Legatus: Design and Exhibition of Loudspeaker-Based, Environmentally-Reactive, Soundscape Augmentation Artifacts in Outdoor Natural Environments

Nathan Villicaña-Shaw, Dale A. Carnegie
Victoria University of Wellington,
School of Engineering and Computer Science
nathanshawsemail@gmail.com, dale.carnegie@vuw.ac.nz

Jim Murphy, Mo Zareei
Victoria University of Wellington,
New Zealand School of Music
jim.murphy@vuw.ac.nz, mo.zareei@vuw.ac.nz

ABSTRACT

Legatus is a three-legged audio and environmentally-reactive soundscape augmentation artifact created for outdoor exhibitions in locations without access to mains electricity. Legatus has an approximate ingress protection rating of IP54, is self-powered, and is easy to transport weighing approximately a kilogram while fitting within a 185 mm tall by 110 mm diameter cylinder. With LED-based visual feedback and a cochlear loudspeaker-based vocalization system, Legatus seeks to capture attention and redirect it to the in-situ sonic environment.

Informed by related historical and contemporary outdoor sonic installation artworks, we conceptualized and tested four installation scenarios in 2021. Installations were presented following a soundscape-specific pop-up exhibition strategy, where the exhibition venue and artifact placement are determined by in-situ sonic conditions. Legatus artifacts use high-level audio features and real-time environmental conditions including ambient temperature, humidity, and brightness levels to influence the timing and parameters of sample playback routines, audio synthesis, and audio recording.

Having developed and tested for nine months, Legatus has emerged as a portable, rugged, affordable, adaptable, lightweight, and simple tool for augmenting natural sonic environments that can provide last-mile distributions of sonic installation art experiences to places and communities where these works are rarely exhibited.

Author Keywords

soundscape, soundscape augmentation, sonic art installation, soundscape-specific, natural soundscape, loudspeaker, audio recording, audio playback, audio synthesis, environmental protection, transportability

NIME'23, 31 May–2 June, 2023, Mexico City, Mexico.

CCS Concepts

•**Computer systems organization** → Realtime systems; **Embedded and cyberphysical systems;** •**Applied computing** → *Sound and music computing;*

1. INTRODUCTION

Legatus is a continuation of our work exploring the use of electronic feedback technologies to augment soundscapes in outdoor natural environments [15, 17]. While prior research focused on mechatronic and LED-based feedback systems, for the Legatus project, we develop a general-purpose soundscape augmentation artifact using loudspeakers that can be easily adapted to novel installation scenarios that we cannot currently realize using our existing systems.

Building on the foundation provided by this prior work, this paper first examines a variety of music compositions and sonic art installations produced in natural outdoor locations. This survey aims to contextualize the design, construction, and exhibition of Legatus by observing successful components and commonalities between works. Next, the Legatus hardware, firmware, and physical characteristics are introduced with a focus on the artifact's audio recording, playback, and synthesis functionality. This discussion is followed by the introduction of four unique installation use cases created to test adaptability to new installation scenarios. An overview of initial findings and observations is provided before concluding with examples of future work facilitated by this research.

2. RELATED WORKS

2.1 Soundscape-Reactive Outdoor Music Compositions

Creating art is often an exercise of discipline and control, where the artist manages the development, presentation, and final form of the artwork. However, within sonic arts and music composition, there are salient works that embrace indeterminacy and stochastic mechanisms either in their construction or to provide variations when exhibited. Our research is interested in music compositions and sonic installation artworks that are exhibited outdoors and which concede the (typical) advantages granted by indoor venues including control over the space's physical size, layout, lighting, color, heating, and presence of organisms (e.g. visitor capacity, absence of wildlife).

With the artistic goal to replace a location's ambient background noise to "take over the environment, putting a new one in its place", Frederic Rzewski's *Street Music* (1968) demonstrates awareness of the in-situ sonic environment as the score instructs performers to "regulate the level of your sound so that it seems to be slightly louder than that of the sound you hear around you... you are always seeking the softest sound."

With a greater focus on supporting and harmonizing existing sounds, a portion of Pauline Oliveros's composition *Environmental Dialogue* (1974) reads, "as each person becomes aware of the field of sounds from the environment, each person individually and gradually begins to reinforce the pitch of one of the sound sources that has attracted their attention" [12]. For *Environmental Dialogue*, performers highlight, support, and reinforce environmental sounds instead of replacing them with new sounds as with *Street Music*.

Taking a similar approach as *Environmental Dialogue*, David Dunn's score for *PLACE: A Performance in Ten Parts* (1975) includes a segment that instructs a solo vocalist to "sustain pitches in response to pitches heard in the environment. An attempt should be made to trigger resonances in the environment and reinforce these through selecting pitches" [6]. While also looking to the in-situ environment as a source for performer actions, *PLACE: A Performance in Ten Parts* additionally prioritizes the venue's acoustic properties by encouraging performers to engage with environmental echoes and reverberations.

Using environmental reactivity as a means of fostering awareness of the in-situ environment, these example works allocate a significant portion of their realizations to the current performance venue. Rather than using any specific notes written on a page, the musicians who realize these works are influenced by real-time environmental conditions. Among other artistic objectives, our research aims to take advantage of the human-driven environmentally-reactive properties demonstrated in these works in installation scenarios driven by electronic devices that leverage environmental sensors and loudspeakers in place of human performers.

2.2 Soundscape Relocation in Outdoor Sonic Art

Sound art historian Alan Licht uses the terms *relocated sound* and *relocated soundscape* to describe a popular strategy used in sonic installation art where the artist mixes external audio recordings and audio streams with in-situ sonic environments to create hybrid listening experiences. Soundscape relocation is often implemented using an offline strategy by playing back a soundscape or sound recorded before the exhibit date from a location different from the exhibition venue. For example, Richard Serra and Philip Glass's *World Relocation Project* (1969) and Jim Green's *Talking Fence* (2010) both used short audio recordings of spoken words as source material for their augmentations [10, 1].

Real-time streamed soundscape relocation can be observed in works such as Benoît Maubrey's *Cellular Buddies* (1996) which allowed people to record audio for playback by calling a phone number. Alternatively, Emekah Ogboh's *Lagos Soundscapes* (2008-) features an uninterrupted field recording from a busy street in Lagos played through loudspeakers in European cities [2, 11]. Adopting the relocated sounds to his own artistic objective, Hans Peter Kuhn's *LICHT* (1999) relocates sounds over time but not space by playing recordings conducted in the installation venue well before the exhibit and when the space was used for different purposes [7, 10].

Considering that our high-level research objective is to design hardware systems that can be reused for several distinct installation scenarios, technologically supporting sound relocation greatly increases the flexibility and reusability of the Legatus platform. Therefore, by supporting this strategy, there is the potential to reduce future project costs and time overhead or enable the conceptualization and realization of greater numbers of installation scenarios. While soundscape relocation is common within sonic art installations, typically the cochlear[1] focus of these works is the sounds produced by the artist instead of the in-situ sonic environment. Our research aims to create installation scenarios where the artist's cochlear augmentations serve to highlight features of the in-situ sonic environment and encourage in-situ listening to sounds not produced by the artist.

2.3 Synthesis in Outdoor Sonic Art

Throughout the 20th and 21st centuries, sonic artists have employed audio synthesis systems to provide real-time cochlear content in outdoor sonic installation artworks. For example, Stuart Marshall's *Usk* (1969-70) mixes synthetic soundscape augmentations with the natural world by focusing on Marshall's cochlear augmentations while ignoring the physical properties of the sound-producing technology. This approach is also demonstrated by works such as Max Neuhaus' *Times Square* (1977) which used a hardware-based stochastic generative synthesis system hidden from view whose sounds are not directly related to environmental conditions [5].

While the installations *Usk* and *Times Square* used nearly continuous cochlear augmentations which mix with existing sonic conditions to create augmented sonic environments, other artists have incorporated silence into their installation scenarios to highlight in-situ sonic conditions or actors. John Cages's *4'33"* (1952) provides a radical example of this paradigm where the only cochlear content is the opening and closing of the piano's key cover and the turning of the score's pages [4]. Periods of cochlear inactivity can also be observed in works such as Annea Lockwood and Bob Bielecki's installation *Wild Energy* (2014) which includes extended interludes of cochlear inactivity to encourage listening to the site's ambient sounds while comfortable outdoor furniture is provided [10].

Instead of hiding their sound-producing mechanisms from view, Jon Hassell's *Elemental Warnings* segment of the installation series *Landmusic Series* "involved 20 miniature oscillators, which beeped their way into the atmosphere on helium-filled balloons one day in 1970" [8]. This exhibition strategy is strikingly similar to the pop-up exhibition strategy we adopt with Legatus as both are conducted on a single day and leverage the spatial distribution of several self-powered, transportable, sound objects according to in-situ environmental conditions.

Also operating in outdoor natural environments, the artist Leif Brush created numerous influential works where the system electronics are prominently featured as a visual component of the installation. Brush's *Terrain Instruments* (1968 – 1970s) featured a centralized electronic system woven into the surrounding landscape using numerous wire-like

[1]We use the terms cochlear and non-cochlear as developed by Seth Kim-Cohen in [9] where cochlear refers to the physical experience of sound waves as they pass through the ear and are translated into neural impulses, while non-cochlear refers to the perceptual experience of sound as interpreted by the brain, which includes cultural, social, and psychological factors.

sensors wrapped around flora. The physical presence of the sound-producing electronics as seen in these works by Hassell and Brush has been observed to promote physical exploration [8].

These works show synthesized cochlear soundscape augmentation as a time-tested and consistently implemented method for creating sonic installation artworks. While many artists choose to hide the physical devices for artistic reasons including the desire to focus attention on the sounds they are adding to the environment, some sonic installation artists including Leif Brush and Hassell prominently feature the physical and visual qualities of their creations along with the sounds their devices create.

To ensure Legatus has a high number of artistic and technological capabilities so future research projects can use it without requiring substantial hardware, firmware, or physical changes the platform should support both of these installation scenarios. Moreover, to support our artistic motivations, Legatus should appear to be more of a sculpture than a consumer-available outdoor speaker. Furthermore, the artifact should maintain a small size and a high-gain cochlear feedback system that allows it to be hidden from sight when installation scenarios require it.

3. LEGATUS SOUNDSCAPE AUGMENTATION ARTIFACT

The Legatus project is part of a larger series of outdoor hardware and firmware systems optimized to provide real-time soundscape augmentation. These artifacts are exhibited with the common artistic objective to create installation scenarios that encourage and promote in-situ environmental listening in outdoor natural locations. Serving as an extension of our prior work investigating non-cochlear soundscape augmentation with Speculātor [15, 14] and mechatronic-based augmentation with Explorator [17], Legatus addresses artistic and technological gaps identified in our prior systems by using loudspeaker-based soundscape augmentations.

Legatus uses the soundscape-specific pop-up exhibition strategy initially developed with the Speculātor soundscape augmentation artifact during field expeditions in 2019 [15]. The soundscape-specific pop-up exhibition strategy uses in-situ sonic conditions to determine exhibition locations and the specific placement of soundscape augmentation artifacts. After soundwalking to determine artifact placement, installation facilitators document the installation and collect subjective evaluation data to inform future exhibits. Soundscape-specific pop-up exhibition prioritizes the in-situ sonic environment over all other environmental or logistical factors and is realized in short day-long installations that are intended to expedite the artistic and technological iterative design process.

3.1 Design Considerations

As Legatus is explicitly created for exhibition in outdoor natural locations, self-power, robust electronic enclosures, and transportability are primary design considerations. In order to increase artifact adaptability and reusability, Legatus needs real-time audio synthesis, audio recording, and sample playback capabilities, and environmental sensors to guide behavior. To summarize, the Legatus genus adopts the following design priorities:

- **Self-Power** to support exhibition in remote natural environments for 16 hours on a single charge.
- **Transportable** so multiple artifacts can be transported by foot by a single person to installation locations.
- **Environmentally reactive** hardware and firmware that can respond to in-situ conditions in real-time.
- **Environmentally resistant** with an approximate ingress protection rating of IP54 to protect electronic systems from exposure to adverse weather conditions.
- **Adaptable** loudspeaker-based vocalization[2] system capable of audio synthesis, sample playback, and audio recording.

3.2 Audio System

Due to the artifact's use of battery power, the audio system must demonstrate reasonable power efficiency while also supporting the realization of synthesized and relocated soundscape vocalizations. To support sample playback the audio system must include non-volatile storage to store audio samples and recordings between installations. A capable DSP processor is needed to process audio files, manage effects, and control filtering. A codec is needed to encode analog microphone voltages into a digital signal and decode audio data from storage for the DSP processor to operate. An efficient amplifier must then boost the signal strength from line to speaker level while a fairly broad-spectrum loudspeaker then must transduce electronic audio signals from the amplifier to audible sound. From a technical perspective, we began the design process for Legatus taking into consideration the following requirements:

- **Common Considerations**
  - voltage regulator power conversion efficiency above 85%
  - minimal external circuitry and PCB layout area
  - compatibility with other hardware components and systems
  - support CD quality stereo recording, playback and DSP at 44.1 kHz with 16-bits
- **Codec**
  - encoding and decoding sample rate of 40 kHz or greater to capture frequencies up to 20 kHz
  - encoding and decoding bit-depth of 16-bits or greater to support industry standard CD recordings and the microphone bit-depth
- **DSP**
  - buffer, read, and write stereo I^2S audio stream to/from non-volatile storage at a minimum rate of 10 MB per minute to support recording and reading stereo .wav files [13]
  - audio rate polyphonic sine, triangle, square, and sawtooth wave production
  - basic audio effects including equalization, echo, reverberation, and distortion
- **Non-Volatile Storage**
  - minimum capacity greater than 7.2 GB to store 12-hours of stereo recordings
  - 10 MB/sec minimum read and write speeds
- **Amplifier and Speaker**
  - minimum reproduction of frequencies from 160 Hz - 17 kHz within ±6 dB
  - optimal reproduction of frequencies from 80 Hz - 20 kHz within ±6 dB
  - less than 1.0% THD at 81 dB-SPL

[2]The term vocalization is used in the paper to describe cochlear content produced by Legatus artifacts and to anthropomorphize the artifacts as electronic creatures. It is not intended to refer to the human or animal voice or to vowels, and is used in contrast to non-cochlear environmental feedback produced by the LED feedback system.

3.3 Hardware Systems

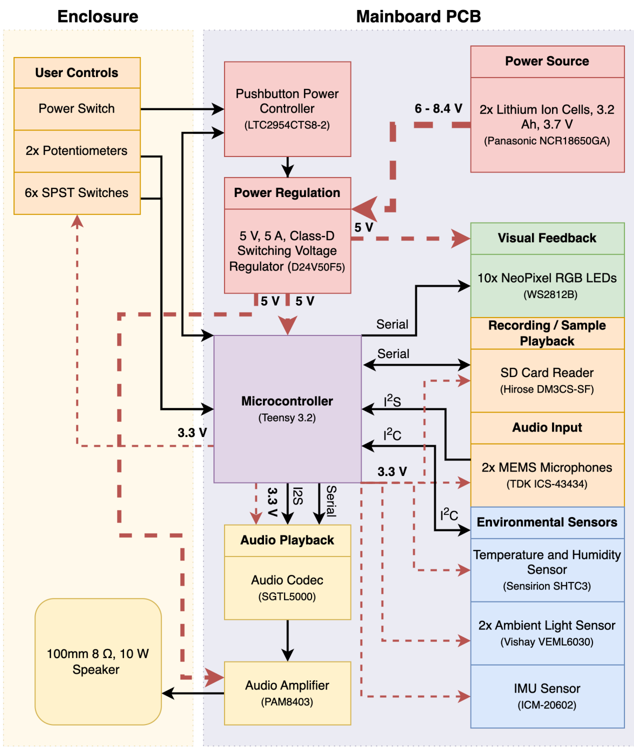

Figure 1: Legatus hardware system integration.

Legatus incorporates findings and components from our prior work creating outdoor soundscape augmentation artifacts for its hardware, firmware, and physical construction. This includes, but is not limited to, an array of onboard RGB LEDs for non-cochlear visual feedback, a transparent acrylic pipe electronics enclosure, a laser-cut acrylic body, three adjustable legs, and 3D printed mounting hardware and feet (Figure 1) [15]. As these related research projects share many technological implementation elements due to the same high-level artistic objective and soundscape-specific exhibition strategy, this paper focuses on the newly explored Legatus features of loudspeaker-based cochlear feedback and audio recording.

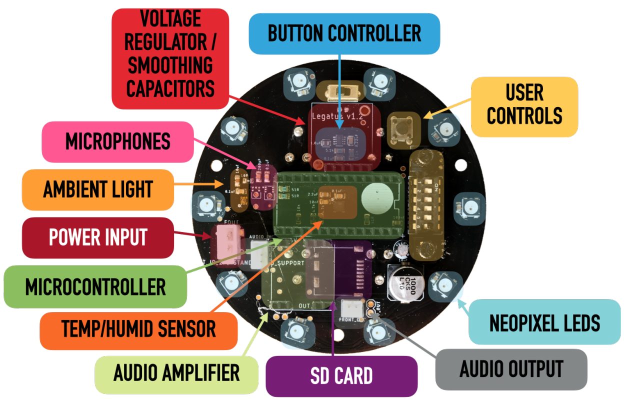

Figure 2: Legatus PCB top side.

Legatus utilizes a single circular 86 mm diameter PCB that houses all electronic systems including a Teensy 3.2 microcontroller that serves as the DSP processor and conduit for sensor and actuator control (Figures 2 and 3). Environmental sensors include an ambient light sensor and microphone on each side of the PCB, a combined temperature and humidity sensor, and an inertial measurement unit (IMU).

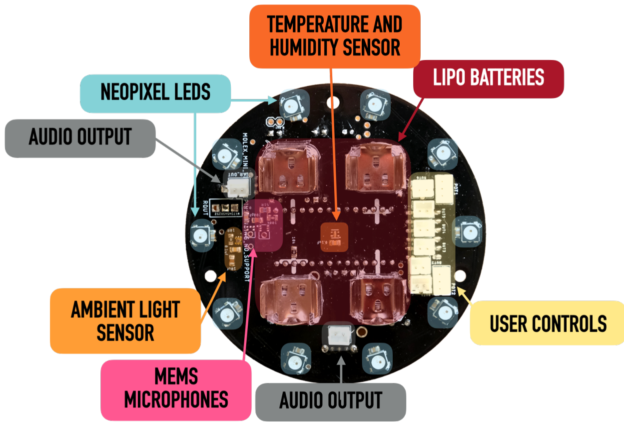

Figure 3: Legatus PCB rear side.

User controls include a power switch, two potentiometers, and six programmable switches which can also be accessed using wire-to-board connectors. Ten NeoPixel RGB LEDs are evenly spaced around each side of the PCB's perimeter while access to stereo audio output is provided on each side of the PCB. Two LiPo batteries and a voltage regulator are positioned onboard to power Legatus during installation.

While the use of solar power was briefly considered for Legatus, its use was not pursued in favor of battery power for several reasons. Firstly, the installations for the artifacts are designed to be self-contained for a single day and require no energy input during the installations. Additionally, the use of solar panels would require the use of batteries to store the energy produced, which would add to the cost of the units and decrease their transportability. Moreover, solar panels would limit the control over visual aesthetics and increase the size of the artifacts. Lastly, if the artifacts were reliant on solar power, they would only be functional when light is present, which would limit their exhibition locations and times[3].

3.4 Physical Design

Figure 4: Legatus installed in the Bear River in Northern California on April 17th, 2021

[3]The hardware systems are open-source under the MIT license and can be found at https://github.com/nathanshaw/Legatus

The physical design of Legatus consists of three primary components: a rounded equilateral triangle body, a transparent acrylic tube electronics enclosure, and three legs (Figure 4). The body has a maximum cross-section of 127 mm while the enclosure has a width and height of approximately 110 mm. A 100 mm clear plastic speaker cone is mounted to the top of the enclosure using screws and silicone sealant while the bottom of the enclosure consists of a laser-cut bottom cap with access to physical user controls. Three 8 mm diameter stainless steel linear rod legs are attached to the body using 3D-printed PETG mounting brackets. A modular foot system supports multiple foot materials, shapes, and colors to accommodate different terrains.

Legatus artifacts weigh just under 1000 g, while the enclosure provides an equivalent ingress protection rating of IP54 equating to protection from water splashes from all directions and the buildup of harmful particulates. Three identical Legatus artifacts were constructed and exhibited following a soundscape-specific pop-up exhibition strategy.

4. ARTISTIC REALIZATIONS

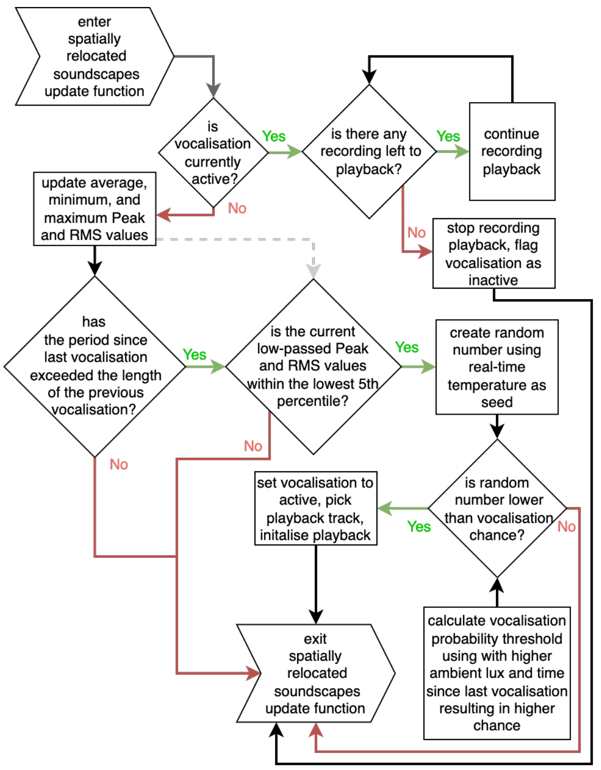

Figure 5: Legatus behavior for installation scenario 1: *Relocated Soundscapes.*

Three Legatus artifacts were exhibited in four distinct installation scenarios in outdoor locations from May 2021 through April 2021. Sharing the high-level artistic objective to highlight and encourage listening to in-situ sonic conditions, Legatus artifacts are programmed with several shared behavior characteristics in the installation scenarios. Among the shared characteristics is the use of artifact "listening" periods where Legatus ceases cochlear feedback while providing audio-reactive LED feedback. This strategy is adapted from Lockwood and Bielecki's *Wild Energy* (see 2.3) and is intended to direct attention from the artifact to the in-situ sonic environment. Another shared characteristic is the use of ambient light, temperature, and humidity sensor data to drive the length of these listening periods, the brightness and color of LED feedback, and the length and parameters of vocalization routines.

4.1 Installation Scenario 1: Spatially Relocated Soundscapes

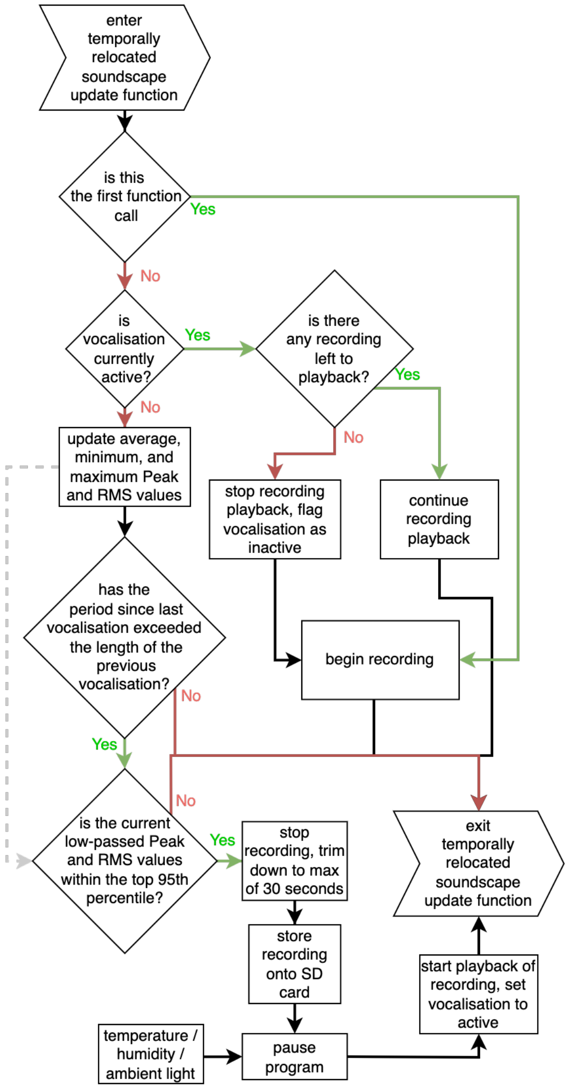

Figure 6: Legatus behavior for installation scenario 2: *Temporally Relocated Soundscapes.*

As demonstrated by works such as Ogboh's *Lagos Soundscapes* and Kuhn's *LICHT*, soundscape relocation is a proven strategy for augmenting sonic environments and promoting cochlear and physical exploration. In actualization of this augmentation strategy, the first installation scenario augments outdoor in-situ sonic environments by relocating sounds over space and time (Figure 5). The samples selected for playback aim to foster connections to the exhibition venue by leveraging components of the location's history, culture, geography, and biological characteristics, and include field recordings of industrial factories, natural soundscapes, burning fires, and sewing machines. As can be seen in publicly available video documentation [16], each of the sample sets (industrial, nature soundscapes, fire burning, etc.) produced drastically varied emotional undercurrents to the exhibition locations.

4.2 Installation Scenario 2: Temporally Relocated Soundscapes

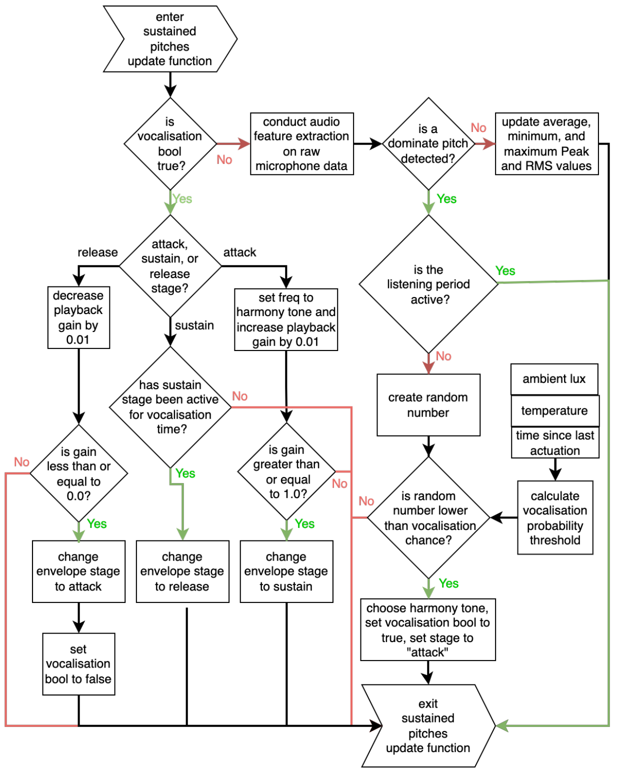

Figure 7: Legatus behavior for installation scenario 3: *Sustained Pitches*

The second scenario focuses on artifacts listening to the in-situ sonic environment, recording loud and abrupt sounds, and playing back its recordings at the location a short period later (Figure 6). This installation scenario draws artistic inspiration from a social phenomenon called "the echo chamber effect" [3]. With these inspirations, Legatus creates real-time soundscape augmentations that amplify, repeat, exaggerate, and distort audio recordings of the in-situ sonic environment.

Recording is engaged at the very start of the installation so Legatus can capture critical sonic events and is only stopped when the artifact is vocalizing. When Legatus does not hear a response to its vocalizations, it repeats its previously recorded sample at a slightly higher gain until it gets a response from the sonic environment. If no new sonic events are identified, Legatus repeats the same sample at a higher and higher amplitude. After several repetitions, the gain increases so high that the sample is distorted beyond recognition. After a period of several minutes, to ensure visitors are given the time and sonic space to listen to environmental sounds, Legatus ceases its normal vocalization routine to engage in a listening period.

4.3 Installation Scenario 3: Sustained Pitches

The third installation scenario tasks Legatus artifacts to enact a part from David Dunn's installation series *PLACE: A Performance in Ten Parts* (1975) that instructs performers to "sustain pitches in response to pitches heard in the environment". To realize this installation scenario, real-time pitch detection listens for the presence of a dominant frequency in the sonic environment (Figure 7). The higher the confidence that a pitch is present the higher the chance of vocalizing. When vocalizing, Legatus harmonize with the identified pitch by vocalizing a tone randomly transposed up or down by harmonic intervals.

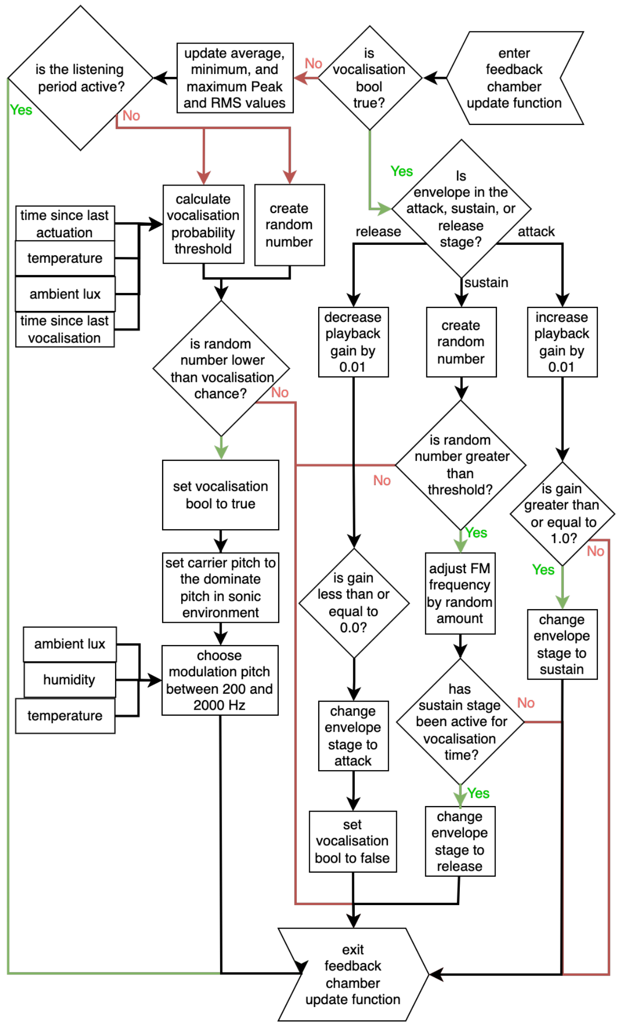

Figure 8: Legatus behavior for installation scenario 4: *Feedback Chamber*

4.4 Installation Scenario 4: Feedback Chamber

The fourth Legatus installation scenario explores mapping environmental sensor readings to influence the parameters of an FM synthesis system while also following the portion of Pauline Oliveros's score for *Environmental Dialogue* that reads, "as each person becomes aware of the field of sounds from the environment, each person individually and gradually begins to reinforce the pitch of one of the sound sources that has attracted their attention" [12].

The realization of this portion of *Environmental Dialogue* involves Legatus artifacts embodying the role of the "person" by listening to the in-situ sonic environment, extracting high-level meaning from the sounds it hears, and using its analysis to determine its vocalization parameter (Figure 8). This realization utilizes an FM synthesis engine and takes advantage of audio effects such as echo and reverberation. The frequency of the modular oscillator is determined by ambient light, temperature, and humidity while the carrier's frequency is the dominant pitch identified by the artifact's pitch detection routine.

5. INITIAL FINDINGS

5.1 Transportability

Legatus's light weight and relatively small size made it easy for a single person to transport multiple artifact instances to outdoor installation venues. By removing the artifact's legs during transportation they fit within a standard hiking pack along with provisions and other soundscape augmentation artifacts.

However, due to the use of acrylic as a primary building material and the placement of the loudspeaker exposed on the top of the electronics enclosure, Legatus can be damaged if mishandled and must be protected when packed for air travel. While conducting fieldwork, the setting up and dismantling of Legatus artifacts was streamlined. The setup time for each Legatus artifact was usually shorter than five minutes, while artifact dismantling took significantly less time at less than a minute per artifact. The majority of setup time was spent choosing the appropriate feet, positioning the legs, and adjusting physical user controls to optimize microphone sensitivity and playback gain.

During the test installations, the ability to install multiple artifact instances afforded larger augmented environments and the ability to stage interactions between Legatus instances by placing artifacts close to each other. While close artifact placement can increase the artistic effectiveness of some installation scenarios, such as with the Temporally Relocated Soundscapes scenario, this strategy must be carefully managed, as on some occasions, the vocalizations of multiple nearby Legatus artifacts clashed with the comparatively quiet in-situ soundscape to generate dissonant and chaotic augmentations.

5.2 Environmental Reactivity

While the timing and quality of Legatus vocalizations during exhibitions were directly influenced by light, temperature, humidity, and ambient sound, for many installation scenarios the mapping was too abstracted to easily be correlated with changes in environmental conditions. While these mappings provide intriguing artistic implications that support our objective to direct attention to environmental conditions, future work could benefit from exploring alternate environmental mappings which can more readily be identified by visitors without prior knowledge of their existence. Future realizations will additionally explore strategies such as directly mapping ambient light to vocalization amplitude for optimizing artifact vocalization gain and behavior routines.

5.3 Non-Cochlear Visual Feedback

The LEDs distributed on the top and bottom of the PCB combined with the transparent plastic building materials used for the loudspeaker, enclosure, and body resulted in a visual feedback system that was effective at directing attention to the in-situ sonic environment [16]. If Legatus did not provide visual feedback between its vocalizations during its listening periods, it is reasonable for observers to assume the exhibition is either concluded or taking a break. As the purpose of these periods of non-vocalization is to redirect attention to the natural sonic environment, the visual feedback helped to transition attention from the artifact's vocalizations to the sounds present in the environment.

6. CONCLUSIONS

Legatus hardware represents an expansion of our prior explorations with soundscape augmentation in outdoor natural

Figure 9: Legatus installed in early April 2021 within the Sierra Nevada foothills in Northern California.

environments [14, 15] by recording audio, playing audio samples, and synthesizing vocalizations. The Legatus soundscape augmentation artifact was introduced as a lightweight, simple, adaptable, self-powered, environmentally reactive, and environmentally protected device for creating sonic art installations in outdoor natural environments. Four test installation scenarios were realized in-situ to test the artifact's cochlear feedback and audio capture systems. Through its artistic and technological performance during this fieldwork, Legatus demonstrates high artistic promise as a cost-effective, easy-to-use, adaptable, soundscape augmentation artifact capable of realizing sonic art installations in locations where these works are rarely exhibited.

6.1 Future Work

To gain a more comprehensive understanding of the impact of Legatus, future work will involve examining the experiences of both the audience and artists. While valuable observational data can be obtained from installation facilitators, feedback from the public and critical perspectives is also necessary. However, due to COVID-19-related research limitations, including limited exhibition options and funding, gathering non-biased feedback has been challenging. As external restrictions gradually ease, future work will focus on comparing the effectiveness of Legatus's soundscape augmentation strategies in promoting and encouraging in-situ environmental listening to the strategies explored in prior research projects.

In addition, exploring the potential for networking Legatus devices could be an interesting area for future work. Multichannel audio is often advantageous in sound installations, and Legatus devices could communicate with each other to create a more immersive sonic experience. This could entail integrating Wi-Fi, Bluetooth, or other methods of establishing a network with each other or with nodes in other locations, such as a laptop or command unit. By taking advantage of Legatus's capabilities, a network could be relatively cheap and low-power using ESP32 microcontrollers instead of the current Teensy 3.2 microcontrollers.

Furthermore, Legatus has the potential to be used in other disciplines, such as a monitor for computer music performance or as an environmentally protected combined short-term audio and environmental data collection device. The artifacts' ambient light sensors could trigger audio recordings of sonorous dawn and dusk choruses, which could be compared to temperature, humidity, and lighting data collected during the same period using the sensor array. Legatus was initially designed for outdoor soundscape augmentation; however, there is no technological obstacle preventing it from being exhibited indoors or in outdoor environments with higher concentrations of people.

7. ETHICAL STANDARDS

This research was conducted in adherence with the ethical standards of the Victoria University of Wellington, including guidelines for the ethical treatment of animals and the protection of the environment. The hardware and firmware systems are open-source under the MIT license[4]. To minimize potential negative impacts on the environment and its inhabitants, we took careful measures during the design, installation, and use of our hardware. Specifically, expeditions were conducted for short periods of a day or less, with a focus on leaving the environment cleaner than we found it. We also ensured that our interactions with animals were conducted in a responsible manner, and that the impact of our presence was similar to that of a loud hiker or camper. The installations were all installed legally on public land or private property with explicit permission, and we made a concerted effort to minimize the risk of environmental pollution resulting from the use of our hardware by ensuring all equipment is accounted for and transported out of installation locations. Our research team remained vigilant in ensuring ethical and responsible conduct throughout the course of our work. We welcome further discussion on these important ethical considerations.

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