Musical Sonification of Super High Frequency Lighting

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ABSTRACT

This paper explores the technical details and artistic possibilities afforded by "super high frequency lighting", a lighting technique in which the high-frequency oscillation of LED color parameters are invisible to human eyes yet visible through video camera lenses. Through the use of microcontrollers and software such as Max/MSP, high-level computer control over banks of LEDs becomes possible and easy to pair with sound-generating processes. We also present an audio-visual installation in which dynamic color patterns invisible to the human eye are tracked with cameras and sonified in real-time. With this paper, we seek to draw attention to the limits of human perception, hidden compositions of sound and images, and potential sonification strategies for high frequency lighting.

1. INTRODUCTION

Our everyday lives are increasingly mediated by technology. As a result, there is a growing global community of consumers spending a significant amount of time on their electronic devices. In the United States, the average person spends about 9 hours a day interacting with media devices such as TV, game consoles, smartphones, tablets and others [1]. Therefore one can observe an increasing amount of people in public staring into bright, illuminated screens, receiving predominantly visual information while consuming media. With this colossal rate of media consumption, users can at times fail to retain their judgement on the accuracy of the information intake. In line with these thoughts and observations, we intend to explore hidden audiovisual compositions that can be revealed through digital devices, through high frequency lighting and sonification of light data, adding another layer to our perceived reality.

In the case of computer music, performers staring into their screens throughout their performance is an ever-present issue in the field [2]. Staging computer music concerts where performers largely stare into their screens with very little physical motion creates a disconnection between them and the audience. It is up to each audience member to decide what sonic result corresponds to which decisions the performer may have taken on their computer, resulting in a very hermeneutic performance[3].

Super high frequency lighting is an interesting but not yet fully explored technique. This paper will aim to document the technical work and aesthetic choices that may be of use to others intending to make creative use of the method.

The relationship between sound and color have been under artistic and scientific investigation for centuries. During the 17th century, Isaac Newton specified seven different colors dispersing from a white light beaming through a glass prism which he called the spectrum: red, orange, yellow, green, blue, indigo, violet. He compared this visible spectrum of light with the musical scale[4] in the form of a color-music wheel. Newton corresponded the entire visible spectrum to one musical octave, starting from D and ascending on the Dorian scale. First, third and fifth colors he identified in the spectrum were colors red, yellow and blue (primary colors in subtractive mixing) respectively, reminiscent of a triadic chord. Newton's efforts of illustrating the unity of tones and colors were rather arbitrary, yet it can be considered as an early example of a search in the triggering of two different senses by the same stimuli. This psychological phenomenon, synaesthesia, would eventually become a significant subject in cognitive science, supporting the condition with more concrete evidence; but further discussion of neurological and psychological effects of synaesthesia is beyond the scope of this paper.

The relationship between color and sound has been investigated within artistic practices as well; in the early 20th century, some inventors designed and built unique instruments that attempted to link together light and sound in expressive ways, addressed as color organs. Color organs existed prior to the 20th century, but merely as a collection of light sources that changed intensity and size according to sound[5]. In the early decades of the century, inventor Mary Hallock-Greenewalt acquired a number of patents on the design of her color organ, *Sarabet*[6]. She considered this preformative combination of light and color to be a new form of art, which she named *Nourathar* [1]. Hallock-Greenewalt performed known musical pieces together with colored light, but on the other hand Hungarian composer Alexander László created original compositions that joined music and painting together; he called the art form color-light music[5] and toured with his original instrument around Europe during the 1920s.

More significant examples of contemporary light sonification deal with data from astronomical observations; the frequencies of brightness variations from star light curves, evocative of sound waves, are scaled to audible range[7]. McGee et al. sonified light data from the cosmic microwave background, the earliest detected light in the universe. This radiation is not visible through optical telescopes[8] and thus the human eyesight, but can be picked up by radio telescopes. Similar to the case of observing the cosmic

[1] Arabic for "essence of light"

microwave background, the lighting phenomena subject to this paper is also invisible to the bare eye, but the observer is able to view the effects through a digital camera, and the data streamed from the devices are sonified as the auditory part of the installation.

2. SUPER HIGH FREQUENCY LIGHTING

To the best of our knowledge, the only artistic implementation of this lighting technique has taken place in the form of visual/architectural installation works *Rate*[9] and *Rate Shadow*[10] by Daito Manabe and Motoi Ishibashi. No technical documentation of the works are available to public; nonetheless, this paper will refer to the technique with the name given by the mentioned artists, *super high frequency lighting*.

The underlying mechanics of the lighting process is as follows: red, green and blue channels are modulated on and off sequentially at a frequency range between approximately 500 Hz and 1 MHz. Due to the high switching frequency rate, the color change is not noticeable to the bare human eye, which detects a solid white light resulting from the speedy mix of red, green and blue channels. However, the frame rate of digital cameras on various media devices we use daily are lower and strictly discrete compared to our eyes, where transition between frames are less sudden and more blurred. Thus when the same illuminating object is observed through a digital camera, the visual information is filtered by through the camera, which is unable to render the frames fast enough due to low frame rate. The image is now revealed as bands of distinct colors that add up to the color observed without any apparatus.

2.1 LED Circuit

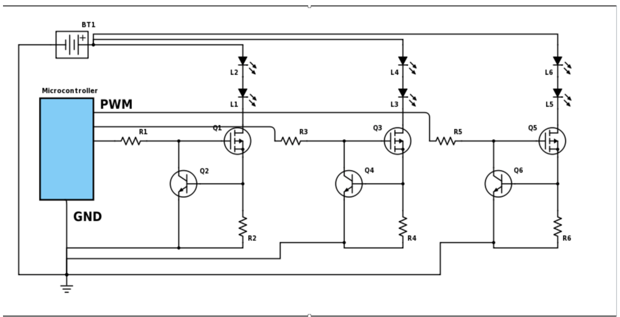

Figure 1. 3-channel, constant current power LED circuit diagram with PWM control

This effect can be realized with a standard microcontroller with PWM control and RGB LED units that do not operate through integrated driver chips; but in order to scale it up to an installation size, more powerful lights and faster controllers are necessary. High-power LEDs operate differently than simple LED lights often working at lower currents between 5-20mA; power LEDs need a much larger and constant forward current with a minimum of 350mA for each channel of 1 Watt units. This can be achieved by either specialized power LED drivers, or constant current circuits. To drive the power LEDs for this project a three-channel constant current circuit is built with a DC power supply, controlling color content and switching with pulse width modulation (PWM) from the microcontroller, as illustrated in the circuit diagram in Figure 1. Q1-3-5 are n-channel MOSFETs acting as variable resistors, Q2-4-6 are NPN bipolar transistors sensing the current on the circuit and R2-4-6 are power resistors. The main current flows through the FET and power resistor in each channel; if the current level on the resistor is over the required current level for the LEDs, the NPN transistor kicks in, turning off the FET and balancing the circuit current to the required level. This feedback loop continuously monitors the circuit and maintains a stable current for independent red, green and blue LED channels flickering in high frequencies.

2.2 Color Variations

The installation work aimed to create a white, steady light emitting from the object, which meant that each set of color combinations should yield white, according to the additive color system. Taking an RGB color wheel as illustrated in Figure 2 as reference, we can determine the possible combinations visually; a set of selected colors on the circle should have their center of gravity overlapping the center of the wheel. Numerically, the sum of color values for the set of color should be [255, 255, 255] in RGB values, or [#FFFFFF] in hex.

Within these technical boundaries, we have tested a number of color combinations, apart from the primary colors red [#FF0000], green [#00FF00] and blue [#0000FF]. Yellow [#FFFF00], magenta [#FF00FF] cyan [#00FFFF] are secondary colors in the additive system, and also produce white when mixed. Furthermore, opposites of primary colors, red-cyan, blue-yellow and green-magenta have been observed as suitable two-color combinations for high frequency lighting. Other two-color combinations we have tried include raspberry [#E30B5D] and malachite [#0BE390], orange [#FF8000] and azure [#007FFF], violet [#7F00FF] and lime green [#80FF00] among others. These mixes contain neither primary nor secondary colors, and thus require much more precise pulse width modulation to showcase the desired effects without having flickering problems. As exemplified above, the number of possible combinations are vast in theory; but, there are some issues with voltage differences that cause changes in brightness as well as the frequency of the PWM cycle from the microcontroller. These potential problems and our workarounds are reported in section 5.

Frequency of the color changes also have various visual consequences. Color bands increase in width when the rate of change is slowed down, and decrease when change occurs faster. Over 500 kHz and approaching 1 MHz, the color bands thin out so much that they blend in with each other, rendering the color combinations imperceptible even through the camera. The directionality of the color band movements are a result of aliasing; the motion depends on the camera frame rate and thus vary when observed through different devices. The speed of color band movement oscillates when flicker frequency is gradually changed, an effect of temporal aliasing inherent to the device's frame rate; during this change, the band speed initially increases, then slowly appears to decelerate due to the stroboscopic effect, and then starts accelerating in the opposite direction.

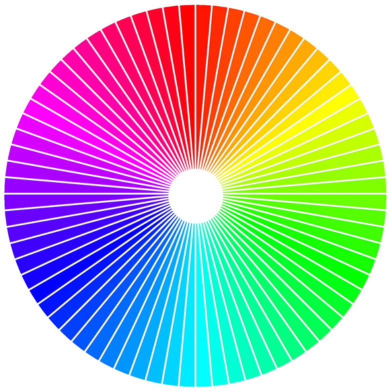

Figure 2. An RGB color wheel for visually determining possible color combinations. Selected colors must have their center of gravity on the origin to create a mix of white light.

3. SONIFICATION

A common definition of sonification is to convert data relations into acoustic relations in order to help communicate to and interpret the data to an observer[11]. The original concept for sonification was to facilitate the discovery of data structures through sound. But, Hermann points out that there is no clearly defined boundary between music and data sonification; since both are organised sound, sonification results can sound like music and interpreted as music, and music can be heard and understood as data[12]. An identical situation is also present in the visual domain, where at times it is challenging to differentiate a picture from a data visualization. Nevertheless, there are different expectations from each work in terms of function. The artistic work aims to affect the observer in a more emotional response through interpretation and inspiration, and data-based works are more concerned with transmitting information that can be discovered and learnt. Furthermore, Hermann introduces a list of prerequisites to define sonification in a strictly scientific construct. According to the author, the sonified result must represent the original data objectively, data-sound relation must be systematic, the sonic results must be reproducible with identical data sets, and the sonification system can be used with different data.

As pointed out earlier, the project and methods mentioned in this paper are primarily for artistic purposes, mediated by unusual use of technology and the limits of perception. Even though the auditory component is more aesthetically concerned than a data sonification project, all the prerequisites described above apply to our sound generation process in varying degrees. Thus, we consider the auditory portion of the work as musical sonification, where a balance between aesthetic experience and data accuracy is formed through the interpretations and decisions of the authors of this paper. Since the light data is generated on site by the microcontroller and not taken from an external objective source, the resulting sounds are aimed to convey both the received information and aesthetic qualities of a musical composition. In turn, the installation becomes a closed system where:

a. Control data is generated by the digital microcontroller,

b. High frequency light is emitted in the room, an analogue environment

c. Light is picked up by cameras, converting data back into the digital,

d. Camera vision is analyzed and selected data are transmitted to the sound engine

e. Sounds are generated, converted back into analogue and diffused in the room.

As described, there is a deliberate attempt to avoid direct sonification of the data, which could be done more efficiently without so many conversions between analogue and digital many times. This way, the sonified data is imprecise; it has more noise and variety and should not be considered as strictly data-related.

The main intention of the installation project was to expand the visual “reveal” effect of high frequency lighting towards a multi-sensory experience. The preliminary version had a stationary USB web camera as a part of the setup, looking into the object up close and sending the video stream to the sonification patch. Here, the revealed camera image of the object in colors was analyzed in terms of color content, density, and movement speed (movement of color bands depend on the camera frame rate).

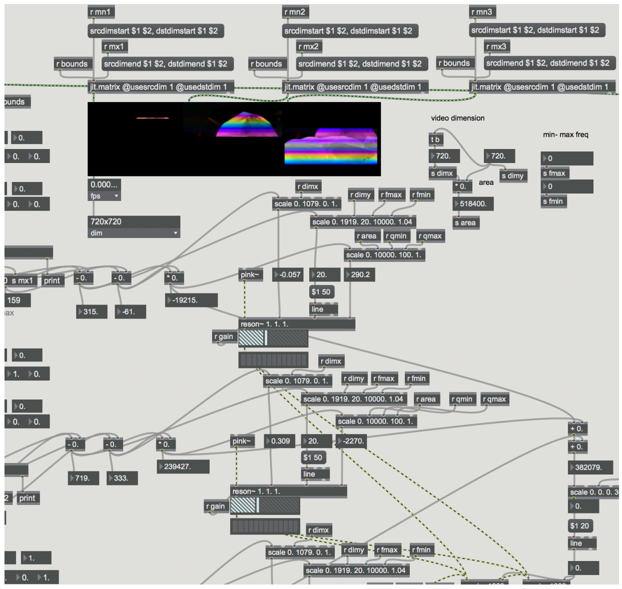

Figure 3. A section of the sonification patch; the streamed video is analyzed by color content, movement and dimension, then mapped into audio parameters.

The sonification patch aimed to create moving clusters of timbre in the stereo field analogous to the visual counterpart. The sound engine is a Max/MSP/Jitter patch as seen on Figure 3; the camera vision is streamed in and analyzed real-time, the values then mapped to specified boundaries for sound generation. An array of pink noise generators going through resonant filters activate if specified colors are detected. Pink noise carries equal noise energy in each octave, so is more dynamically balanced compared to a white noise source. Width, height and motion of color bands affect the center frequency, filter gain and Q parameters. Furthermore, the total size of detected colors determine room size and level of reverberation. Further away the camera is positioned, softer are the sonified sounds, while as the camera nears closer to the object, sounds become brighter and louder. An interesting effect occurs when the color mix and switching frequency jump to different values; the sudden change causes the filter to expand and contract rapidly, changing the perceived width of the sound. Visible flickering of the light source is undesired and avoided in this project, since it impairs the experience when our plain eyesight is able to pick up dynamic information from the system; yet, we would like to note the sonification of the observable flickers also put out interesting sounds when streamed to the sonification patch.

The most recent tested version operates through a more interactive sonification process. Instead of a fixed camera reporting to the sonification engine, participants view the camera image through a mobile application wirelessly connected to the engine, sending various visual data via OSC messages through their own devices. The application can be downloaded via scanning a QR code or entering the link provided at the installation site. This way, the participants are encouraged to move around the object and observe it through changing proximity and angles, influencing the data and the sonic output through their devices. The application is an iOS camera application made with Unity game engine (C#), outputting pixel color data via OSC messages to the central sound engine on a static IP address. The sonification engine receives the data and analyzes the color content, color movement that results from temporal aliasing and image brightness altered by the proximity of camera to the object.

4. INSTALLATION

The installation was set up in a dark room without windows, and consisted of nine 10-Watt RGB LEDs placed in a 3×3 grid, based under a frosted acrylic sculpture and homemade alum crystals. Stereo reference monitors, a webcam streaming the image to the sound engine(first version), and a tablet viewing the object via a front camera demonstrating the visual effects. The constant current circuit, DC power supply, a Wi-Fi hotspot for the second version, audio interface and computer running the sonification engine were hidden from the display.

In order to make sure all participants' devices focused on the installation piece with ease, the bright illuminated object was surrounded with black fabric, covering other bright surroundings and reflecting the least amount of light possible. This way, cameras focused on the object with ease and revealed the lighting effect and initiated the sonification. Observing through smart phone and tablet cameras may require manual focus on the object in order to reveal the composition if the device fails to handle it automatically; on touch screen devices tapping on the object image quickly adjusts the focus to the desired state, depicted in Figure 4. We have noticed that powering both the microcontroller and the audio interface through the same computer causes a signal interference. The PWM signals from the constant current circuit bleeds into the monitors and excites the speaker cones, unintentionally sonifying the control signals. We recommend powering these modules separately to avoid signal intrusion.

Although the stationary tablet on the installation site was successfully demonstrating the effects, we have had problems communicating to the audience that they can observe through their own devices too; some of the observers assumed the image on the tablet was another footage and not live. In order to facilitate interaction between the object and the observer, we first put up a sign encouraging them to take a picture. This was replaced with an instructive illustration in the subsequent version. Even though the first version of the work was a fixed audiovisual composition of about four minutes on a loop, a number of viewers could not be sure whether the installation was interacting with their physical motion or not, an unexpected response worth noting.

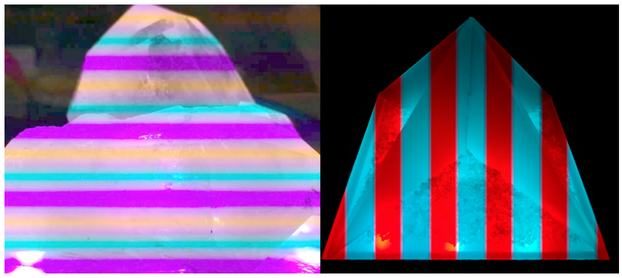

Figure 4. *RGB Gate*: Test footage (left) and installation (right)

5. CONCLUSIONS & FUTURE WORK

This paper discussed the sonification of high frequency lighting, demonstrated by an audiovisual installation project. We believe this lighting technique has the potential to become a creative tool for diverse artistic projects; thus, the paper documented the concept and reported the implementation of the method for others who may wish to use it. The installation brings up numerous discussion topics, such as our perceptual thresholds and their limitations, observing different layers of reality via everyday communication devices and our association of color with sound. Furthermore, we intend to encourage the audience to contemplate on the accuracy of information transmitted to us through our devices and its relationship to the physical reality.

Common LED driver modules do not perform with PWM rates fast enough for super high frequency lighting. While this may make no difference when mixing colors that require either 0% or 100% duty cycles (i.e. R-G-B, C-M-Y), other colors that require duty cycles in between will cause flickering and sudden changes in color temperature, ranging from reddish white to bluish white. Microcontrollers with longer PWM cycle durations caused problems with rates above 200 kHz, because the switching frequency was higher than the PWM frequency. As a result, the PWM cycle was not finished and the desired stable white light effect could not be achieved; visible flickering hindered the desired effect. To control the color temperature, the Kruithof curve was a useful reference to our project in that it describes the region of color temperature and illuminance that yields a pleasing white light to the audience.

For future works using this method, we intend to have a cross-platform mobile application for sonification in order to include a wider range of suitable devices, although the visual effects can be achieved with any ordinary digital camera. Due to the size of data transmitted from the cameras to the sonification engine, especially when multiple devices were active, we have had problems with latency and thus effective real-time sonification. As a workaround we have limited the rate of transmitted matrix data to about %25 of the default camera frame rate; this ensured the system was leaner and minimized the latencies without causing significant sonification errors. For future versions we consider compressing the color matrix data sent and decompressing at the sonification engine to improve the sonification resolution. We anticipate that a standard compression format such as H.264 will achieve the desired results. We also intend to expand the sonification process for a multi-channel setup with more spatial activity to correlate visual and auditory motion. Furthermore, the system has the potential to be presented on stage as an embodied audiovisual performance, where the cameras are gesture controlled over multiple light objects.

6. REFERENCES

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