Prototype Overview – SoundFire System

Praxis 3 Design Dossier 2 Submission

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1. Prototype System Final Design

The SoundFire system uses sound waves to extinguish fires. The system consists of a sensor network that collects temperature and humidity, and collimators that act as air cannon vortexes, designed for use in backyards in Alberta, where boreal forests are 61% of all forests and small fires are frequent (**DD1/02.3/Framing_Research**). When temperature and humidity sensors, placed away from the servos, signal a high risk of fire, the collimators enter patrol mode – they survey the perimeter with a sensor (photoresistor in prototype) assisted by the tilt and pan of the servos. If a fire is detected, the collimators point to it, constructively interfering and smothering the fire. Once the fire has been extinguished, the collimators return to their monitoring state, repeating this until zero fire risk. This is shown in Figure 1.

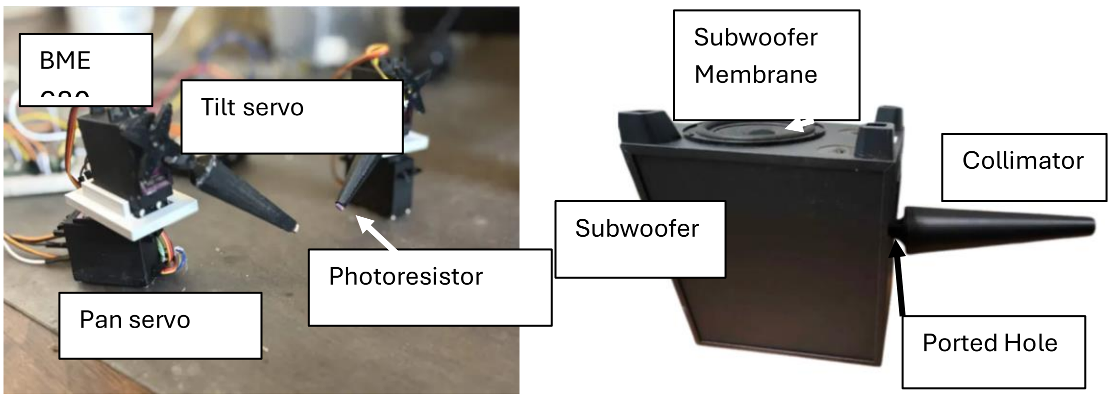

Figure 1 (L) and (R) – The prototype system: the left is the scaled-down sensor-actuator system, and the right is the subwoofer subsystem with the scaled-up collimator on the functioning ported hole.

2. Prototype System Design

2.1 System Architecture Diagram

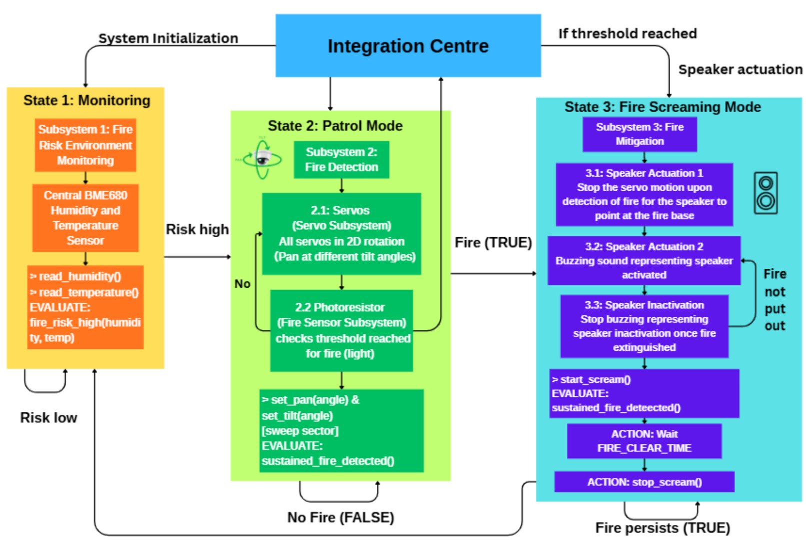

Figure 2 – The prototype-level system architecture of the SoundFire system.

The system architecture is shown in Figure 2, illustrating how each subsystem operates in conjunction with others and feeds into the integration centre to create the functional SoundFire system.

2.2 Implementation of System Architecture

2.2.1 Subwoofer-Collimator System

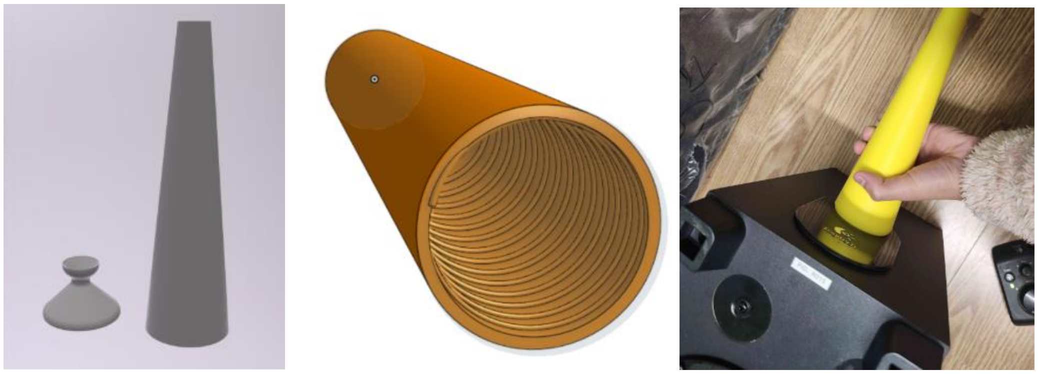

*Figure 3, 4, 5 from **04.2/Collimator_Documentation** show the initial collimator (left), the coils embedded in its walls after speaking with MyFAB (middle), and in-use on the subwoofer (right).*

The final collimator, in Figure 3, consists of a converging-diverging duct that funnels air in from the subwoofer-ported hole and accelerates it towards the fire when a 20 Hz – 40Hz sound is played, ideally 30Hz, as seen in **04.4/6.1.2_DATA.mp4** and can detect 20Pa pressure within 22.5cm, as tested in **Team0110D/Removed Artifacts for SizeTesting_collimator_range.mp4.**. The collimator prototype was designed with CAD and 3D printed with PLA due to its effectiveness in creating curved surfaces and smooth and lightweight prototypes. The key design decisions for the collimator were:

1. Coils inside the collimator to increase air vorticity. The coils were embedded in the collimator walls instead of a separate part to lower turbulence and facilitate 3D printing (Figure 4).
2. To use the ported speaker hole instead of the actual subwoofer. This was done because the air displacement from the subwoofer was not as large as that from the hole because of the porous membrane. The air coming out of the hole is caused entirely by the displacement of the subwoofer but is stronger since no air leaks out.

One key challenge came from the porous subwoofer membrane; the air displacement was much less than required. Furthermore, the radius of the subwoofer was much larger than printing constraints for the collimator. To fix this, the collimator was attached to the ported speaker hole (Figure 5), where air would come in accordance with the subwoofer's displacement. Since the hole was much smaller than the subwoofer, a collimator that was large enough to fit it was a feasible print request at MyFAB.

2.2.2 "Fire" Sensor Subsystem – PIR, Photoresistor, and BME680

The aim of the fire sensor, pictured in Figure 1L, is to detect a fire and convey this to the integration center and servo. To determine the most optimal fire sensor, through **05.0/Conversations_with_Teaching_Team_and_MyFAB** sensors for temperature, light intensity, active infrared, passive infrared, and cameras were considered. For environmental monitoring, the BME680 sensor was used for temperature and humidity as seen in **04.2/BME680_Sensor_Documentation**. The first physical iteration of the fire sensor was a PIR sensor (**03/SensorResearch**).

Despite being effective at detecting fires, the range of the PIR was too large (12 meters and 120 degrees), and the threshold was too low to use effectively for this project. Furthermore, being binary, the only feedback we could receive from the PIR sensor was a positive or negative flag for *change* in incoming IR radiation, and the threshold for this could not be changed. Photoresistors were chosen instead, and the fire was modelled with a flashlight. PIR code logic was largely retained, and the photoresistor enabled us to test the functionality of our sensor-actuator subsystem much more effectively. The design process undertaken for these two sensors is detailed in **04.2/ PIR&Photoresistor_Documentation**. Calculations were done for photoresistor to determine optimal resistance (**04.1/Photoresistor_Calculations.docx.)**

2.2.3 Servo Subsystem

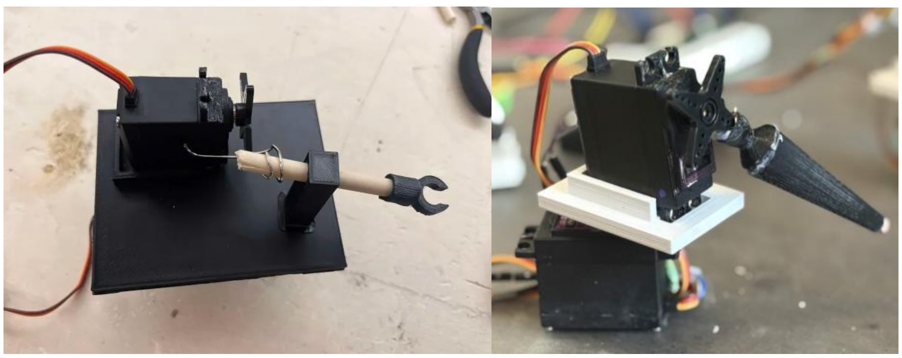

Figure 6 and 7, with the initial tilt function design compared to a simplified system (right).

Every collimator is mobilized using two servos, one servo to pan the collimator (horizontal), and one to tilt (vertical) as shown in Figure 1L. The major design iterations and decisions made are:

- The servos pan 180 degrees when both BME680 sensors are triggered, and 90 degrees when only one BME680 sensor is triggered. Outside the house, the stands would face *inward* to the house, as only the interior region needs to be monitored. When only one sensor is triggered, the integration system will only scan the sector corresponding to the activated BME680 sensor, resulting in a 90-degree sweep.
- The pan servo is below the tilt servo, rotating the entire stand. This keeps the system's weight centered over the base, improving the stability of the head system, reducing weight to accommodate.
- To design the tilting of the servo, inspiration was drawn from conversations with MyFAB (**05.0/Conversations_with_Teaching_Team_and_MyFAB**) from a wire around a pole to translate the left/right motion of the servo to an up/down motion. A prototype of this was made. However, after a conversation with a TA (**05.0/Conversations_with_Teaching_Team_and_MyFAB**), this system was simplified by attaching the collimator directly to the servo shaft and rotating the servo 90 degrees to get the same up/down motion. The preliminary and final design are in Figures 6 and 7 respectively.
- The size of the platform attached to the bottom (pan) servo, which the top (tilt) servo was initially large to accommodate the pole-wire mechanism. After the final iteration of the tilting functionality, this was made smaller (Figure 7). The initial platform obscured a part of the photoresistor's vision because of its size. This iteration removed the obstruction, giving the photoresistor its complete vision back.

As discussed in **04.2/ServoStand_Build_Artifact/Stand_Documentation.docx** several iterations needed to be made to both the servo-collimator, and the servo stand as our ideas for tilt functionality improved. This meant that several rounds of CAD fabrication needed to be done, and that solutions needed to be brute-forced when initial prototypes were not functioning as required – designs needed to be cut apart using wire cutters and pliers to test new dimensions in low-fidelity. It also required significant disassembly and reassembly of the stand and servos, which was time consuming. However, the result was a minimal stand and tilt mechanism that was effective and non-obstructive to the photoresistor. The iterations are in **04.2/ServoStand_Build_Artifact/Stand_Documentation.docx**.

2.3 Integration of Subsystems

The subwoofer-collimator system is an independent proof of concept from the sensor-actuator system, which would only include the fire sensor subsystem and the servo subsystem.

The integration center receives temperature and humidity readings (MONITORING) from BME680 temperature and humidity sensors, and when the readings exceed the threshold for fire risk (> 57ºC, <25% humidity) (**04.2/BME680_Sensor_Documentation)**, instructs the servos to start PATROLLING, enabling the photoresistor to start collecting data. It receives readings from the photoresistor, and if a fire is detected, it activates FIRE_SCREAMING mode, turning on the buzzers to indicate sound. Once the fire has been "put out", as seen by the photoresistor, the servos will PATROL until the BME680s do not detect anything. The setup is in Figure 8.

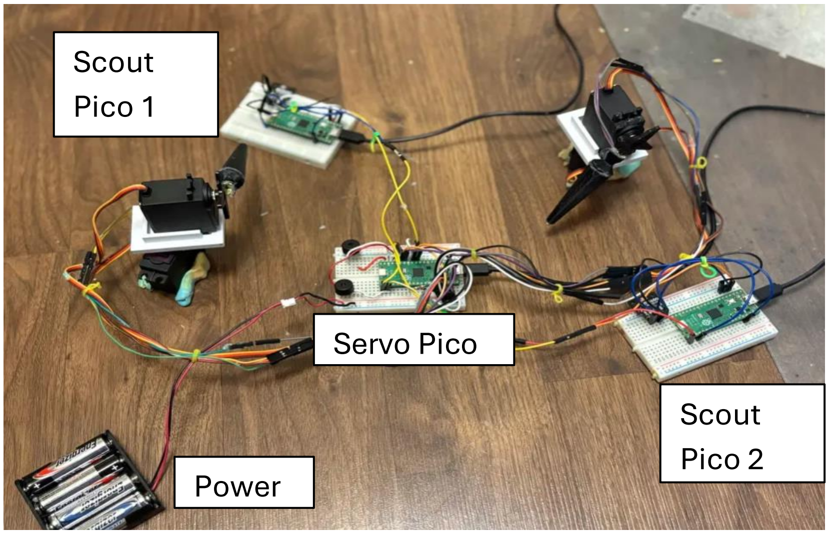

Figure 8- The sensor-actuator system, with two mock collimators containing photoresistors, powered by the Servo Pico, with BME680s on Scout Pico.

The Scout Picos contain the BME680 sensors, to test spatial recognition with two 'sectors'. The Servo Pico has the servos and the photoresistor, as well as the buzzers for audio feedback of a detected light.

3. Verification

The SoundFire system was tested against 19 specifications, of which 8 are described here. The following specifications and 10 others passed. The full details can be found in **04.4/0110D_DD2_VerificationProtocol+Results** . Only one failed, being the inability of the photoresistor to have a minimum monitoring area of 12m in radius, falling short at 8m.

Overall, our system has a monitoring area of 8m in 180 degrees in 2 directions (S-1.2.1), providing fire risk updates at least once an hour (S-1.3.3). When there is a fire (simulated with a light source), it can detect light within 30 seconds (S-1.2.3), with a 0.1cm error radius, well below the 5m threshold (S-1.2.4) with no false alarms (S-2.2.2). Once a fire has started, the system takes less than 0.000001s to signal the buzzer that the light has passed the threshold (>15K Ω), below the 2-second limit (S-2.2.1). The system then suppresses the small-to-medium fire in under 60 seconds (S-6.1.1) with an output pressure above 20Pa, within the required zone of 20 Pa-60 Pa required to disrupt combustion and put out the fire (S-6.1.2).

4. Conclusion

In accordance with the NGO from Phase 2, taking time and resource limitations into consideration, two separate prototypes were built: the system of sensors and actuators validate the IoT component of the design, and the collimator with the subwoofer constituted proof of concept for air particle acceleration.

Goal 1 of continuous data collection regarding fire risk was achieved with the servo and the photoresistor in action, as seen in **04.4/0110D_DD2_VerificationProtocol+Results**. Additionally, the algorithm developed for Goal 1 Objective 2 produced a spatial map for optimal actuator placement as seen in **04.2/Map_Documentation**. Goal 5 was inherently satisfied due to the non-invasive nature of using sound to put out fire. For Goal 6, the emitted jet reached a velocity of 5.4 m/s (**04.4/Verification_Artifacts/6.1.3_Calculations)**, successfully extinguishing a candle flame as seen in **04.4/Verification_Artifacts/6.1.1.** However, Goal 3 for resistance to environmental stress and Goal 4 for power usage and durability were not met by the prototype as they require large-scale, long-term testing.

Material and time constraints to build more complex prototypes were the main limitations. Specifically, the photoresistor should be replaced with an IR sensor or camera for more precise detection of the fire base location. A wind speed sensor should be used in conjunction with a humidity and temperature sensor for more accurate fire risk assessment. Additionally, time constraints restricted the level of iteration and refinement possible, particularly for mechanical durability and full system integration.

Some next steps will focus on improving system robustness, accuracy, and scalability. Mechanically, the system can be enhanced by creating a box for the breadboards and wires, a fully fabricated base for the bottom (pan) servo and a custom mounting component should be designed to securely attach the collimator to the tilt servo, replacing the current hot-glued connection. From an IoT software perspective, the system can be extended to have more advanced spatial tracking of fire locations such that only speakers close to the activated sensors would PATROL. Also, we want to prioritize where the "most important" fire is, and only speakers in proximity would activate, to account for multiple fire bases.

Overall, the prototype design validated the key ideas proposed by the design concept either through physical building, proof of concepts, or calculation. Most of the NGOs have been satisfied or could have been accomplished with replaced sensors, proving the validity of the design concept.