Thermal Music: Exploring Sensation of Temperature as a Performance Parameter

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ABSTRACT

Thermal Music is a project to explore the possibilities of coordinating control of temperature sensation with control of sound and light. Unlike convective heating technologies that change the temperature of the air around us, radiative heating works by directly heating the surface of our skin via infrared. The technology is widely used in portable heaters in outdoor dining areas of restaurants. One interesting advantage of radiative heating is that if the source of infrared radiation is shaded by a thermally reflective surface, the change in perceived temperature by a person near the heater is very rapid. We worked to create a system that could quickly control robotic shades in front of a radiative heater to synchronize changes in perceived temperature with music and light. We also explored the inverse, using thermal camera input as a control method for audio, and presented both of these techniques at a “Thermal Music” concert at Princeton University in October of 2023.

Author Keywords

thermal, sensation, music, temperature, robotics

CCS Concepts

•**Applied computing** → **Sound and music computing;** Performing arts;

1. INTRODUCTION

In 2018, Forrest Meggers and Jeff Snyder had a conversation about the potential of controlling an audience’s sense of temperature as a performance parameter. Meggers, a professor of environmental engineering, believed it should be possible to do so quickly enough to make rhythmic effects perceptible through temperature alone. The idea of using temperature as an element of a performance, coupled with sound and light, was interesting to Snyder for its artistic potential. A grant from Princeton University’s CreativeX initiative supported the development of the concept into a working prototype, and led to a public concert/installation event in 2023 in collaboration with the Princeton Laptop Orchestra (PLOrk). While the concept of controlled thermal output was the origin of the idea, once an event was planned, thermal sensing and input were also considered as additional aspects of the “Thermal Music” presentation. At the event, PLOrk presented two pieces using thermal input sensing, and three pieces using the thermal output control technology we developed.

Figure 1: Audience members experience the thermal output portion of the Thermal Music concert

2. THERMAL OUTPUT CONTROL MECHANISM

It appears that there is very little research into thermal output for performance purposes. One interesting project is Thermoscore[4], which uses peltier junctions to heat piano keys for interaction with a performer, but it isn’t intended for the audience to experience. Outside of performance experiences, there is a body of research aimed toward simulating the sensation of temperature in virtual reality environments, from projects that use actual heat to an intriguing project that uses chemicals to trick the body into perceiving an altered temperature[1]. There is also an interesting PhD thesis by Moesgen that focuses on designing thermal experiences, exploring aesthetic dimensions of the temperature experience as well as technological[5]. Based

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Figure 2: Building the mechanism in the lab

on Meggers' experience, we decided to use a radiant heating source, shuttered with a robotic louver. We designed a mechanism that would be mounted to a commercially available heating unit by Infratech, so that the only part we needed to solve was the louver design and the opening and closing of the louver. We considered many options, ranging from a single flap to a "venetian blinds" style array, and settled on a design with two horizontal flaps made of aluminum, one on the top and one on the bottom, which open by rotating away from the center of the unit (Figure 1). Two flaps meant stress on the motor from the weight of the metal would be less than it would with one flap, and it still allowed us to move the metal flaps entirely out of the way of the heat source, which a "venetian blinds" option would have prevented. Each flap is driven by a NEMA23-sized stepper motor positioned to one side of the unit, powered by a 24V supply. We chose parallel-wired stepper motors to maintain torque during high velocity movement, since stall torque was much less important to the application. The flaps are each connected to the custom-built aluminum frame by a piano hinge, and to the motor shaft by a bracket (Figure 2).

We felt that the effect would be more dramatic and unusual if we could control heat coming from multiple directions, so we built three units, and positioned them left, center, and right of the audience (Figure 3). For cost reasons, we used smaller heaters for the side units and a larger heater for the center.

The power needs of the radiant heaters themselves were high, as the large heater required its own 30Amp circuit of 210VAC, and the smaller heaters each required a 20Amp circuit at 240VAC. This restricted the possible venue options significantly, but the Embodied Computation Lab in the architecture department at our university had an outdoor space that could support those power needs, and could serve as an ideal venue for the event.

The heating effect is most dramatic if the ambient temperature is low, creating more contrast. However, it is also more effective if the audience has more exposed skin to heat. This meant that, in the climate where the performance was happening, a time frame of fall or spring performance was a reasonable compromise to have brisk temperatures without all the audience members being too bundled up.

The motors were controlled by microcontrollers which received MIDI commands from a computer nearby. We used a Teensy 4.0 for each heater mechanism, since it was especially simple to set them up to appear as a USB MIDI device. We developed a protocol of MIDI-to-movement mapping that used note-ons to send open and close commands, and CC values to change parameters like speed of motion, acceleration curvature, and how far the flaps should move when given an "open" command. We also allowed for direct control of the position of the flaps via CC values, although that option sacrifices some of the elegance of acceleration profiles for immediacy, and therefore can result in somewhat jerky movement. The Teensy microcontroller sent pulse signals to a stepper motor driver, which controlled the stepper motors. Limit switches were affixed to positions on the aluminum frame to sense when the flaps reached fully open or fully closed positions, as this was necessary to compensate for skipped steps when moving the flaps quickly, and to avoid damage to the motors.

Figure 3: Audience members experiencing the Thermal Music concert

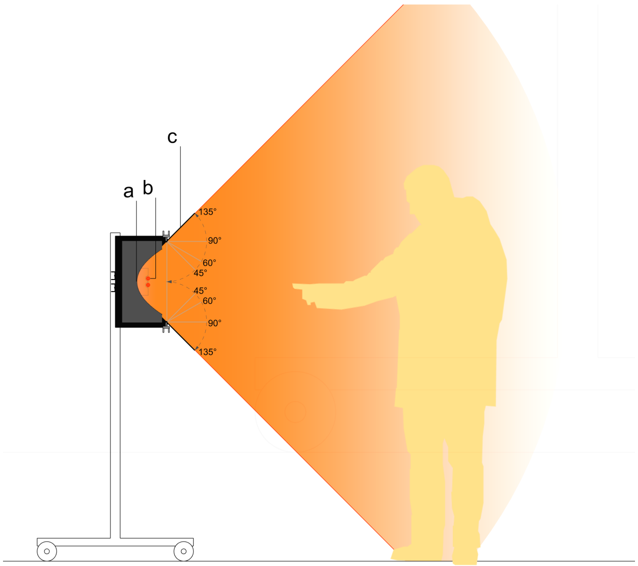

Figure 4: Left-view drawing of the heat output device composed of (a) a parabolic reflective surface, (b) quartz infrared heating elements, and (c) motorized and rotatable aluminum flaps.

3. THERMAL INPUT CONTROL

Since we knew we wanted to build a concert/installation experience around the theme of "Thermal Music", we decided that we should also explore the potential of using thermal sensing input to control sound.

Unlike the thermal output concept, using thermal camera

Figure 5: Front-view drawing of the thermal output device showing the placement of (a) an upper aluminum flap, (b) an upper piano hinge, (c) upper limit switches, (d) an upper motor, (e) a lower aluminum flap, (f) a lower piano hinge, (g) lower limit switches, (h) lower motor.

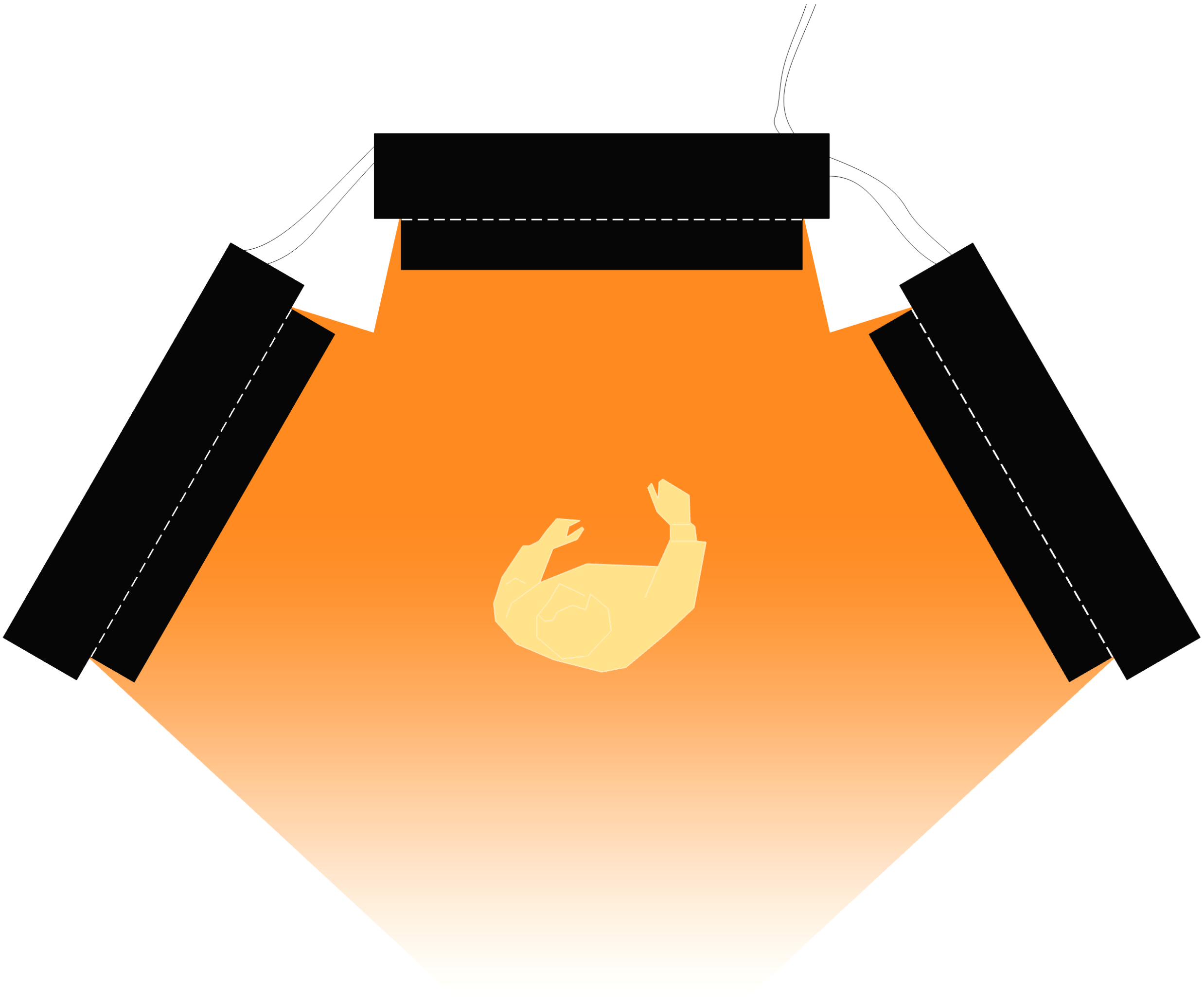

Figure 6: Top-view drawing of the setup using three thermal output devices.

Figure 7: Thermodynamics by PLOrk, using a thermal camera pointed at a large bucket of water as a sonfication source

data as input for creating sound has more precedent. Ignoring the thermal nature of the image, there is a large body of research that explores using camera tracking or image sensing as a control input for sound, and a long precedent of interactive systems like David Rokeby's Very Nervous System[8] or STEIM's BigEye. Roger Dannenberg has an excellent overview of his experience in the field[2]. Because this field has been well explored, there were several useful tools available to us once we had the video signal, and the two pieces we developed were built using video detection objects that are available in Max/MSP (such as Pelletier's cv.jit library[1]) and TouchDesigner[2]. When the thermal nature of the image is considered, there is also some precedent, as infrared is a relatively common sensor input, used in object detection, distance sensing, and other purposes.

We began the exploration by borrowing a high quality thermal camera (which still only means 320X480 pixels) and testing out actions and objects to see what created interesting results. Some things that stood out in our experiments were ice cubes (which showed up as dark spots and left painterly tracks as we moved them around a surface), candles (which give an interesting glow), and water of different temperatures mixing together (which gives a marbled, slowly changing response). Composer Juri Seo composed a piece, "Sèance"[3], around the ice cubes and candles, creating an occult ritual that tasked performers with moving ice cubes and candles on a Oujia-like surface. PLOrk as a group composed a second piece around the swirling water, "Thermodynamics"[4], with video artist Moad Musbahi using TouchDesigner to divide the image into concentric circles, and using the brightness of the pixels in each circle to control the spectrum of each sound performer.

4. CONCLUSIONS

While the thermal input control lent itself easily for live performance, the thermal output mechanism felt less well suited to live control, as there is a latency in the minimum time that it takes for the flaps to physically open and close. Davis Polito composed one piece for live performance, "reH3AT'r", using the thermal output mechanism, in which he controlled audio which was being sensed to control the flaps, and also utilized feedback by adding contact microphones to the flaps themselves and mixing them into the audio as a rhythmic element. Jeff Snyder and Ian Accetta wrote pieces, "FireTongues" and "Nightshift", respectively, that worked more as installations, with audio playback synchronized to thermal output mechanism motion and DMX-controlled lighting.[5]

Figure 8: Séance by Juri Seo

Limitations in how many audience members could experience the thermal effects at one time led to our organization of the event as more installation-like, where 5 or 6 audience members crowded around the mechanisms at a time to experience the pieces. Audience reactions were very favorable, but a formal user study has not yet been done on how people respond to the thermal output mechanism. The thermal output portion of the event was unquestionably the most unusual and novel experience of the evening.

The thermal input control pieces were successful, and allowed for a more standard performance situation, where the entire crowd could experience them at once (with the thermal camera image being presented on a large monitor).

5. FUTURE WORK

The development and first performance of the Thermal Music project offer an interplay between thermal and auditory perceptions, suggesting a potential for experience enrichment using the integration of sensory modalities. Future improvement can look into heat output modulation with a better response rate by enhancing structural stability and increasing motor torque. In the meantime, the performance may also benefit from or even facilitate a better understanding of the variability of the performance's reception among different demographics, such as the elderly with decreased thermal perception capacity[3]. Further, by quantifying heat output, the thermal music devices provide opportunities for empirical studies on the sensorial and emotional enhancement functionality of the thermal stimuli previously

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[1] https://jmpelletier.com/cvjit/

[2] https://derivative.ca/UserGuide/TouchDesigner

[3] https://youtu.be/2jFV17qOjq8

[4] https://youtu.be/J3FRbs4VbvU

[5] https://youtu.be/gNly7xbN0Xk

explored by Salminen *et al*[6]. and Tewell *et al*[7].

6. ETHICS STATEMENT

This project was undertaken within the standards of the NIME ethical code of conduct. A formal user study was not conducted as part of this research, so no ethical issues relating to study subjects were encountered. Surprisingly, nobody even accidentally burned themselves, except with a soldering iron.

7. REFERENCES

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