siren disk and motor

The controllers are each connected by more plastic tubing to a dedicated, acrylic siren disk (Fig. 7). The siren disk is mounted to a triangular stand that houses the rotating motor and also serves to route the plastic tubing. The back of the stand has holders for the four air streams, directed to four rings of holes in a column configuration. The disks are 6" in diameter.

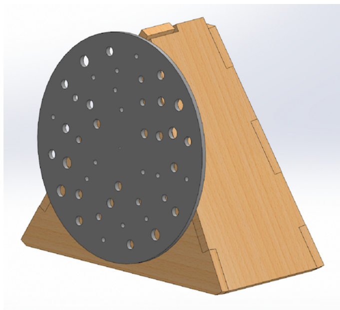

Figure 7: The siren disk is comprised of four concentric rings. Each ring has a series of evenly-spaced holes that create a fundamental frequency.

The inside of the siren disk stand (Fig. 8) routes four plastic tubes to each of the four rings. A threaded hole in the middle of the disk secures it to the shaft of the motor, also inside the stand.

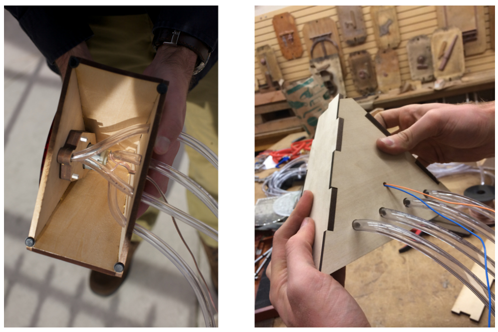

Figure 8: The inside and back of the siren disk stand.

The integer ratios between the number of holes in each ring create natural harmonic relationships: rings with twice as many holes as other rings have an octave relationship, a 3:2 ratio creates a perfect fifth, and so on.[2] By varying the

[2] The exact ratios used were 10:12:15:18 (Disk 1, a minor 7th chord), 6:9:14:16 (Disk 2, a P5, m3, and P4), and 8:10:12:16 (Disk 3, a major chord). Disk 2 had holes of modulating radii (e.g., small-med-large-med-small and so on).

size of the evenly-spaced holes, we can create harmonics [4]: the inner ring, for example, has 6 holes, three with a smaller radius than the others. By alternating between these two holes, we can create an octave below the fundamental.

Our motors are rated to spin at up to 19850rpm ($\simeq$331Hz). The weight of the disk lowers this to about 200Hz (see seconds 10-17 in Fig. 9). The rotating motor produced significant sound, but we found that the cylinder could be pinched on either side to greatly reduce the sound. Its 2.1A maximum current rating informed our choice of a 12VDC 12.5A switching power supply. To control its speed, we used an Arduino to output a pulse-width modulated (PWM) signal amplified by a MOSFET. In early prototyping phases, we blew at least one motor due to heat. Therefore, we added a heat sink to these MOSFETs. We also upgraded to higher quality wiring from our power supply, as occasionally the thinner wires would melt after extended use. Doing this let us play the siren organ for 2 hours continuously without any of the electronics getting too hot.

The ability to change the motor speed provided not only “sirenness” but also transposition to other keys. Hence, we did not worry about the intonation of our siren disks.

3. PERFORMANCE & EVALUATION

In our limited time performing with the siren organ, we discovered many different modes of producing sound. Beginners of the instrument will tend to play with sharp attack, but a bit of practice enables quite legato tones. When the motors are spinning at full speed, it is harder to play softly. Opening more than one valve redirects some of the air flow into other open valves, probably due to their proximity and the strength of the air flow. Thus, the siren organ is clearest in pitch when only one voice is sounding. Because the airflow is shared by three performers, the pressure divides during polyphony; however, the amount of airflow one controller gets is limited by its master valve.

We placed the air compressor outside of the performance space because it is very noisy during refill. We began the performance with the tank full, and it did not need refilling for our 5-minute performance.

We experimented with the sounds of the components in isolation—i.e., just the sound of the spinning motor-siren disk pairs with no applied air flow, or the sound of pressurized air against a static disk. The humming motors and hissing valves provided contrasting sections in our performance that showed the siren organ could perform unaccompanied.

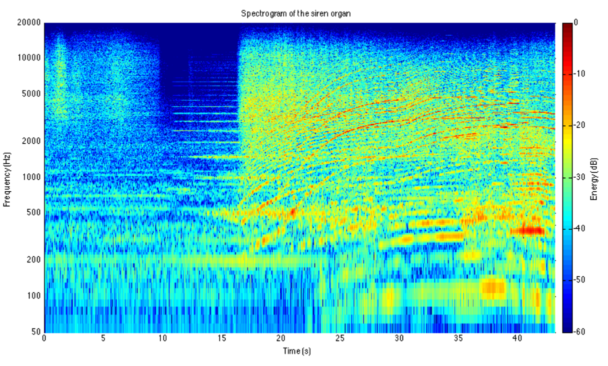

Figure 9: Spectrogram of three distinct sections of our performance: the air against the stationary disks (0-10s), the motors starting up (10-17s), and the crescendo with both the air blowing into the spinning disks (17s onwards). The recorder was about 30 feet from the instrument.

The dynamic range of the siren organ has not been carefully measured, but from a recording with an audience of about 50 people, the difference between lightly and fully pressing the valves is about 30dB (compare seconds 4-5 to seconds 40-41 in Fig. 9). In an empty room, the volume can reach a level of discomfort, especially when standing in the direction of airflow. The range of both air raid sirens and ambulance sirens are much smaller ($\sim$3dB), because they are not meant to be played at low sound pressure levels.

The motor spins the disk up to about 200rpm, and the weight of the disk, tightness of fit to the motor, and power rating of the motor all dictate how quickly the motor responds to the fader. We saw a latency of about 10 seconds when moving the fader large distances, and the frequency of the fundamental changes linearly, having a logarithmic affect on pitch. The fundamental frequencies of our disks with the motor at maximum speed ranged from 1200-3600Hz, and the glissando can sweep over more than 8 octaves. The second, third, fifth, and sixth partials all overpower the fundamental when high pressure is applied, “overblowing” the siren organ (see seconds 20-30 in Figure 9). The harmonic characteristics of overblowing are also present in classical sirens.

4. FUTURE WORK & CONCLUSION

We have many ideas for how the siren organ could be improved. The tubes could be able to be quickly plugged in and out; as is, only the “master valve” can be easily detached, by unscrewing it. More mobile tubes could enable many siren disks at once and give the siren organ a “patch cord” kind of character, like a modular synthesizer.

An enclosure for the disks would change the acoustics of the instrument and potentially would require a stator. We vetoed making an enclosure because we were worried that it would make our organ even louder. On that note, a siren organ that does not require a noisy air compressor (at least during performance) is another area of improvement.

In conclusion, we believe that our reinterpretation is justified for manifesting the siren as a musical instrument. Our siren organ is more automated, has more control over dynamic range, and offers different modes of sound production.

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