Miren: An Attentive Musical Siren

Peter Murray
Robotics Engineering
Worcester Polytechnic Institute
Worcester, USA
pnmurray@wpi.edu

***Abstract*—Miren is a robotic instrument that captures and transforms ambient sound into compelling musical phrases. Using a rotational air pump within a perforated stator, Miren produces a loud wail characteristic of 20th-century civil defense sirens. The instrument's pitch and volume are dynamically controlled with a brushless motor and airflow valve, allowing for continuous pitch variation and a wide variety of volume envelopes. Designed to be placed in an open outdoor environment, Miren is sent control signals wirelessly. To generate music, Miren uses a Markov chain altered to account for rhythm matching and control signal generation to produce novel melodies that exploit the instrument's musical affordances.**

I. Introduction

The deafening, sustained cry of a chopper siren occupies an indelible place in human memory since its introduction in the early 20$^{\text{th}}$ century. A tool of civil defense, chopper sirens warn of approaching danger: natural, in the case of tornadoes or tsunamis, and man-made in the case of aerial bombardment or nuclear disaster evacuation. The characteristically harsh wail takes on an ethereal quality as it reverberates through a cityscape. Chopper sirens achieve this feat by closely encircling a centrifugal air pump with regularly-spaced pillars that interrupt the pump's airflow at certain intervals, producing a unique, synthesizer-like waveform. As the siren's rotor increases in speed, the sound's intensity climbs; the rotor draws in air at an increasing rate, coupling pitch and volume and creating the familiar 'up-and-down' portamento as the siren's motor accelerates and decelerates. These qualities make the chopper siren both a compelling and challenging means to produce music, and offer a unique opportunity to create an interactive robotic instrument.

A. Defining the Problem

Transforming a siren into an interactive instrument immediately poses several challenges. At its core, Miren utilizes a powerful brushless motor and accompanying controller to precisely modulate pitch. A butterfly valve located above the rotor increases and decreases airflow through the siren, modulating volume. While at the current moment not live-time, Miren contains software capable of processing an audio file as an *input*: perhaps someone humming a tune, perhaps the drone of an airplane overhead. Extracting a monophonic melody, Miren becomes a musical partner and attempts to build upon what it has heard from its partner. Musical companionship is frustrating, especially for computers. For this reason, I have taken inspiration from previous research and have created the *continuatron*: a melody generator that aims to continue a musical phrase by reducing the input into distinct pitch regions, using a pre-trained, 2$^{\text{nd}}$ order Markov chain at its foundation.

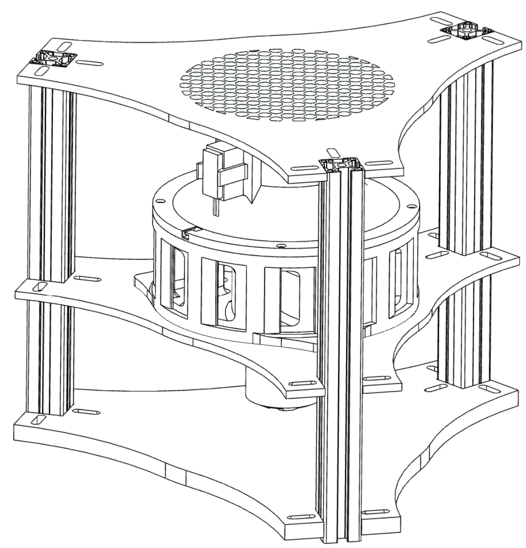

Fig. 1. Simplified wireframe render of Miren.

II. Background & Literature Review

This project is closely related to the fields of musical robotics and musical generation, each with distinct roles that I have used to guide the design of Miren.

A. Sirens

Throughout this report, the word 'siren' is used to define a range of sound-producing devices. Fundamentally, a siren is some device that interrupts moving air at regular intervals at a rate where the pressure waves created by the interruption is perceived as pitch to a human ear. A handful of researchers and artists have had varying level of success with two main forms of sirens which I will be referencing: disk-based and cylindrical-based. A disk-based produces sound by forcing air through a perforated, spinning disk. The aforementioned cylindrical (chopper) siren produces sound when a cylindrical rotor pushes air through a stationary perforated cylinder.

Best known for their widespread use as air raid warning signals, sirens have found use both in scientific and expressive environments. One of the earliest examples of a siren as described above was the work of Riemann Hemholtz. Seized by the 'problem of space', Hemholtz's research into human perception lead to the creation of the *Hemholtz double siren* in 1870, whose novel, two-pitch siren gave unique insight into the aesthetics of intervals and musical patterns [1]. Recently, control of the exact waveform produced of sirens was of particular interest of researches who were able to develop sirens capable of active noise cancellation in loud, harsh environments, like aircraft [2]. In one case, this was achieved with disk-based siren that features a precisely-machined rotating profile whose edge covers and uncovers a stream of air with a continuous, fluctuating area. [3].

B. Sirens & Music

Using sirens as a means of musical expression has been attempted many times, across many different fields. In 2014, Engineers at Stanford built a disk type siren featuring three disks, each with four sets of holes and accompanying (mouth-powered) air tubes for a total of 12 voices. Their "Siren organ" produced a wide range of timbres, but was difficult to control with slow and imprecise pitch control and volume troubled by airflow disrupted by interdependant valves [4]. In 2020, Engineers at Worcester Polytechnic Institute's Music, Perception & Robotics lab (`mprlab.org`) greatly expanded on this design by creating *Parthenope*, whose interface and controller afford the player much more flexibility. Capable of rapid and precise articulations, Parthenope shares the fundamental disk-and-tube based design with its Stanford counterpart, but is digitally controlled and employs a strategy to optimize accuracy and minimise motor speed changes [5].

Franz Clochard, a french artist and inventor (famed for his "Flying Chainsaw" act) has built and performed alongside a "well balanced polyphony" of seven chopper-based sirens, dubbed the *Sirènes Musicales* (Siren Orchestra). Consisting of a bass, tenor, two altos, two sopranos, and a piccolo, each cylindrical, chopper-based siren is controlled with a variable-speed motor and valve assembly to modulate pitch and volume. Clochard has built a set of precisely articulated and electronically controlled musical sirens robust enough to be driven through the streets of France and perform in the show *Mécaniques Vivant* (Living Mechanics) [6].

C. Interactivity

While some of these works have framed musical instruments as being primarily mechatronic with no sensory perception, there are many examples of interactive musical systems. In 2002, François Pachet debuted *The Continuator*, a interactive MIDI instrument that utilizes a Markov selection process to continue a polyphonic piece being played by a human. Instead of the traditional Markov transition matrix, the Continuator quickly and completely learns a corpus by building a prefix tree, effectively creating a variable-order Markov chain. Among other techniques, Pachet's process manages polyphony by using a collection of aggregation schemes, and manages unlearned 'continuations' by employing reduction functions by expanding the range of possible next notes [7].

In 2010, Hoffman and Weinburg introduced *Shimon* as an improvisational marimba robot, capable of anticipating a human player's musical intention and responding accordingly. Shimon uses physical movement as a means of expressivity and communication, purposefully built with four arms that are capable of spanning the entire marimba, but need to move quickly to play the correct notes. Additionaly, Shimon features a 'head' that bobs up and down to the beat and makes eye contact with the appropriate band section to signal future action. The improvisational ability of Shimon is not precisely described, but involves a "decaying-history probability distribution" that uses "clustering techniques" to learn from its human counterparts, which suggests the authors take advantage of some stochastic decision making process [8].

Moving away from improvisational robotics, more experimental work has ventured deeper into space of human-robotic interaction. In the 2011 piece "Spatial Sounds (100dB at 100km/h)", artist and researcher Edwin van der Heide investigates the effect of harsh physical and auditory movements on interactivity by bolting a loudspeaker to a length of metal box frame, then rapidly spinning the entire assembly with humans standing nearby. Equipped with an ultrasonic sensor attached to the loudspeaker end of the 'arm', the robot goes through a predefined set of "inteaction modes" based on an algorithm that detects if people are nearby. As the robot moves, it produces a loud, percussive noise that increases in frequency as the the motor's rotational speed increases. Sometimes it selects a single person to follow of many people in the vicinity- ignoring some, rewarding others with attention. One of several modes detects when there are too many people too close to the robot. Feeling overwhelmed, the robot then spins faster and faster, "scar[ing] most of the people away." Van der Heide's work proves even a simple robot capable of basic distance detection, noise and 'pointing', is capable of creating a believable being whose presence creates a rich and interesting social environment [9].

The wide range of work covered in this literature review presents a great number of opportunities in formulating the fundamental design of Miren. Previous work has proven mechatronic sirens are are not only highly configurable sound producing devices in waveform, pitch and intensity, but robust and articulate as fully-fledged musical instruments that have allowed meaningful insight into the aesthetics of music and human perception. Additional research has shed light on creative ways to integrate digital improvisation into musical performance, and proven robots have a particularly poignant role in social contexts. This leaves the problem of creating an articulate, interactive, siren-based musical device that is capable of continuing a musical phrase as an unexplored area of research.

III. Methodology

A. Requirements

In any sufficiently complex engineering project, it is necessary to develop requirements to guide progress towards a well-defined goal. For this project, a hierarchy of requirements has been developed. An overview of the high level requirements are displayed Table 1 below for clarity.

TABLE I
REQUIREMENTS

Requirement Category	Requirement
The Instrument shall produce sound	Instrument shall use a rotor/stator type sound source.
	Instrument shall minimize mechanical noise.
	Instrument shall modulate pitch and volume.
	Instrument shall be playable and responsive in real-time.
The instrument shall be a physical object	The instrument shall be capable of outdoor operation.
	All parts must be safe.
The instrument shall be interactable	Instrument shall use a physical interface capable of exploiting the instrument's characteristic allowances.
The instrument shall be electronically powered	Power and electronics must be safe.
	Components should be able to be powered from multiple different sources
	Electronic hardware design must be robust
The instrument shall be made and manufactured according to time and budget restrictions	Instrument shall be 'prototypable'
	Prototyping stages shall use a virtual testing configuration to learn and implement abstract implementations

1) Sound Requirements: The first requirement category is also the most crucial requirement: "the instrument shall produce sound." The design choices and specific requirements that are made from this design requirement are as follows:

- **Instrument shall use a rotor/stator type sound source.** Since there are many different siren designs, this focuses efforts by reducing the scope of the project to the chopper siren.
- **Minimize mechanical noise.** Since this instrument is creating sound, excessive noise is not ideal.
  - *Mechanical noise shall not exceed siren noise as heard from a distance of 10m at 50% duty cycle.*
- **Modulate pitch and volume precisely**. Here, we can be more specific with how the robot acts.
  - *Incorporate a high level musical planner.* Ideally, the musical planner conveys to the listener that 1) Miren has understood the input, and 2) transforms the phrase in an interesting way that exploits Miren's affordances.
  - *Generate smooth pitch and volume transitions*. The role of continuous changes in pitch and volume can not be understated when constructing a instrument whose design affords such iconic gestures. At the level of hardware, we must command an actuator to move at a certain speed, so we need to convert a planner's output (a series of notes) into a *trajectory*, a continuous pitch curve the motor is capable of following.
  - *Maintain a pitch range of 100-1000 Hz with a response time of 50ms.*
  - *Guarantee audibility at a distance of 100 meters.*
  - *Enable control over air intake source with 100ms actuation time.*
  - *Pitch and volume control must be precise to within +/- 1 Hz.*
- **Instrument shall be playable and responsive in real time.**
  - *Ensure rapid response times for both pitch (50ms) and volume (100ms).*

2) Physical Requirements: The second category, "The instrument shall be a physical object," is responsible for the physical requirements of Miren.

- **Outdoor operation.**
  - *Limit weight to under 50 lbs.*
  - *Limit footprint to 2 x 4 ft.*
  - *Support music playback for upwards of two hours.*

3) Interactivity Requirements:

- **Physical interface capable of exploiting the instrument's characteristic allowances.**
  - *Be capable of listening to its environment and understand a musical note and duration.*
  - *Generate a simple three-voice minor and major harmony.*
  - *Only play when being interacted with.*
  - *Capable of generating pitch and volume envelopes.*

4) Electronic Requirements: The fourth category covers the electronic considerations of Miren.

- **Electronic hardware design must be robust**. This implies
  - *Electronic components must be able to be powered from multiple different sources,* for example, a desktop or computer power supply. This facilitates the choice of flexible hardware, eliminating dependence on a single power source.
  - *Miren must be able to be controlled wirelessly.*
  - *Critical power wiring must use rated, spark-proof connectors.*
  - *Data wires must be routed safely and securely.*

5) Practical Requirements: We must also consider the practical limitations of this instrument.

- *Project must be completed within a school semester.*
- *Project must not exceed $1000 in total cost.*
- *High level sound design audio shall be generated by code for iteration purposes.*
- *Instrument shall implement a modular siren rotor and stator design.*

6) Safety: As a blanket requirement, safety must be taken into consideration. Of particular note are the mechanical and electrical safety considerations. Mechanically,

- *Ensure all rotating components remain within chassis members*,
- *Secure all parts with locking or redudant fasteners*

Electrically,

- *Power electronics must share a common ground.*
- *High current wires must be insulated, exposed wires must be covered either within a container, or insulated.*
- *Power supply components must be contained within a clearly labeled container within chassis members.*
- *Install a visible indiactor light to notify anyone the instrument is powered on.*
- *There must be a physical obstacle between the electronics and any rotating components.*

B. *Electrical & Mechanial Design*

Miren is split into two units: the **siren** and the **siren controller**. The siren is the physical instrument and contains all the elements of physical sound production. The microphone, 'continuatron' and trajectory generator responsible for creating Miren's control signal is located a distance away from the siren itself, near the user. This separation captures a key design intent: by placing the siren in a wide open space, the environment shapes its sound and subsequently the listener's experience. The artifacts of large outdoor reflections amplify the user's presence in the outdoor space, affording them an increased understanding of the surroundings in which they are a part of.

1) Electrical Design: Given the time and budget restrictions, I used two microcontrollers for both the siren and siren controller: an Arduino Uno r3 and a PJRC Teensy 4.1, chosen as they were readily available and provide all necessary PWM outputs as well as an SPI interface, necessary for a robust wireless connection established by a pair of RFM95W LoRa breakout boards. The LoRa wireless interface was chosen over more common WiFi and bluetooth interfaces since it is inexpensive, offers a higher bandwith than necessary for my data, and features a ~2km range depending on obstructions and frequency. Additionally, Adafruit offers a premade breakout board that does not require time-consuming custom PCB design, and there is a wealth of documentation and supported Arduino libraries online. At the siren side, a Turnigy Aerodrive SK3 (6374-149Kv) brushless outrunner motor provides plenty of power- upwards of 3000 watts (70A at 44.4v, continuous). I will be using a single 6s (22.2V) Multistar LiPo battery, with 10,000 mAh of capacity. These components were chosen as they were both readily available and boast extra performance headroom, should it be required. The motor controller is a Vedder Electronic Speed Controller (VESC) 4.12, an open-source, highly configurable motor controller capable of 50A continuous. An RS-1270 servo motor was chosen to be the valve actuator as it was the fastest actuating of the servos available, capable of rotating 60°in 110 ms. This is just shy of the 90°, 100 ms actuation speed required, but is not mission critical. This controller is both compatible with my hardware and offers a configurable PID speed controller, which offers flexibility in adjusting the siren's performance throughout note transitions. Additionally, this VESC offers overcurrent protection in the event of faulty signaling and FOC mode, a low-level motor controller that provides increased efficiency and quieter operation than the more traditional BLDC controllers. The schematic for both siren and controller-side circuits are shown below in Figure 2 and Figure 3. Note in Figure 2 the VESC 4.12 incorrectly labels their 'PWM' input as 'PPM', a legacy naming convention from RC hobbyists.

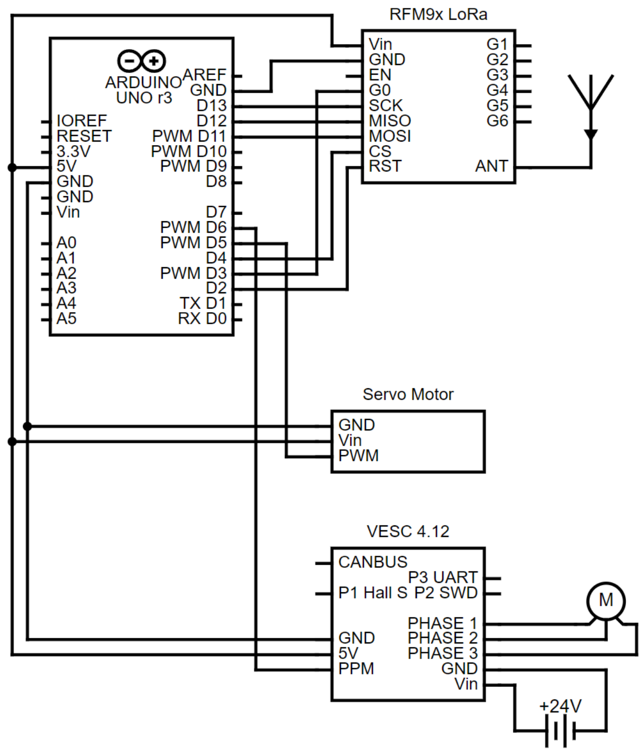

Fig. 2. Siren-side circuit diagram.

2) Mechanical Design: The robot is constructed from three upright 3030 aluminum rails, intersected with three plywood layers each separated approximately 30 cm, 100 cm, and 200 cm, moving from bottom to top. Each layer is structural in bracing the three upright rails, and are each joined to the rails with three 30 cm, 90°angle brackets. The bottom layer is 0.5" thick and provides a location for an enclosed electronic box to be mounted, and features a hole for the three motor wires to pass through, safely separating the electronics and the motor's spinning outrunner. The motor is mounted in the center of the second, 0.25" thick plywood layer, the rotating shaft protruding through a hole in the wood. A collet and tapered washer is mounted to the motor's shaft, precisely and securely mounting the stator to the motor. A direct-drive approach was chosen after continuous iteration upon modular siren designs proved increasingly expensive in terms of time and material, so I eventually chose a monolithic design for both the rotor and stator. The stator is 195 mm in diameter, and is concentric to a stator with an interior of 197 mm, creating a +/- 0.5 mm tolerance between the two edges. This way, the

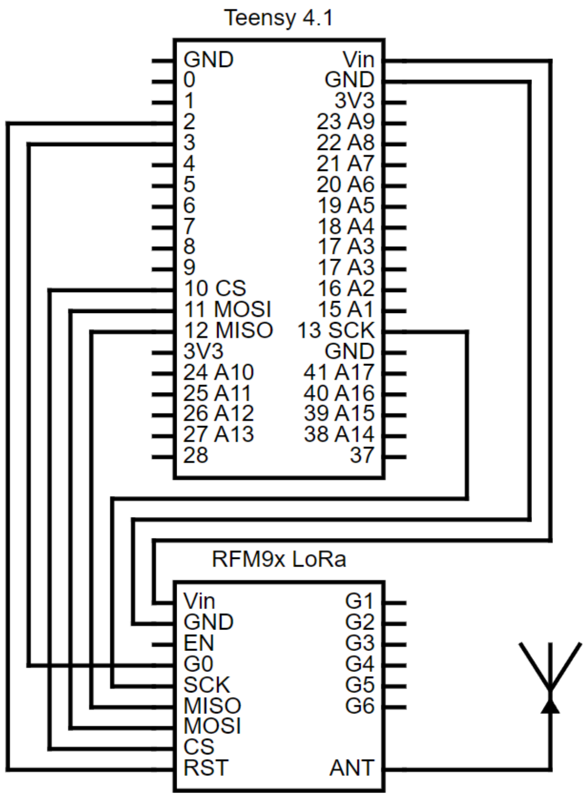

Fig. 3. Controller-side circuit diagram.

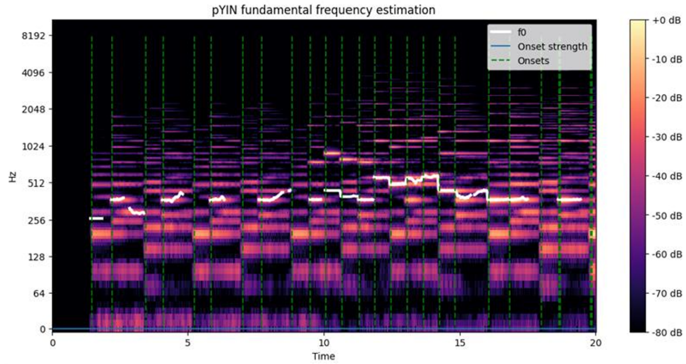

Fig. 4. pYIN algorithm with onset detection for ”Gymnopedie No. 1”

siren is louder, as it more efficiently creates pulses of air by minimizing the area air can escape through. The stator itself is mounted to the middle plywood plate, and the shroud is mounted to the top of the stator. The rotor, stator and shroud are each 3D printed using FDM and PETG, a flexible and impact-resistant filament that at less risk of shattering when spun at rapid speeds. Each 3D printed part is mounted by means of M4 screws and brass heat set inserts, chosen for their improved strength and holding ability when compared to plastic threads that more readily deform, and do not require the extra design time required for snap fit parts.

C. The Continuatron

To extract notes from an audio file, I make use of Librosa's implementation of the probabilistic YIN algorithm for fundamental frequency detection, paired with a energy onset detection by calculating the RMS energy of the audio file. An example of this type of analysis is found in Figure 4 below. This is capable of extracting distinct notes from an input audio file, which then must be processed before being handed to the Continuatron.

Put bluntly by François Pachet, ”Markov chains and music is an old and rather repetitive story.” [1]. While it might be repetitive, Markov chains remain a compelling way to generate convincing short-term musical phrases. The idea behind a discrete time markov chain in terms of musical generation is simple: when generating melodies, randomly select the next note by considering the chances of going to the next note based on your current note. That is, having previously analyzed a melody or a number of melodies, you can extract the conditional probability of a note following another note. For instance, in the *corpus* $\mathcal{C}$:

$$\mathcal{C} = \{D, E, F, G, E, C, D\}$$

It is clear to see when your current state is E, there are two options: E and C. Since there are two you have a 50% chance of picking either one as your next note. More precisely, the *transition probability* from E to F is 0.5, and from E to C is 0.5. This method of calculating transition probabilities can be scaled to encompass thousands of melodies. Calculate the transition probability for every note to every other note, and you can generate an novel, n-length musical phrase. Having no memory of longer term gestures, this method of generation only works during small time scales. In order to capture longer term dependencies, a simple addition to the model would be to capture both the current note and previous note when selecting a next note. This is a second order Markov model, and is the model I have used to process nearly 10,000 monophonic midi files as organized by van der Wel and Ullrich of the University of Amsterdam [10].

However, a discrete time Markov chain is not an interactive model, which is required for Miren. This problem is well addressed in Pachet's *Continuator*, where an input phrase is continued with consideration for (but not limited to) rhythm, having been learned in the Markov process, polyphony, using a combination of aggregation techniques, and imprecision, using a series of reduction functions that expand the range of possible next notes [7]. This level of style matching is advanced enough to pass the Turing test. Simply put, the level of technical and conceptual complexity of this system is beyond the scope of this project. Instead, I will be taking inspiration from Pachet's reduction functions to preserve long-term gestures of input data in order to stylistically match a musical input. The idea here is also quite simple: split an input melody into separate ‘regions' that each contain multiple steps. For instance, splitting the MIDI pitch sequence $\mathcal{N}$ into pitch regions $\mathcal{N}_{PR}$ containing five notes each would be akin to dividing the MIDI note by 5 and rounding down. For example:

$$\mathcal{N} = \{60, 61, 60, 64, 65, 71, 53, 52\}$$
$$\mathcal{N}_{PR} = \{12, 12, 12, 12, 13, 14, 10, 10\}$$

To this end, I have created the *Continuatron*, capable of taking an input sequence and returning a similar sequence that preserves the longer-term contour of the input. It first identifies the pitch regions that make up an input sequence and uses the second order Markov model as described earlier to generate pitches within the predefined pitch regions for each pitch region in the sequence. Optionally, the second order Markov chain can inherits the first two notes of the input phrase to create the characteristic ‘call and response’ of simple musical improvisation.

The design of the Continuatron is very extendable. For instance, to make the Continuatron able to develop melodies more similar to the input melody, the pitch region can be decreased, or an input bias probability can be set to determine if the current pitch region uses 1) the Markov generator to create a novel pitch or 2) a copy of the input melody at that point in time. To make it more dissimilar, the pitch region can be increased, or the amount of notes *per* pitch region can be altered to increase or decrease note frequency, which is usually set to copy exactly the same number of notes in each region.

Currently, the Markov Model I have created is capable of creating a novel string of MIDI pitches, durations (1: whole note, 0.5: half note), and relative MIDI pitches (-1, 0, -2, 4). At this moment in time the planner can only create these novel sequences independently, so rhythm generation is decoupled with pitch. A quintic spliner is capable of joining these pairs of pitch and duration to create useful motor speed trajectories, and I have written a simple sine and triangle wave generator to play back these trajectories which have helped with understanding the output of these generators. While time constraints have limited my work on the Continuatron to pitch regions, there is no reason this could not be applied to duration, relative pitch, or relative duration.

IV. Results

The instrument is capable of reproducing perceived pitches from a quiet C3 (~130 Hz) to an ear-splitting C6 (~1109 Hz), and is capable of both steady and modulating trajectories with varying levels of success. Figure 4 below shows a graph of motor speed throughout a sweep up and down two C Major scales.

A. Pitch

I created two trajectories to test the pitch response of the siren. the first trajectory moves across two C major octaves, climbing a series of whole and half steps until it reaches C6, then climbs back down. The second moves across four octaves in 12 step intervals: C3, C4, C5 and C6. Each note transition uses a ramping time of 20ms to prevent motor current spiking

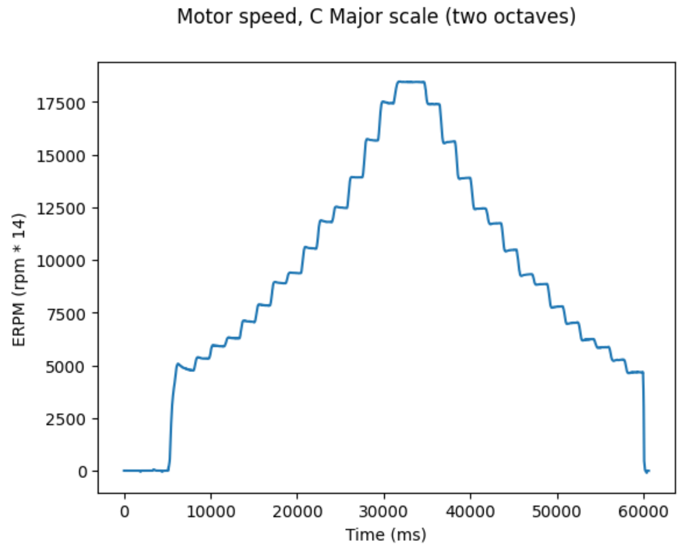

Fig. 5. Motor speed over a two C major scales.

beyond safe levels and triggering an overcurrent fault, disabling the motor. After setting current limits and tuning the PID controller, I was able to achieve 50-150 ms pitch transition time over single steps, and a 500 ms transition time over 12 steps. These are measured from initial ERPM rise and peak of the motor controller’s overshoot.

The controller’s performance over short intervals at low speeds look very similar to the performance over short intervals at high speeds, as illustrated in Figures 5 and 6 below. Indeed, each transition takes around 50-100 ms, with exception of the slowly ramped starting frequency, as shown clearly in Figure 4. The controller seems to have had a slightly harder time transitioning between low speed notes as shown in Figure 5. This might be attributed to the motor’s rotor gaining angular momentum and having a smoothing effect during faster speed transitions.

Over large intervals, the pitch response becomes much slower at ~500ms. In the worst case, between notes C5 and C6, the motor does not settle over the course of two whole seconds. Perhaps the most difficult part of tuning the controller was to adjust overshoot and settling times across a different variety of scenarios.

B. Volume

I recorded several different pitches, valve states, and distances to further provide more insight to the instrument’s performance. To see how much the valve changed the pitch of the instrument, I left it fully open and closed while both near (1m) and far (7m) away from the siren. I then did this at several different intensities. Hardly audible at a distance, C3 produced a much more muted sound when heard up close. At C4, there seems to be little difference between valve open and closed states at a close proximity, but a much more muted sound at a distance with the valve closed. It does seem some high end gets removed when heard from a distance. Comparing noise

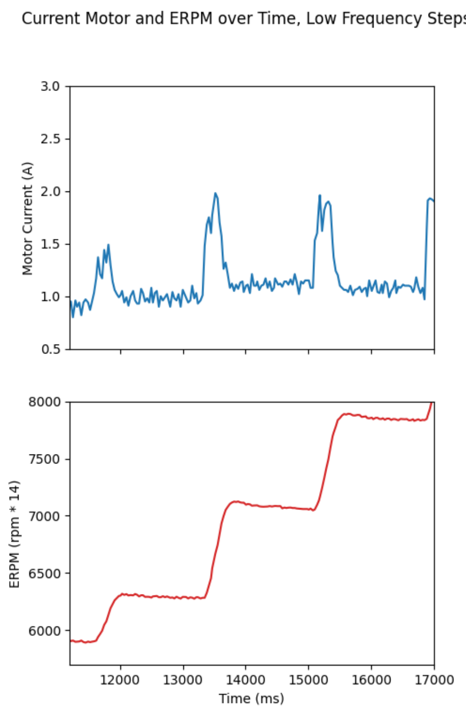

Fig. 6. Small transitions, low speed

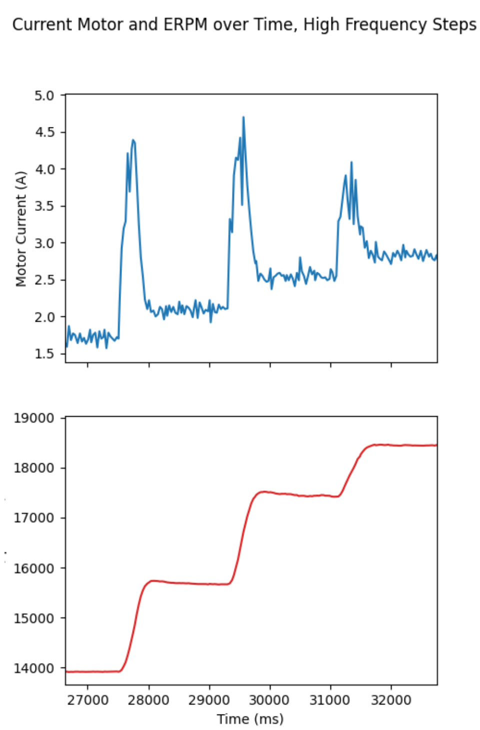

Fig. 7. Small transitions, high speed

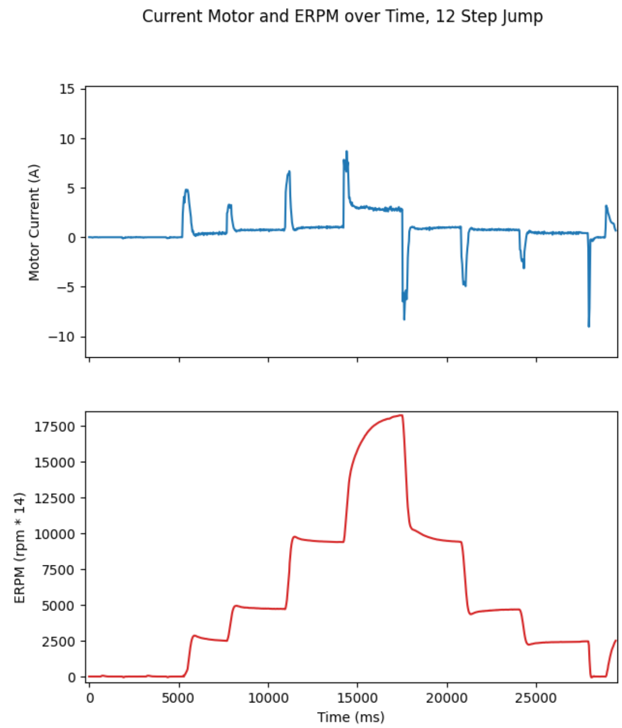

Fig. 8. 12 step tranitions

levels between Figure 11 and Figure 10 shows a significant jump in sound intensity, and even more so between Figure 12 and Figure 11. At C6, it is clear the fundamental frequency is losing intensity with a closed valve at both close and far distances.

V. Evaluation

While the time I have had to extract results from the instrument have been limited, the siren in its current state is in fact capable of a wide range of pitches, ranging from C3 ($\sim$ 130 Hz) to C6# ($\sim$ 1109 Hz). I realized after analysis I had mistook the siren's fundamental frequency for the second harmonic, which is double the fundamental. For the purposes of a musical instrument, since it is the loudest of the fundamentals, I would like to say this requirement has been at least partially fulfilled.

There does exist a high level musical planner capable of generating a transformed input phrase, however the complete integration of this planner into the robot to create a live, interactive experience has not been fulfilled.

Since there is some mechanical noise in the vibration of the mounting plate at certain motor speeds as well as some coil noise from the motor, the requirement limiting excess mechanical noise has been fulfilled in all but the lowest of frequencies.

Miren is also capable of rapid pitch modulation (around 50-100 ms) in the context of small intervals at high rotational velocities, even if they still suffer from a small amount of over-

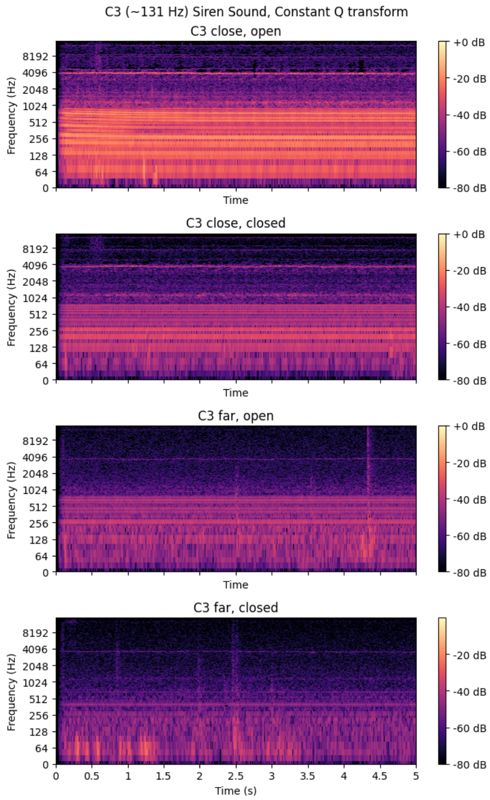

Fig. 9. Spectrogram at C3 (proximity, valve state)

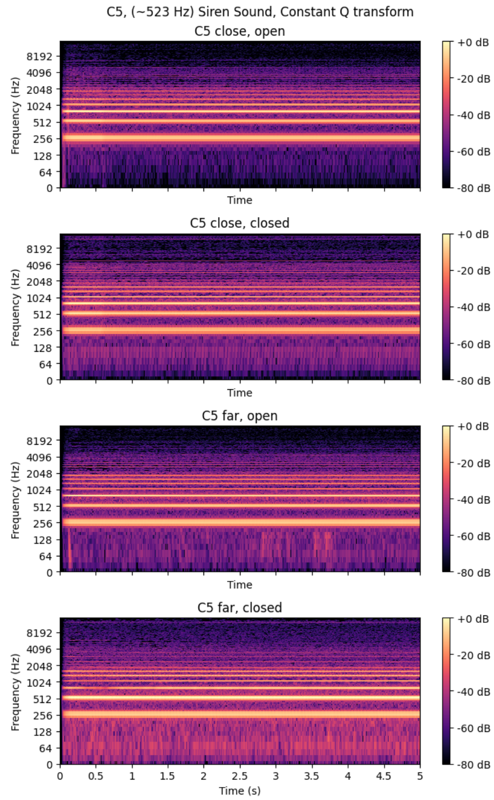

Fig. 11. Spectrogram at C5 (proximity, valve state)

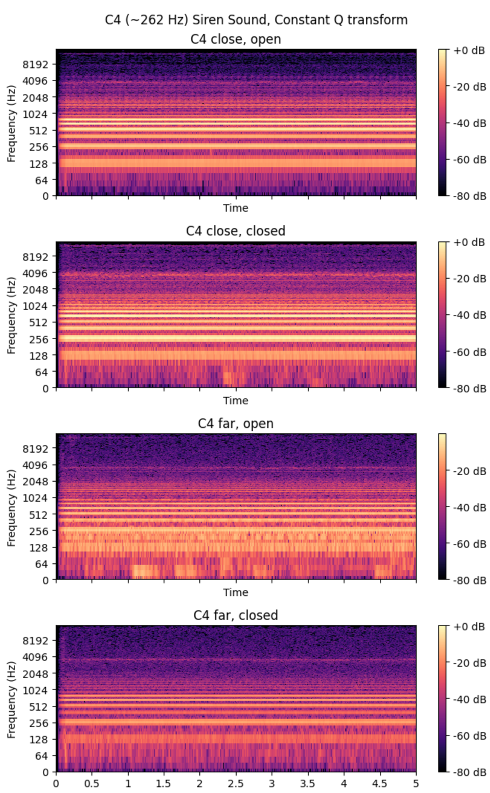

Fig. 10. Spectrogram at C4 (proximity, valve state)

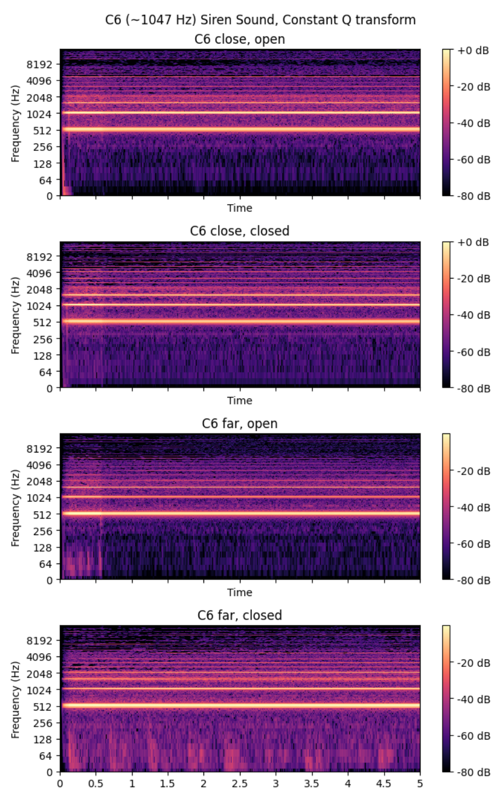

Fig. 12. Spectrogram at C6 (proximity, valve state)

shoot. However, larger intervals suffer from much more pronounced undershoot. To create a controller adequate in most scenarios, there must be a balance in the speed controller's configuration without completely changing the design. Perhaps additional tuning or increasing the motor current limits might allow for more precise pitch articulation. This leaves the requirement of 50 ms pitch response as unfulfilled. However, having listened to the siren as the controller works hard to spin up and down, unique pitch envelopes are displayed.

While I haven't tested this instrument outdoors, it is an auditory safety hazard indoors. You must wear earplugs if you are within a ten meter radius of the machine. At full speed, the siren can be heard from much further than 100 meters. Since it is quiet at lower speeds, the requirement to be clearly audible from a distance of 100 meters is partially fulfilled.

Equipped with a 80 cm inlet, the valve practically mutes the siren at low speeds, and subtly removes low end at high speeds, as shown in results. The requirement to be "capable of controlling the air entering each siren source" has been fulfilled, but in service of reducing the siren's volume, hasn't been tested to be able to give a clear answer beyond 7 meters. While volume control hasn't been tested beyond the fully closed and fully open scenarios, the siren is very capable of maintaining a pitch request within +/- 1 Hz, as clearly seen in figures 8-12, fulfilling this requirement.

While unforeseen material and time constraints have made weatherproofing the siren difficult and therefore a secondary consideration, the two subsequent requirements, not weighing in excess of 50lbs and not exceeding a 2 x 4 ft footprint, have been fulfilled. While first glance power estimation would suggest a 10,000 mAh battery is capable of powering the motor for hours at a time at a steady state, I have not made any calculations for the typical power consumption of this siren over the course of an melody that may be played with a variety of articulations. The requirement of being able to play music upwards of two hours is unfulfilled.

Though initial tests were promising, the wireless abilities of Miren have not been implemented. This requirement remains unfulfilled. Other hardware and electrical requirements have been fulfilled with the exception of the modular design requirement, having been de-scoped for consuming excess time and material.

A. Limitations

VI. Conclusion

This report has presented a semester-long project where I attempt to create a musically-interactive chopper based robotic siren, the research and development of which has resulted in the creation of several different core components of what could eventually turn into a truly compelling robotic instrument. While setbacks by unforeseen material problems (and foreseen time problems) have prevented me from creating a real time interactive siren, Miren currently functions as a unique electromechanical device that produces an intense and haunting noise that is capable of reproducing a wide range of pitches and monophonic melodies. The Continuatron has also been developed: a style-matching melody generator that is guaranteed to produce contours in a shape identical to that of melodies it has perceived.

VII. Acknowledgments

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References

[1] P. Pesic, "Helmholtz, Riemann, and the Sirens: Sound, Color, and the 'Problem of Space,'" Phys. Perspect., vol. 15, no. 3, pp. 256–294, Sep. 2013, doi: 10.1007/s00016-013-0109-1.

[2] J. Drant, P. Micheau, and A. Berry, "Active noise control in duct with a harmonic acoustic pneumatic source," Applied Acoustics, vol. 176, p. 107860, May 2021, doi: 10.1016/j.apacoust.2020.107860.

[3] A. Allard, N. Atalla, and P. Micheau, "Design and experimental validation of a high level electropneumatic source," Applied Acoustics, vol. 182, p. 107968, Nov. 2021, doi: 10.1016/j.apacoust.2021.107968.

[4] R. Collecchia, D. Somen, and K. Mcelroy, "The Siren Organ," Jun. 2014. doi: 10.13140/2.1.3520.9602.

[5] M. Sidler, M. Bisson, J. Grotz, and S. Barton, "Parthenope: A Robotic Musical Siren," Sep. 2020.

[6] "Mécanique Vivante — Inventions et spectacle," Mécanique Vivante. Accessed: Dec. 17, 2023. [Online]. Available: https://www.mecanique-vivante.com/fr/

[7] F. Pachet, "The Continuator: Musical Interaction With Style," Journal of New Music Research, vol. 32, pp. 333–341, Aug. 2010, doi: 10.1076/jnmr.32.3.333.16861.

[8] G. Hoffman and G. Weinberg, "Shimon: an interactive improvisational robotic marimba player," CHI '10 Extended Abstracts on Human Factors in Computing Systems, pp. 3097–3102, Apr. 2010, doi: 10.1145/1753846.1753925.

[9] E. van der Heide, "Spatial Sounds (100dB at 100km/h) in the Context of Human Robot Personal Relationships," in Human-Robot Personal Relationships, M. H. Lamers and F. J. Verbeek, Eds., in Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering. Berlin, Heidelberg: Springer, 2011, pp. 22-33. doi: 10.1007/978-3-642-19385-9_4

[10] E. van der Wel and K. Ullrich, "Optical Music Recognition with Convolutional Sequence-to-Sequence Models." arXiv, Jul. 16, 2017. doi: 10.48550/arXiv.1707.04877.