Interactive Piano Alley

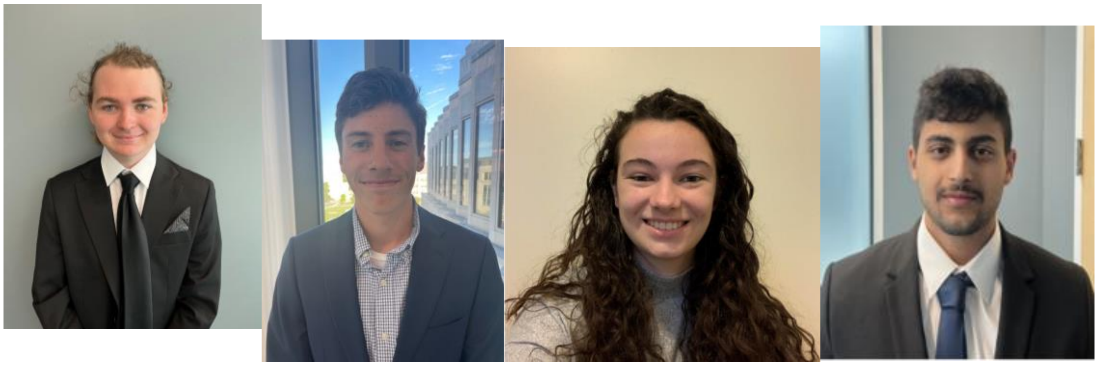
Intelligent Systems Engineering

at Indiana University

Noah Probst, Keith Soruco, Erin Seliger, Omair Alhajeri

TABLE OF CONTENTS:

Introduction



From left to right: Keith Soruco, Noah Probst, Erin Seliger, Omair Alhajeri

Keith Soruco is the project coordinator. His concentration is Cyber physical systems. He has experience with CAD, Python, C/C++, and PCB design. Also, he was part of a Robotics team where he got experience with autonomous and control systems.

Noah Probst is the System Manager. His concentration is Cyber physical systems. He has experience in CAD, Python, C, vision sensors, and some machine learning models. In courses during school, he has experience of working with lots of different microcontrollers and sensors. CAD software experience includes Inventor, Fusion360, and SolidWorks.

Erin Seliger is the report manager. Her concentration is Cyber Physical Systems. Through her classes she has had experience coding in Python and C, working with wearable sensors, and CAD modeling in SolidWorks.

Omair Alhajeri is the Prototype Designer. His concentration is Computer Engineering. He has some experience in 3D modeling, Python, C, C++, basic Verilog and signals sampling filters. In previous courses he had worked on client-based projects including producing 3D models and automated systems.

Client Request

The Heart of Jasper organization is seeking some engineering support for a design project. We have a team of IU Eskenazi students designing and painting an alley to look like a piano. We have plans to put a piano in the alley based off the original mural as well for the public to play while they are downtown. We had an idea to include sensors on the sidewalk so as you walk on the painted piano keys, the sensors play the sounds of piano keys.

Project Management

The Team meets in class twice a week on Tuesday and Thursday from 3:00 to 4:15 PM to work on the project. Outside of class we meet on Mondays from 11:00 AM to 12:00 PM. We also have biweekly meetings with our client in which we present our progress and receive feedback on design ideas, part choices, budget allocation, etc.

Available Resources

We have multiple resources at our disposal for this project. In Luddy, we have access to all the machines in the makerspace. Team members have brought in various electronic components such as a gyroscope and Arduino that could be used in prototyping. Throughout the year we've received advice, guidance, and materials from our professors (Bryce, Suha, and Mary). Bryce has provided us with an STM32 Dev Kit and Raspberry Pi. As the piano project was inspired by the Kimball Piano, Kimball Electronics is willing to provide us with parts as well. Our client has given us contact information for city engineers, electricians, and officials in Jasper that we've been able to reach out to regarding regulations. As far as the budget goes, we have not been presented with a specific number, but were told that we will have somewhere around the low thousands of dollars to work with.

Communication/Decision Making

We will use majority vote to make decisions. If the team cannot make an effective decision according to the agreed upon guideline, they may appeal to the professors. The professors have the final call on any decisions being made.

Similar products

There are multiple implementations of floor pianos and interactive art. For example, a floor mat piano can be bought from various places and is attended for child use. Some cities have installed pianos directly into the sidewalk. Interactive art has also started being placed inside buildings to attract visitors. In research, it has been found that many consumer products have failed to meet expectations as they are unable to change volume, not safe to use as they are slippery and hard, not durable, and unable to be stored. Out of these problems, the most important ones to address are durability and safety.

Floor Piano

This is an example of a floor matt piano that we found online. The dimensions of the piano are 71 x 29 x 1 inches. Reviews have shown that this piano is extremely loud, and children may be injured using it as they tend to do somersaults on it and otherwise not use the piano as intended

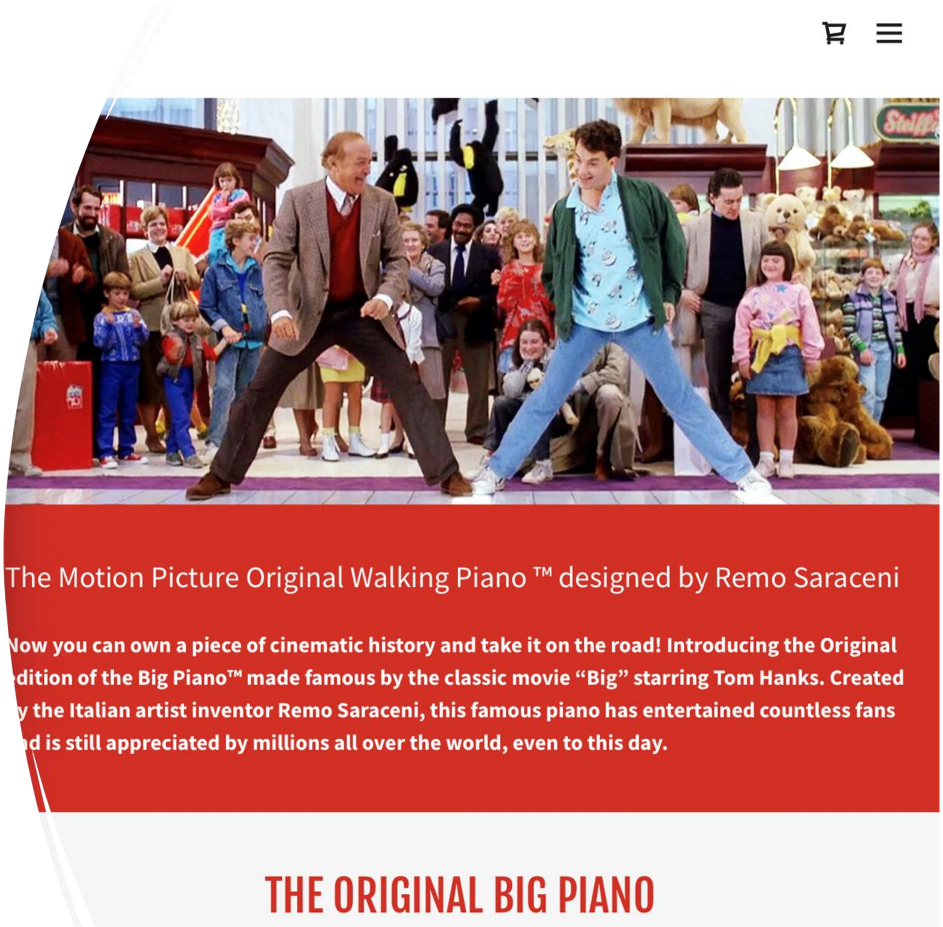
[1].

PercussionPlay Grand Floor Piano

This floor piano is much more expensive at over $50,000. It has dimensions of 3.4 x 1.1 m and contains 2 octaves. Holes must be excavated for the installation of this piano [2].

Big Piano

This piano from the movie *Big* is probably the most well-known and similar to our goals for this project. Our client sent us information about this piano for the inspiration of the piano alley's design. The piano produces a tone and the key that's been stepped on lights up (something we hope to incorporate in our design) [3].



Intellectual Property – Patents

While our project didn't require a patent or NDA, we researched patents for products similar to ours just to get an understanding and to see if our project infringed on any products out there. The first patent we found was for a Touch Sensor Detector System and Method. It is a detector system that utilizes a touch sensor array configured to detect proximity/contact/pressure via a variable impedance array [4]. Our product is not infringing on this patent because we are not using the same type of detector. The second patent we found was for a Portable Floor Piano with Folding Keyboard. A flexible cover plate with images of black and white piano keys on it covers support beams that have pressure sensors on them. A note is sounded when the sensor detects a person standing on it [5]. We are not infringing on this patent because our piano is permanent, not portable. Instead of putting the sensors on support beams we are drilling into the concrete and storing them in an enclosure. The last patent we looked at was for a Keyboard

Instrument Stand and Keyboard Instrument Set. It includes an electric keyboard and stand. The patent gives numbers for the height, angle, and shape of the design but does not specify any electronics [6]. We do not infringe on this patent because we are not building a piano stand or creating piano keys.

Public safety.

As mentioned above one of the main problems that needs to be solved is the tripping hazard posed by extruding objects from the pavement. The device will need to be textured to prevent slipping. Along with also needing to withstand foot traffic to prevent it from shattering and causing injury. In addition, we might have some privacy concerns as our device could be used to collect information. While the only data is when the device is stepped on and played, it could be used to play sounds and speeches. This is something that another group will need to look at to limit security risks with our device.

Engineering Standards

Non-Trip Hazard Compliant

"Section §405 of the ADA curb ramp requirements for 2021 covers the following ADA curb ramp design standards: Clear Width: A ramp run must be at least 36 inches wide between the ramp's handrails. Rise: A maximum of 30 inches per run, with no limit on the number of runs. Running Slope: 1:12 maximum slope, or one foot in elevation change for every 12 feet. Cross Slope: The ADA permits a maximum ratio of 1:48. Alterations: Are permitted on running slopes with limited space, such as: 1:10 maximum with 6 inches maximum rise 1:8 maximum with 3 inches maximum rise A slope of no greater than 1:12" [7]

One of our clients' concerns are tripping hazards and allowing disabled people to interact with it. By Having our project ADA compliant we hope that this will solve both problems for the city. It will allow wheelchair users to activate the keys by going over them without being too big for them to have too hard a time. In addition, we hope that this will stop any legal concerns as it is safe for a wheelchair, it should be safe for a bipedal person.

Standard for Wireless Sensor Data of Power Transmission and Transformation Equipment

Zigbee: P3363

Zigbee: ISO/IEC 30118-17:2021

"This standard specifies the data unit format for use by Internet of Things (IoT) power sensors. The data format describes the exchange of service data, control data, and fragmented data via the IEC 61850/IEC 60870-104 or Message Queuing Telemetry Transport (MQTT) protocol. The standard may be used with wireless IoT power sensors that communicate via Zigbee, LoRa, Wi-Fi. The standard addresses power automation systems for power system applications. Furthermore, the standard enables wireless IoT power sensors to efficiently exchange information and to monitor the status of power transmission and transformation equipment. The standard provides guidance in the design, development, and testing of integrated applications of related systems and devices. Specifically, this standard provides unified coding rules and a lightweight and scalable data unit format for the status parameters of power transmission and transformation equipment, to shorten the length of data packets and reduce the power consumption of wireless IoT power sensors." [8]

This standard will be adhered in terms of Bluetooth connection between the key sensors and the microcontroller to maintain a high-quality flexible system with a clear flow of data.

Speaker Quality

Speakerphones: IEEE 1329-2010

"This standard provides techniques for objective measurement of electroacoustic and voice-switching characteristics of speakerphones that connect directly or indirectly to an analog or digital telephone network. Due to the various characteristics of speakerphones and their environments, not all test procedures in this standard are applicable to all speakerphones. Application of the test procedures to atypical speakerphones should be determined individually. [9]

Our speakers will be chosen to adhere to the standard in terms of ensuring the quality of such sound transmission and minimizing the noise in the corresponding area of the speakers.

Recommended Practice for the Design and Construction of Prefabricated and Modular Outdoor Battery Enclosures

Outdoor batteries: P3189

"This recommended practice covers the design and construction of prefabricated and modular enclosures for diverse environments, both indoors and outdoors. These enclosures house batteries and related equipment that may include chargers, inverters, distribution panels, protective devices, and ancillary systems. This document covers functional requirements for enclosures for all battery technologies and all stationary applications. Recommendations are included for ventilation, thermal management, spill containment, and fire suppression, as appropriate. Those recommendations apply also to battery compartments in electronic equipment cabinets for applications such as telecommunications and power generation, transmission, and distribution, but the design of such cabinets and enclosures is beyond the scope of this document. While all battery enclosures are transportable, mobile (wheeled) units are not covered." [10]

Each of our key-side enclosures will contain a battery, in addition to the PCB with the LED, STM32 chip, and accelerometer. This standard covers the requirements for enclosures, both indoor and outdoor, that house batteries.

IEEE Standard Definitions of Terms for Solar Cells

IEEE 307-1969

"This IEEE standard provides uniform and acceptable terms for use in the application of solar cells to power systems. The terms are useful in unifying expressions used in engineering writing and in the preparation of specifications and procurement documents. It is expected that this standard will be most useful to persons not expert in the solar cell field." [11]

At this stage, we are still considering using solar power to power our device. If we do, this standard would be useful in understanding how a solar cell is used to power a system.

IEEE Recommended Practices for Modulating Current in High-Brightness LEDs for Mitigating Health Risks to Viewers

IEEE 1789-2015

"This document includes a definition of the concept of modulation frequencies for light-emitting diodes (LEDs), a discussion on their applications to LED lighting, a description of LED lighting applications in which modulation frequencies pose possible health risks to users, a discussion of the dimming of LEDs by modulating the frequency of driving currents/voltage, and recommendations for modulation frequencies (flicker) for LED lighting and dimming applications to help protect against known potential adverse health effects." [12]

As part of the user interface with the system beside hearing the piano key sounds the LED lights guide the user in engaging with the system. Managing that interaction our lights will adhere to the standard in terms of protection lens to eliminate risks from light pollution from the lights.

Gantt Chart

PROJECT: Piano Alley

ISE - Capstone Engineering Design

Team 2

Legend:

Project start date: 1/11/2024

Scrolling increment: 0

Milestone description	Category	Assigned to	Progress	Start	Days
software key					
Bluetooth connection/Mqtt server	Milestone	Keith	100%	1/11/2024	20
Gyro	Milestone	Keith	100%	4/27/2024	30
User interface	Milestone	Keith	100%	1/31/2024	60
Light	Goal	Keith	100%	1/31/2024	7
Zigbee / subscriber, publisher	Milestone	Keith	100%	1/31/2024	30
Mechanical design					
Key Enclosure	Milestone	Erin	100%	1/12/2024	20
Speaker/Pi Enclousre	Milestone	Erin	100%	1/12/2024	20
"lid"	Milestone	Erin	100%	1/15/2024	20
Board layout	Milestone	Erin	90%	1/15/2024	20
Bluetooth connection					
pi and div connect	Milestone	Noah	100%	1/11/2024	4
CAD modeling	Milestone	Noah	100%	1/11/2024	14
command interfacing	Milestone	Noah	100%	1/11/2024	6
software "PI"					
Bluetooth / Mqtt files	Milestone	Omair	100%	1/16/2024	20
sound integeration (pi - speaker)	Milestone	Omair	100%	1/11/2024	20
lights control	Goal	Omair	100%	3/1/2024	15
Power Supply					
Circuit Design	Milestone	Erin,Noah	100%	1/11/2024	

When developing our Gantt chart, we thought about our project goals for the fall semester that would be reasonable to achieve. Our main goals for the first semester were to identify the main constraints and objectives of the project by meeting and conversing with the client, draft up several different design options for the client to choose from, and determine our design and begin the first stages of prototyping. At this point in the semester, we have successfully decided on a design – using input from the client and instructors – and are beginning to research components and start the process of prototyping.

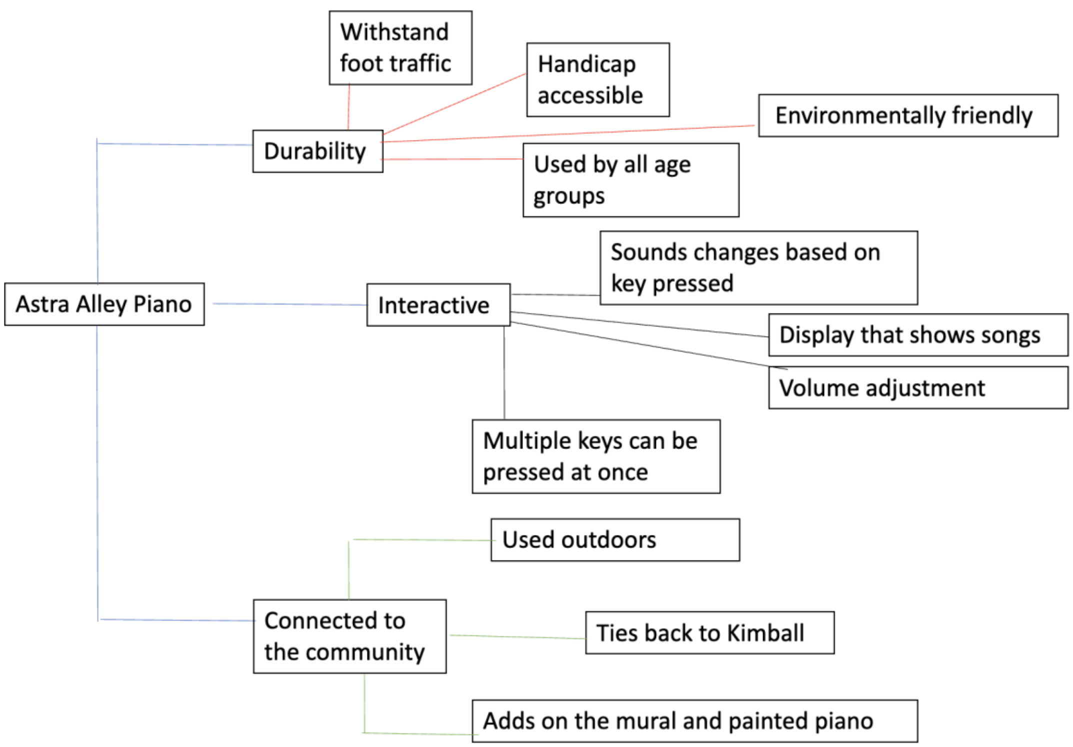
Designing the System

Meeting with the Client

We prepared for our first meeting with the client by brainstorming a list of questions to ask them. We wanted to know things like their main constraints and objectives, target audience, size and dimensions of the piano, approximate budget, power source availability, and just any general concerns they had. Coming out of the meeting, it was clear that their main goal was for the alley to be interactive, entertaining, and to attract people. The target audience is kids, but the piano should be accessible to all. They mentioned that the alleyway gets foot traffic in addition to people on bikes and scooters. Their main concerns were that our implementation is safe, weather durable, and not intrusive. Overall, our client gave us a lot of free range for the project and was willing to hear any ideas that were within their guidelines of being both interactive and safe.

Objectives and constraints

Objective Tree:



We had our clients' requests in mind when coming up with our objectives. The project is centered around being interactive and connected to the community. Our clients wanted something that people, specifically children, could physically engage in. While the core of our project is for a key to make sound when stepped on, we included some ways we could take the project a step further in our tree (such as having an interactive display that shows songs, volume adjustment, etc.). Our third main objective is durability as the alley will have to hold up over the years through different weather conditions and multiple forms of foot traffic.

Constraints
Must incorporate in alley
Weather resistance
Withstand foot traffic (Durability)
Should not conduct electricity
Budget (couple thousand/TBD)
Finished before graduation
Restricted by Chocolate Bliss owner's allowance/ city regulations
Safe (Meet TBD safety regulations)

Originally, the project was constrained by not being able to drill into the concrete. However, it was later decided with the permission of the city that we would be able to drill into the concrete. From the client request and meetings with city officials, safety became the primary concern. It was also mentioned that nearby shops owned the walls of the alley. The wall that has electrical outlets that we are considering connecting to is owned by Chocolate Bliss and Kitchen Essentials. Our clients said they would speak to the owners on our behalf to obtain permission to use that wall. Lastly, from the similar products, durability was a major concern as many similar products do not last long.

Selecting a Design

Based on these objectives and constraints our design ideas included a hockey puck underground, hockey puck above ground, sensor fence, sensor sheet, button, shoe sleeve, ultra sonic/infrared sensors, tilting keys, kinetic tiles, and vision processing. We created a comparative chart, putting a “Y” if the design met the constraint and a “N” if it didn’t. We also ranked each design for each of our objectives on a scale of 1 to 5. One meant that it would be very difficult for the design to meet the objective and 5 meant that it would be extremely easy for the design to meet the objective. We summed up the point values for each design at the bottom of the page, with the highest values corresponding to the most easily implementable designs. If a design summed to a negative point value it meant that it did not meet one of the constraints, so we automatically threw out that idea

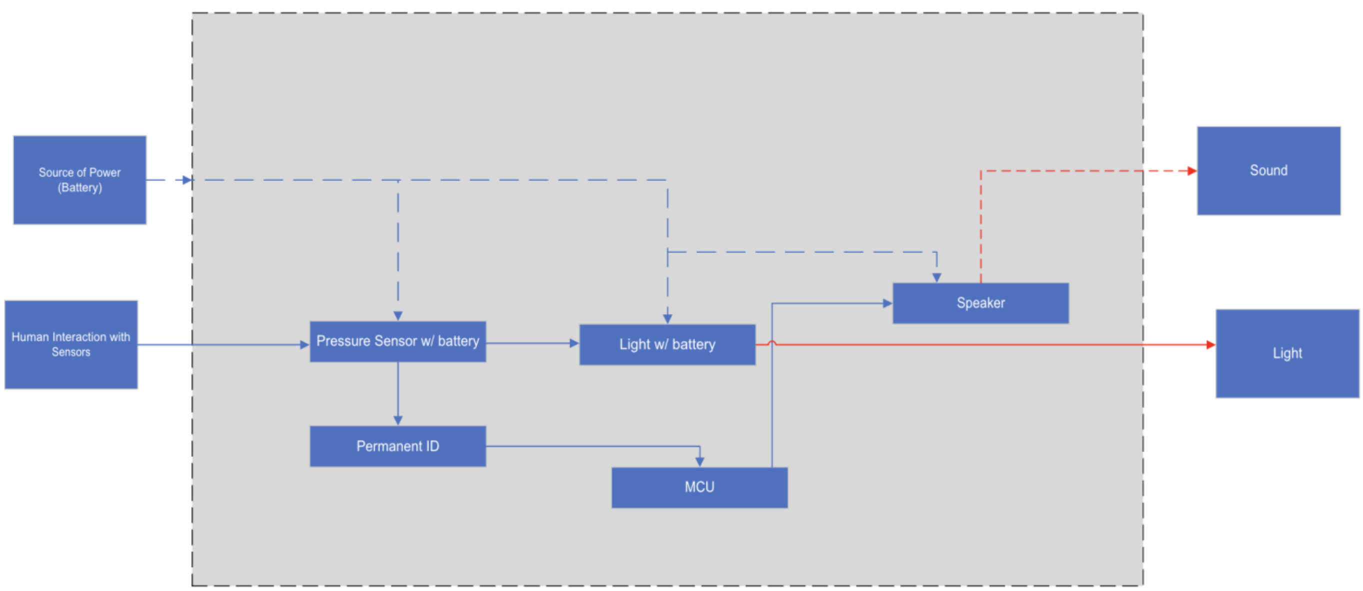
constrains/objectives	c or O	YES or NO(for constraints only	importance 0-5	Hockey puck(underground)	hockey puck(aboveground)	sensor fence	sense sheet	button	shoe sleeve	ultra sonic sensors	tilting keys	kinetic tiles.	Vison processing
Must incorporate in alley	C	Y	5	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Weather resistance	C	Y	5	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Withstand foot traffic (Durability)	C	Y	5	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
must not conduct electricity	C	Y	5	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Budget (couple thousand/TBD)	C	Y	5	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Finished before graduation	C	N	5	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Visually show selected key	C	Y	5	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Restricted by Chocolate Bliss owner's allowance/ city regulations	C	Y	5	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
Cannot drill into sidewalk		Y	5	N	Y	Y	Y	Y	Y	Y	Y	Y	Y
Safe (Meet TBD safety regulations)	C	Y	5	Y	Y	Y	Y	Y	Y	Y	N	Y	Y
Limited budget	O	N	5	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
Play sound	O		5	5	5	5	5	5	5	5	5	5	
Replaceability	O		5	4	4	2	3	3	4	4	1	2	1
sound changes based on key pressed	O		5	5	5	5	5	5	4	5	5	5	5
on step of a key sound is played (speed)	O		2	5	5	5	5	5	3	5	4	4	1
Enviromently friendly	O		4	5	5	5	5	5	5	5	5	5	5
non-invasive	O		2	5	4	2	4	5	3	5	1	3	5
interactive	O		5	3	3	3	3	3	5	3	5	5	3
keys are weighted	O		2	4	4	1	5	1	2	2	5	5	3
should add on to the mural and painted piano	O		3	4	4	1	3	5	5	4	1	1	5
ties back to kimball	O		2	1	1	1	1	1	1	1	2	1	1
must be finished before graduation	O		5	5	5	5	5	5	3	5	3	3	3
light up			2	4	4	2	5	2	1	1	5	5	1
display that shows songs	O		1	1	1	1	1	1	1	1	1	1	1
visually show selected key	O		1	5	5	5	5	5	1	5	5	5	5
mult. keys can be 'pressed' at once	O		3	5	5	5	5	5	3	5	5	5	3
allows for adjustment of volume	O		1	1	1	1	1	1	1	1	1	1	1
used by multiple age groups	O		2	5	5	5	5	5	3	5	3	3	5
handicap accessable	O		2	5	5	5	5	5	3	5	3	3	5
visually appealing	O		3	3	3	3	3	3	3	3	5	5	3
Handability(how easy/intuitive will it be for others to use	O		4	4	5	5	5	5	4	5	5	5	5
Partial sum				247	249	216	245	239	209	241	221	228	182
FUll SUM				-653	249	-684	245	239	209	241	171	173	182

The top three designs were the puck insert devices, ultrasonic or infrared sensors, and a pressure sheet. We created a PowerPoint describing how each of these designs would be implemented and the pros and cons of each and brought it to our client meeting. Our most favorable design and the one our client chose was the underground puck insert design which would involve drilling a few inches deep into the concrete where we would have our sensors in a small puck shaped enclosure that would be flush with the ground. It would be non-invasive, easy to replace, and we estimate it will only require a battery change every year or so. We can also make the lid translucent to allow light to shine through when the key is activated, making the alley more interactive and fun for users. Some cons of this design is that it will require battery changes and the user will have to step specifically on the puck to play a sound, not just anywhere on the key.

Box diagram

Puck Insert Design Black Box Diagram

Puck Insert Design Glass Box Diagram



The two main inputs to our system are the power source via battery and human interaction with the sensors. Within each "puck" that's drilled into the ground we plan to have a pressure sensor, a light that shines when the pressure sensor is activated, and a microcontroller that is connected via Bluetooth to a speaker on the alley wall. Our system's outputs will be the sound and light produced when a key is interacted with.

Enviromental Impacts

Due to the location of the project, many people and animals will visit this location. As a result, the project must not be toxic. It is planned to use Environmentally friendly sealants to limit any contamination of rainwater that through the alley. However, it is connected to two streets and all water will be contaminated from debris and oil on the roads. Our device will also emit light, this will cause some light pollution at night. As a result, we plan to have the lights dimmer at night to reduce this. Lastly, there is the sound pollution. The devices' primary function is to play sound as a result, it will cause sound pollution. To limit this we can lower the sound depending on the time of day. In addition, we plan to allow the city to limit the hours at which it can be planned and manually adjust the sound to create the perfect balance.

Morph chart

Functions	Means				
detect key pushed(touch)	button	force/pressure	gyro	projected touch capacitance	IR touch
detect key pushed(prox)	IR	Vison processing	ultra sonic	lidar	Heat sensor
Enclosure	strip against the wall	individual enclosers on each key	large mat	hockey puck	
produce sound	use a small speaker for each key	use a electric piano	use one large speaker	use a few speakers spread out over all keys	
produce light	use a small led in each key	hang led from the wall	have led hanging over each keys	led around each key	
display info	use an old kindal	use an IPAD	create out of own with a pi	paper display with covering	
power supply	battery	kinetic tile	solar	power line	

Block Diagram Description Table

Block #	Block name	Owner	Brief description of block function	Power interfaces	Digital interfaces	Analog interfaces
A	Key Software	Keith	Detects movement of device then sends info to Main control. It will also light up on signal or pushed	In: possibles olar In:3.3V	In/Out: Bluetooth	Out: light
B	Main Control Software	Omair	Takes in Bluetooth information then determines the sound and volume + sends to speaker to play	In: 5v/3.3V	In: Bluetooth	Out: speaker
C	Wireless Connection	Keith/Omair	We are doing a wireless power for each key enclosure, as well as wireless connection for communication via BT. A possible option includes BLTE 5 or Zigbee	In: 3.3V	In/Out: wireless signals	NA
E	Key Hardware	Erin	Includes the PCB and the components on it.	In: 3.3V	In/Out: Bluetooth	Out: light
F	Enclosures	Erin/Noah	The enclosure will be the casing and protection for the electronics inside the puck insert and speakers/MCU on the wall. The tops of the enclosures is what users will step on	NA	NA	NA
G	Display (extra)	Everyone	This part will act like an electric piano. Allowing the user to change volume.	In: 5v	Out: Bluetooth	NA

Detailed design

Accounting

The current version of our device requires many parts. Based on the current design, the total production cost should be around 1,000. Each key currently costs $21, and the promised fund is $2000. The next design plan includes a better and bigger encloser. It should increase the total cost by $390. Below is a current Bill of materials.

Name	cost per unit	Amount	Per A Key.(Y or N)	cost	Total Amount
BTLE : Bluetooth low energy	3	1	Y	117	39
Battery (common AA batery)	0.3	2	Y	23.4	78
Enclosure	10	1	Y	390	39
Microcontroller	1	1	Y	39	39
Speaker	4.1	3	N	12.3	3
LED lights (display lights)	0.1	2	Y	7.8	78
Wiring	0.1	1	Y	3.9	39
Board	3	1	Y	117	39
Gyroscope	3	1	Y	117	39
Pressure sensors		1	Y	0	39
battery holder	0.5	1	Y	19.5	39
voltage converter	5	1	N	5	1
capacitors based on BTLE specifications	0.1	1	Y	3.9	39
main circuit board	9	1	N	9	1

Intro to key side device

To make the alley interactive, testing has been done on the key side. The key side requires the ability to communicate with the main computer. The device can send Realtime temperature reading at this moment. In the future, it will be able to send its voltage and detected weight/movement. In addition to sending data, we hope it will be able to receive it. Apon receiving data, it will be able to enter a sleep mode for a set amount of time, turn on a light, or run self-diagnostics and tuning.

STM32

The Stm32 is a microchip used in many devices in many industries. For example, it is used in both engine control units and smart phones. It will be used in this project as it is good at keeping low power consumption. In addition, it also has a lot of documentation and tutorials. The piano alley way well use these as the control unit for each key. Its jobs will be to receive data from the gyro, calculate a weight value, transmit data to and from a Wireless module, and turn on and off power. It will also be configured to allow the maintainer to configure the device name, note, and the run cycle. Another reason why we decided to use STM32 is that it has a good power control system built into the Ide which will allow implementation of various modes to limit power usage. With this it should lower the maintenance required for the system. Lastly, the chip we are using has a built-in antenna. With the built-in antenna, the device should be able to do over-the-air updates. In addition, it will limit the overall cost, limit the size, enhance performance, and greatly enhance the physical security of the device.

Wireless comunication

The wireless communication module used will oversee the communication to and from keys and the main control unit. It will most likely be configured in a ZigBee manner which allows for group communication. This will allow all devices to monitor each other and run synchronous Dianostics to determine which key is being used. In addition, the devices should be able to send battery data and device health so all devices can turn off. It is important for this to be low power usage, to save battery and make the system the most efficient it can be. We have worked a lot with this in our initial prototype design trying to figure out the best way to send the data wirelessly. In Cube IDE we found a folder of code and downloadable files with the STM32 microcontroller we are using.

In the end we decided to use ZigBee, due to it’s use in the home automation field. Zigbee is good at setting up a mesh of various devices that need to interact with each other. By starting up the Zigbee network, other nearby areas can connect to it allowing for continues projects to be added onto the system. Which corresponds to what the client had envisioned for the alley way. Another reason is Bluetooth does not work well for multiple devices. For a system that needs to have limited maintenance, Bluetooth does not have the reliability to stay active long enough. On top of that, a custom application would need to be built to allow for proper communication.

Intro to Main control Unit

To build a system that can manage different commands from the user playing different piano sounds we are using the Raspberry pi (model 3) to receive data from the key sensors and process each key sensor command based on the unique ID of the key sensor to play the exact piano key tune requested. The Raspberry pi will be then sending commands toward the speaker to play the sounds requested.

Speaker

To generate the sound of the desired key our speaker will be connected to the Raspberry pi that has already managed and processed the sound to play. Then the speaker will start to audio out the sounds of the piano keys back to the user and then wait for new requested sounds to play from the Raspberry pi.

Wireless connection with Raspberry pi

In our system we have decided to use Zigbee connection to receive the data from the key sensor to the Raspberry pi. For Zigbee connection for the part of receiving the data Omair and Noah are working on translating the data received on the Raspberry pi side from the key sensor so it can be later managed and processed by the main unit to produce the sound desired.

Testing demo:

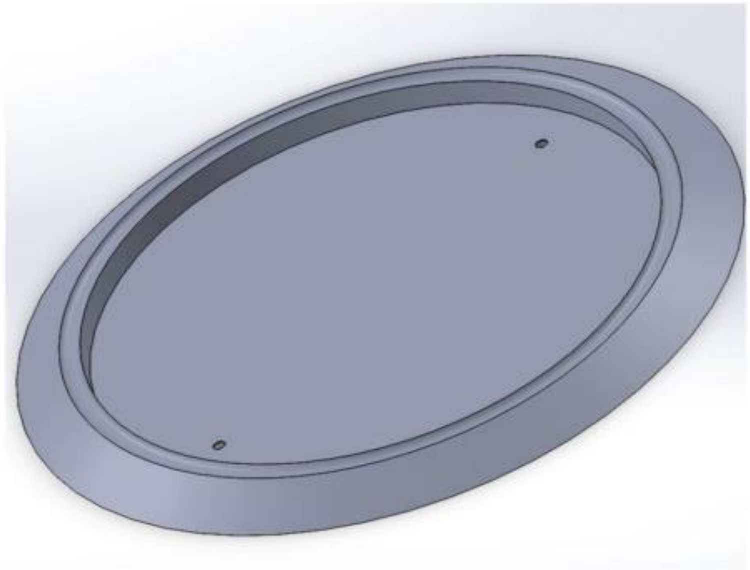
We have started working on the Raspberry pi to build the mechanism of processing received user commands to play the piano sounds. For testing purposes, we have written a python code receiving inputs from the user the key names to play and then the code processes the input and plays the sound for that key. For now, we have only included the white keys of the piano (C, D, E, F, G, A, B) and their different pitch tunes. In the code we are using WAV files that contain the actual sounds for the piano keys. The code can be run in the pi and in the local machine, for now we have run the code, and it generates the expected sounds when run via our local machine. Code snippets can be found below also attached as a python file with this document.

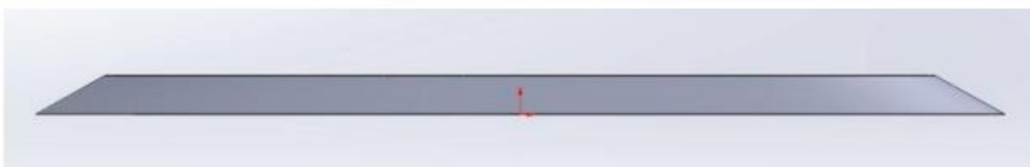
```python
import pygame

pygame.init()

sounds = {
    'a0': pygame.mixer.Sound('piano-a0.wav'),
    'a1': pygame.mixer.Sound('piano-a1.wav'),
    'a2': pygame.mixer.Sound('piano-a2.wav'),
    'a3': pygame.mixer.Sound('piano-a3.wav'),
    'a4': pygame.mixer.Sound('piano-a4.wav'),
    'a5': pygame.mixer.Sound('piano-a5.wav'),
    'a6': pygame.mixer.Sound('piano-a6.wav'),
    'a7': pygame.mixer.Sound('piano-a7.wav'),

    'b0': pygame.mixer.Sound('piano-b0.wav'),
    'b1': pygame.mixer.Sound('piano-b1.wav'),
    'b2': pygame.mixer.Sound('piano-b2.wav'),
    'b3': pygame.mixer.Sound('piano-b3.wav'),
    'b4': pygame.mixer.Sound('piano-b4.wav'),
    'b5': pygame.mixer.Sound('piano-b5.wav'),
    'b6': pygame.mixer.Sound('piano-b6.wav'),
    'b7': pygame.mixer.Sound('piano-b7.wav'),

    'c1': pygame.mixer.Sound('piano-c1.wav'),
    'c2': pygame.mixer.Sound('piano-c2.wav'),
    'c3': pygame.mixer.Sound('piano-c3.wav'),
    'c4': pygame.mixer.Sound('piano-c4.wav'),
    'c5': pygame.mixer.Sound('piano-c5.wav'),
    'c6': pygame.mixer.Sound('piano-c6.wav'),
    'c7': pygame.mixer.Sound('piano-c7.wav'),

    'd1': pygame.mixer.Sound('piano-d1.wav'),
    'd2': pygame.mixer.Sound('piano-d2.wav'),
    'd3': pygame.mixer.Sound('piano-d3.wav'),
    'd4': pygame.mixer.Sound('piano-d4.wav'),
    'd5': pygame.mixer.Sound('piano-d5.wav'),
    'd6': pygame.mixer.Sound('piano-d6.wav'),
    'd7': pygame.mixer.Sound('piano-d7.wav'),

    'e1': pygame.mixer.Sound('piano-e1.wav'),
    'e2': pygame.mixer.Sound('piano-e2.wav'),
    'e3': pygame.mixer.Sound('piano-e3.wav'),
    'e4': pygame.mixer.Sound('piano-e4.wav'),
    'e5': pygame.mixer.Sound('piano-e5.wav'),
    'e6': pygame.mixer.Sound('piano-e6.wav'),
    'e7': pygame.mixer.Sound('piano-e7.wav'),

    'f1': pygame.mixer.Sound('piano-f1.wav'),
    'f2': pygame.mixer.Sound('piano-f2.wav'),
```

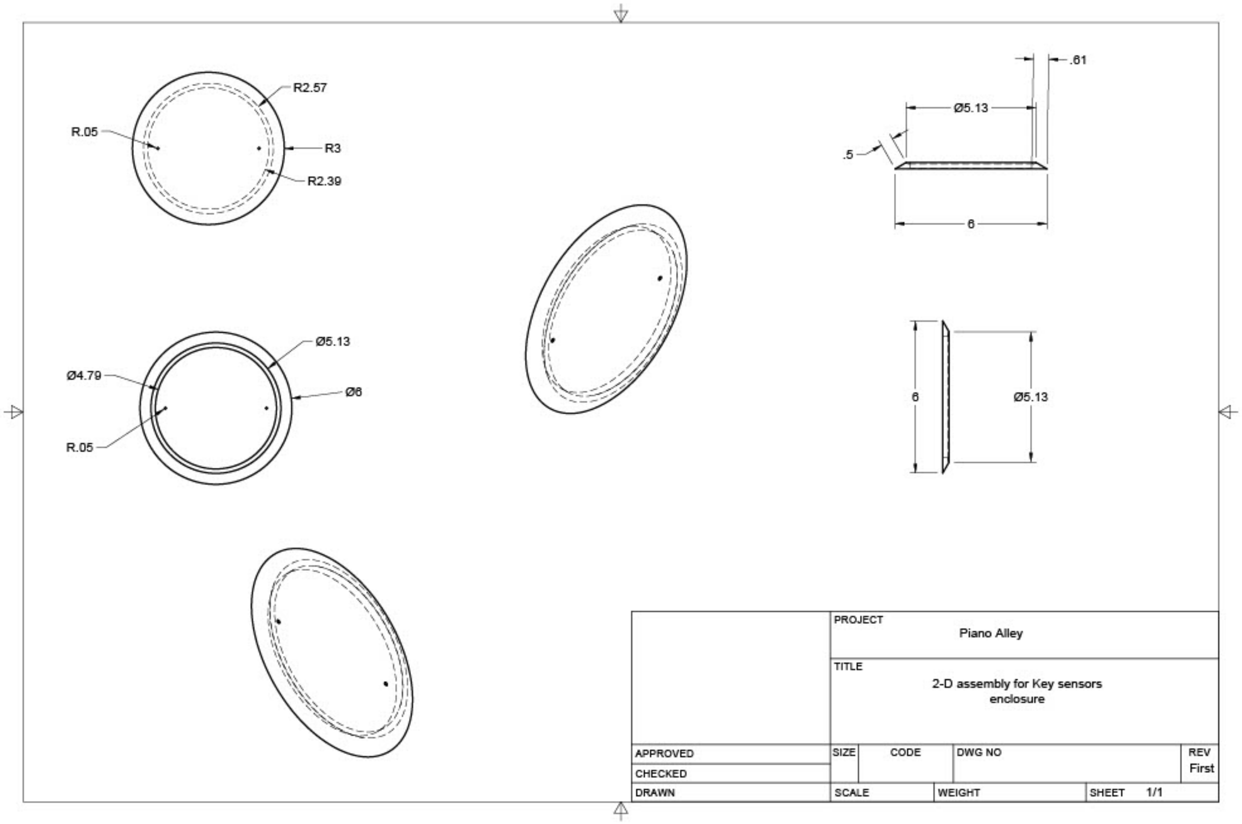
```python
    'f3': pygame.mixer.Sound('piano-f3.wav'),
    'f4': pygame.mixer.Sound('piano-f4.wav'),
    'f5': pygame.mixer.Sound('piano-f5.wav'),
    'f6': pygame.mixer.Sound('piano-f6.wav'),
    'f7': pygame.mixer.Sound('piano-f7.wav'),

    'g1': pygame.mixer.Sound('piano-g1.wav'),
    'g2': pygame.mixer.Sound('piano-g2.wav'),
    'g3': pygame.mixer.Sound('piano-g3.wav'),
    'g4': pygame.mixer.Sound('piano-g4.wav'),
    'g5': pygame.mixer.Sound('piano-g5.wav'),
    'g6': pygame.mixer.Sound('piano-g6.wav'),
    'g7': pygame.mixer.Sound('piano-g7.wav'),


}


def play_sound():
    key = input("Enter a key to play the sound (or 'q' to quit): ").strip().lower()
    if key in sounds:
        sounds[key].play()
    elif key == 'q':
        return False
    return True



def display_keys():
    print("Available keys: ", end="")
    for key in sounds.keys():
        print(f"{key}, ", end="")
    print("\n")



run = True
display_keys()
while run:
    run = play_sound()


pygame.quit()
```

Initial Enclosure design

We plan to make enclosures for 39 piano keys (including both black and white keys). Using SolidWorks, we have made, and 3D printed a model for our key enclosures. It is 6 inches in diameter, so it doesn’t take up the full width of a key (which is about 2 feet) but is still large enough to easily step on. The enclosure must be extremely thin as it cannot pose a tripping hazard for people walking through the alley. We talked to the city engineer and learned that anything above 0.25 inches is considered a hazard, so our model currently stands at exactly a quarter inch. The sides of the enclosure are sloped (as seen in the second picture) to make the change in height more seamless and gradual. The top of the enclosure has a ridge in it that will hold an O-ring we will purchase so that it is sealed well. The sensors inside need to be easily accessible so that maintenance teams can take off the lid and change the batteries if needed. To make the device more interactive we also plan to include a light that will shine when the key is pressed. The lid of the enclosure will be made from some kind of frosted plastic/glass so that the light will shine through. We are still considering using solar panels instead of batteries to power the electronics in each enclosure. If we go through with this idea, a small cutout in the lid will include a solar panel. In the bottom of the enclosure, I’ve included 2 small holes that we could put screws through to secure it to the concrete. We plan to buy enclosures for the speakers and the main control unit that will be on the wall of the alley.

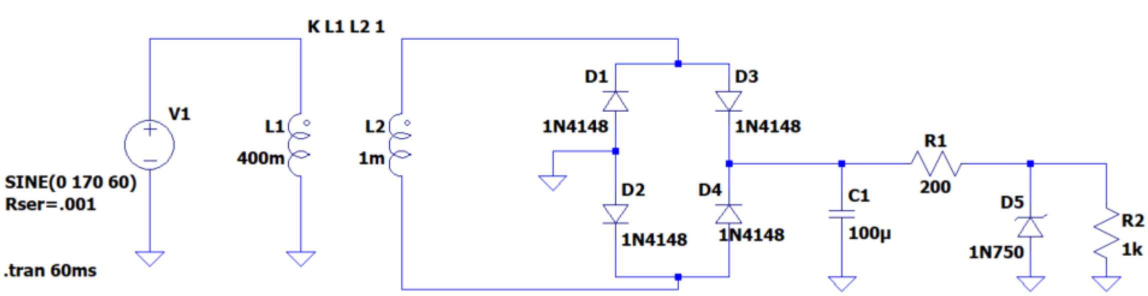


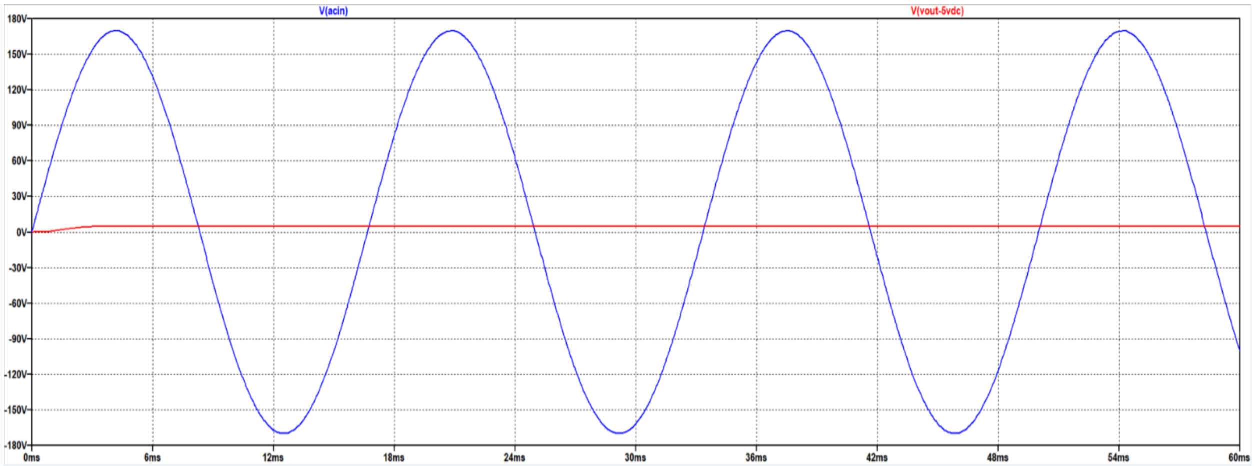




Power supply for MCU

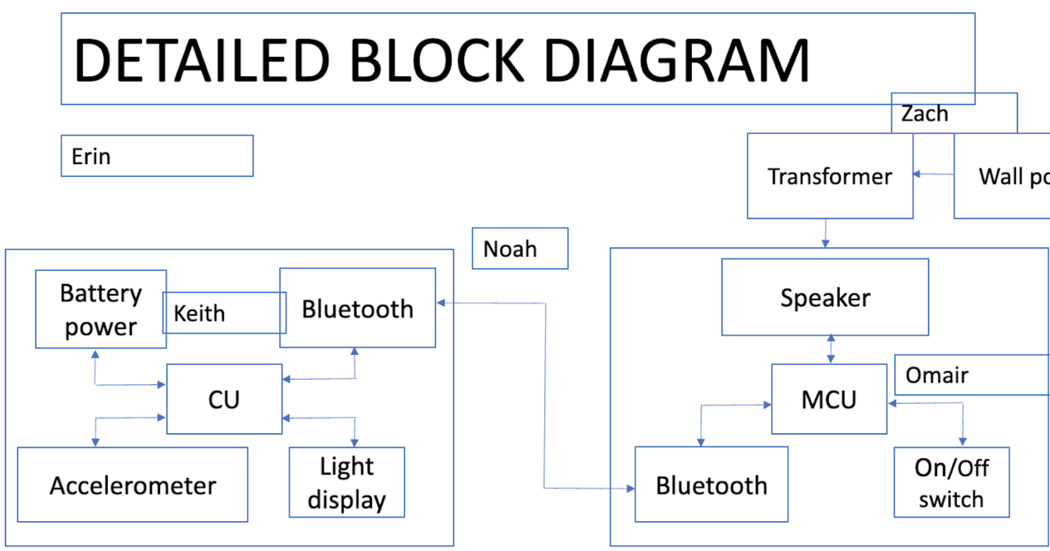
To power our main control unit (the Raspberry Pi), we decided to hard wire power from the building on which our main control unit will be mounted. This will involve stepping down the 120VAC that comes from most standard wall sockets and converting the AC signal to a clean DC voltage with an appropriate value to power our MCU. Since we have not yet defined the final design of our MCU, nor have we inquired with the building owners nearby to see what kind of power connections will be available, the current design of the power supply is somewhat general; however, as we finalize the design of our MCU and start to talk with the nearby building owners and city engineers, the design will be populated with correct components.





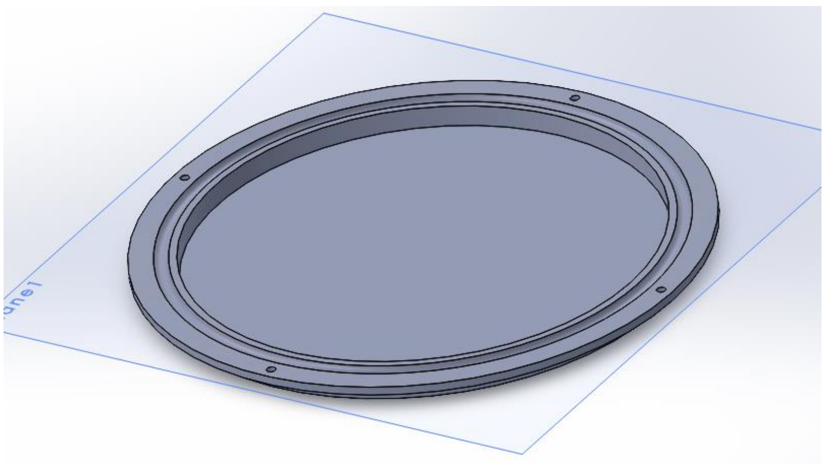
The first stage of the power supply, inductor L1 and L2 will step down the voltage from the wall power (120V AC) to a smaller amplitude signal, around 5V peak-to-peak. This smaller AC voltage will then enter the Full Wave Bridge-Rectifier, diodes D1, D2, D3, and D4, and be converted into an *almost* DC voltage. There is still some ripple voltage left after the signal passes through the bridge rectifier, which is the reason for the capacitor and Zener diode, these components help to further smooth the voltage before it reaches the load resistor R_2, the "load" in our case being the Raspberry Pi. As we further define the details of the design, more accurate component and signal values will be presented.

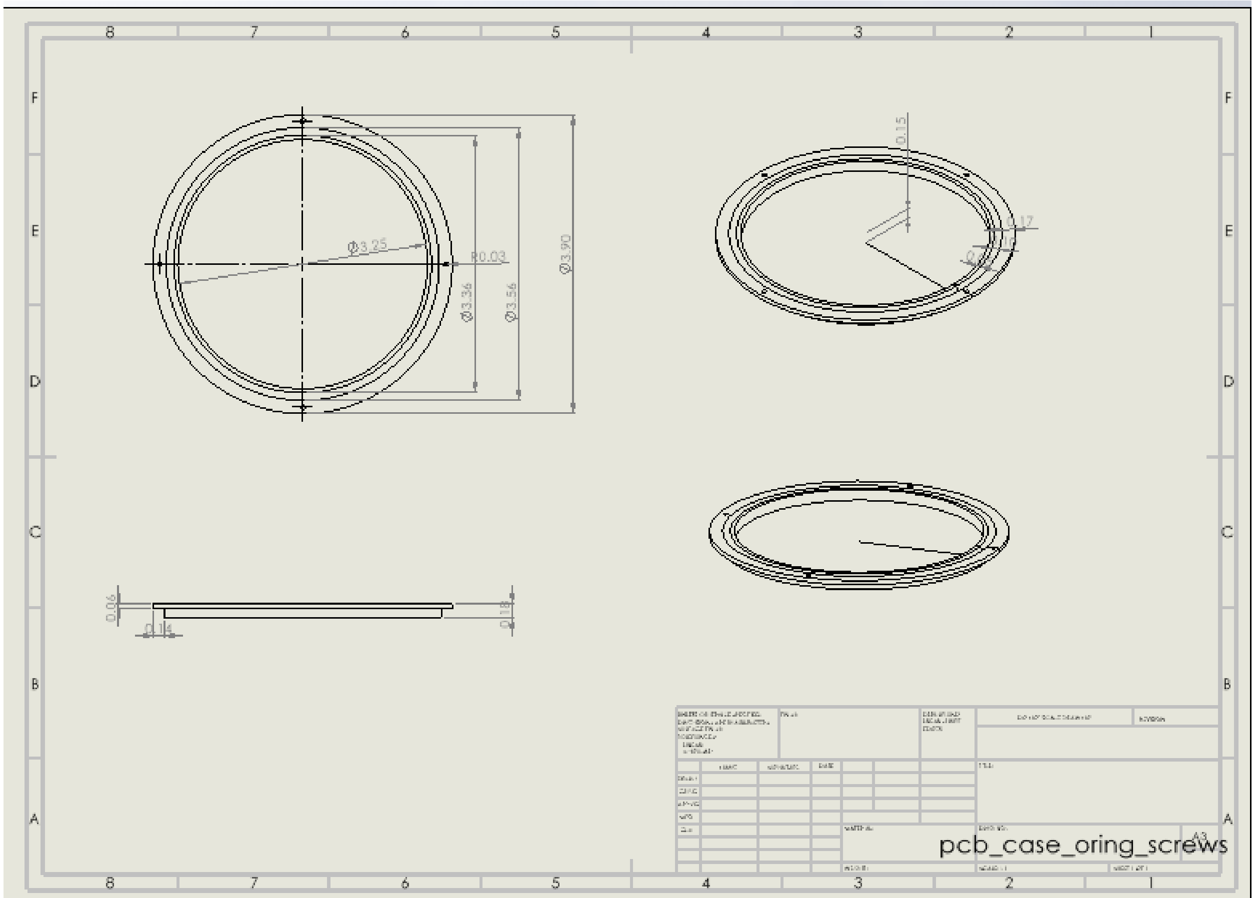
Hardware-key Side

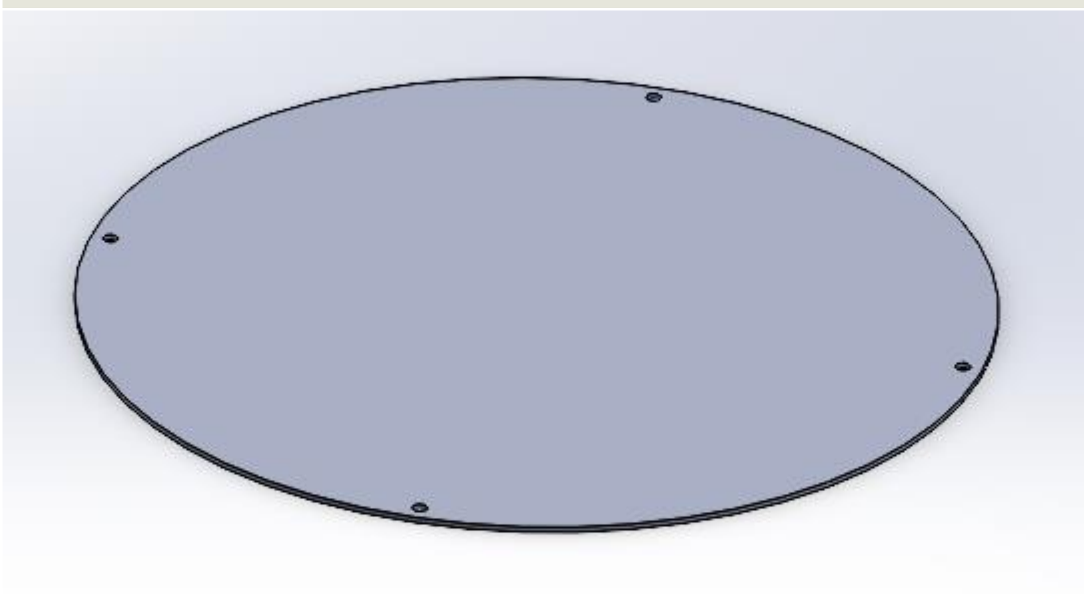


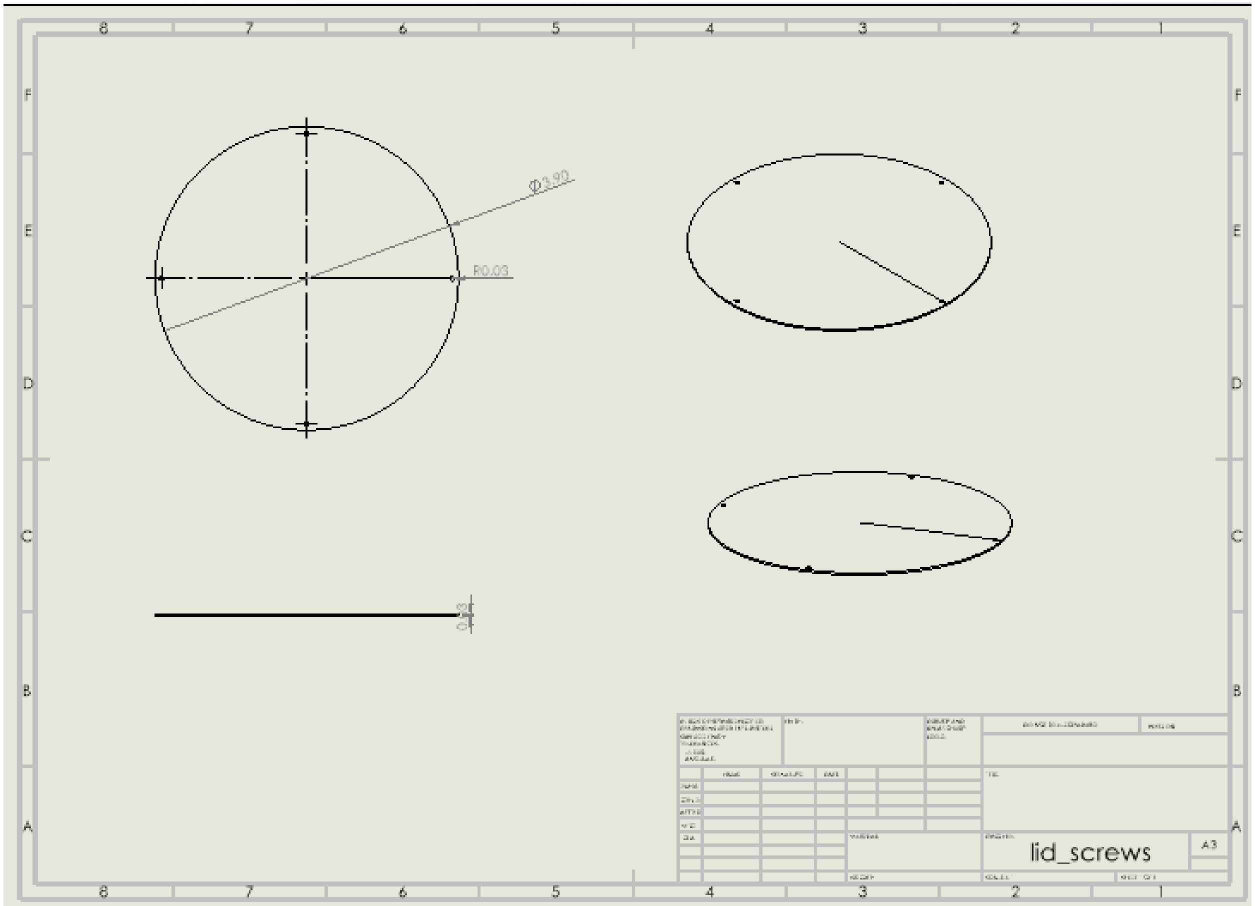
This section discusses the hardware (enclosure and PCB) for the key side of the project, shown by the left half of our block diagram.

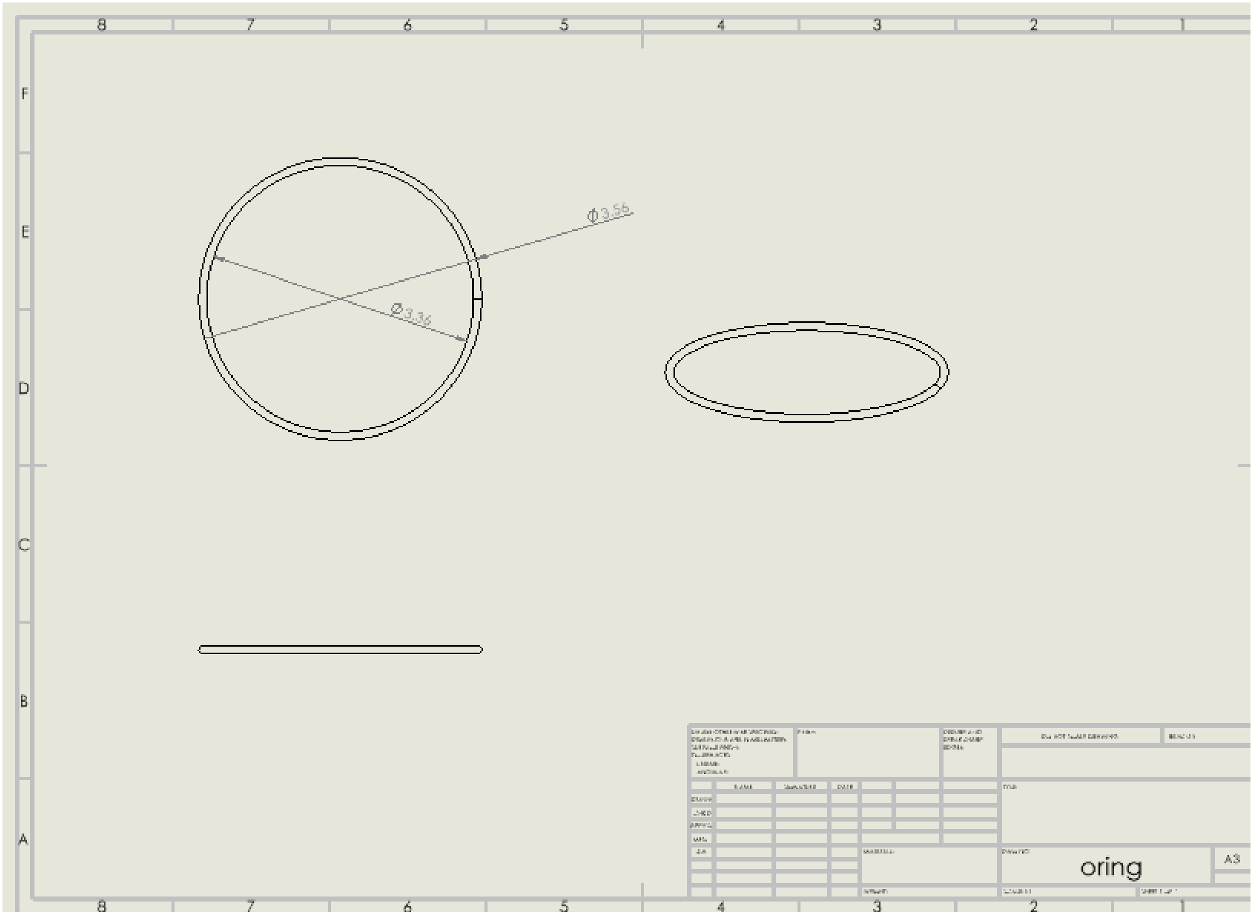
Noah and Erin worked together in SolidWorks to design an updated enclosure. For the final product we are using a combination of our designs. The part that Erin designed is a smaller inner casing about 4 inches in diameter that will contain the PCB and battery. It has a lip all the way around for an O-ring that we printed using NinjaFlex, a flexible and rubbery material. It also has 4 small holes on the perimeter for screws to secure the lid. The lid is a clear color so that light from the LED can pass through. It is flat so that it will squish the O-ring down, sealing the contents of the case so that rain/other elements cannot get in. The engineering drawings for the PCB case and lid, along with specific dimensions are shown below.



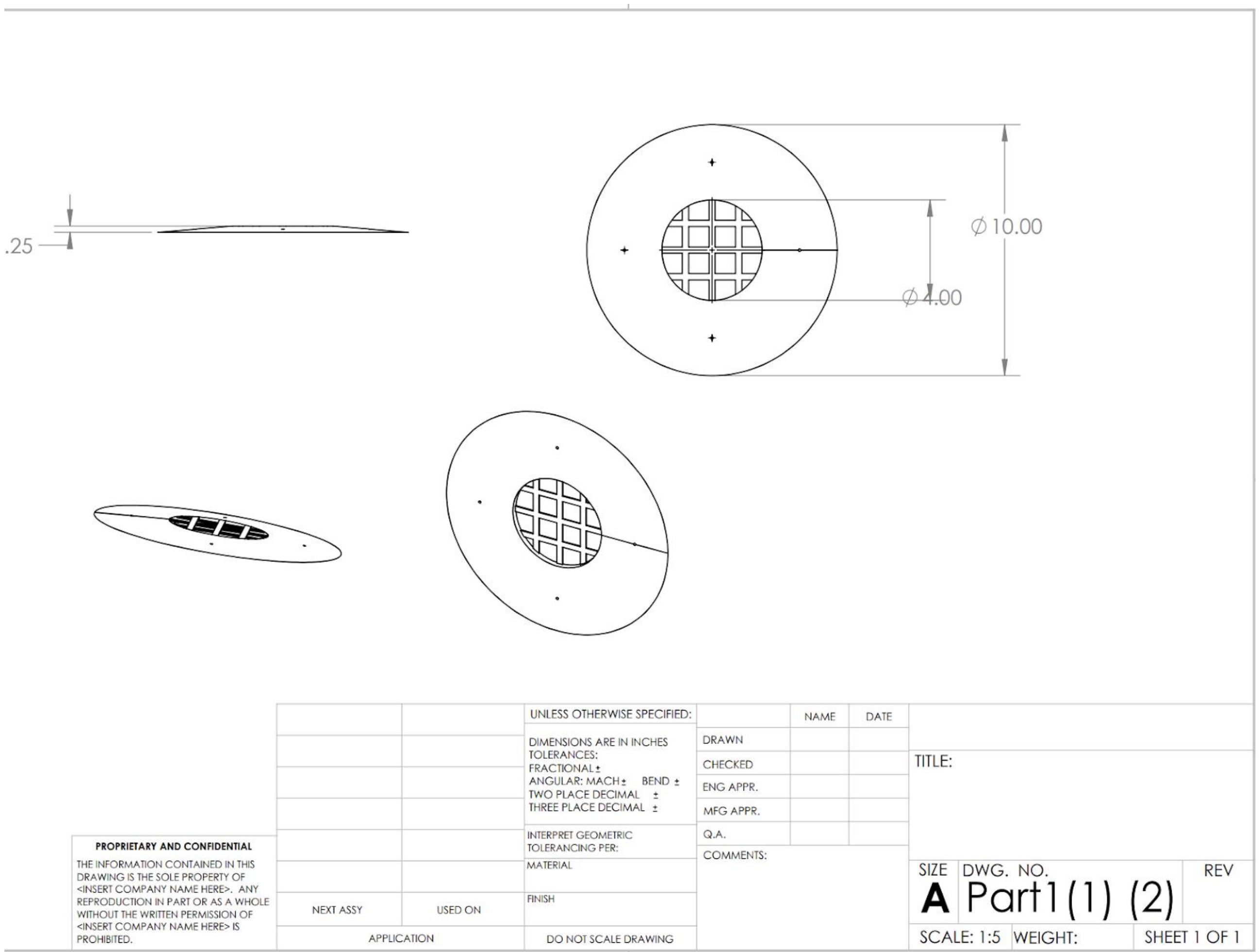

Ø3.25
R0.03
Ø3.36
Ø3.56
Ø3.90
0.15
0.17
0.06
0.14
0.18
pcb_case_oring_screws



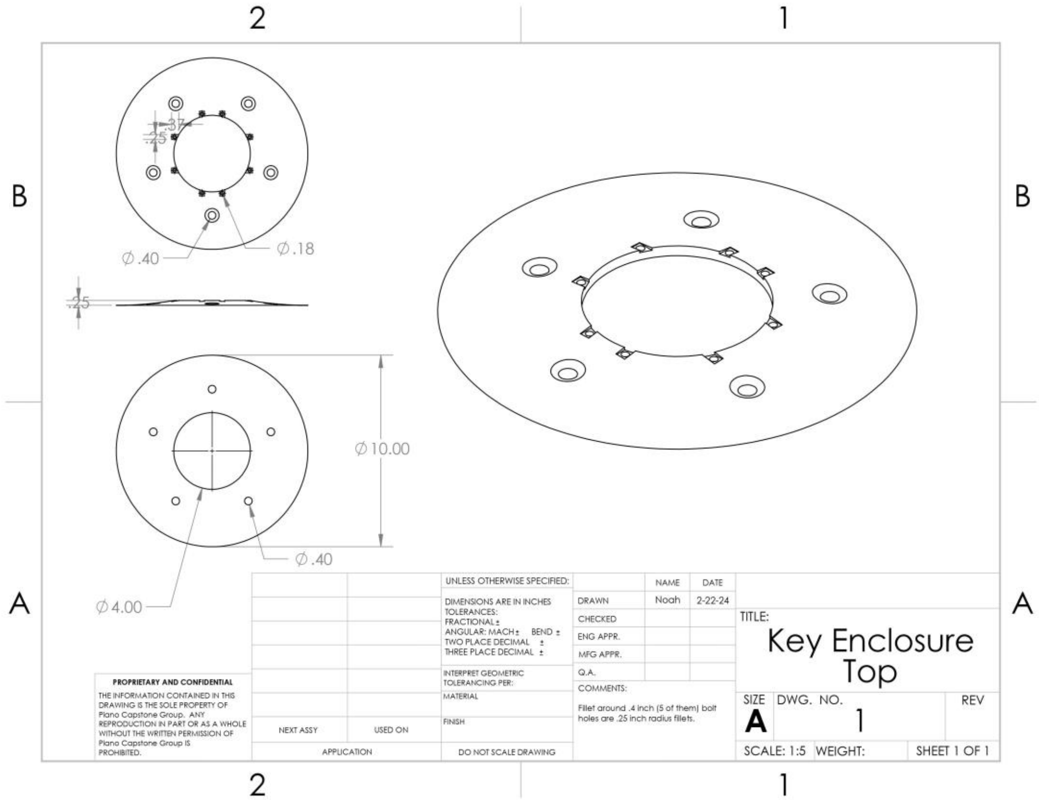

Φ3.90
R0.03
lid_screws
A3



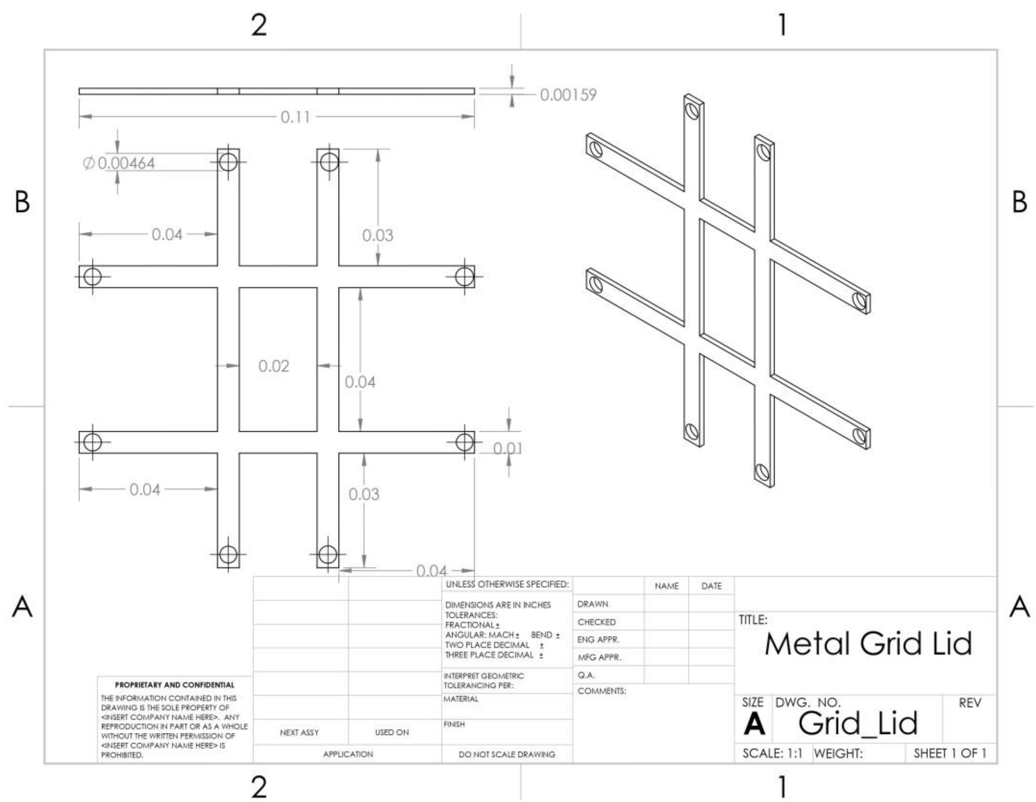
To protect the case and firmly secure it to the ground, we’ve also created a piece to go over the PCB case. This piece is 10 inches in diameter with a 4-inch opening in the center where the case will go. The total height is 0.25 inches, adhering to the ADA curb requirement and the limitations set for us by the city engineers. The rise occurs over a space of 3 inches to make it even more gradual and subtle of a change. The enclosure will be secured to the concrete via concrete screws of some kind. The specifics of securing it to the ground will be later in the design process. Both Noah’s and Erin’s design for this piece includes a grid covering the circular hole in the center to protect the case inside. In Erin’s design (below) the grid is connected to the rest of the enclosure.



In Noah's design the grid piece is removable and screws into the rest of the enclosure, secured by 8 screws. While the first design requires less assembly, we decided to use Noah's as it makes maintenance and upkeep easier. Instead of unscrewing the enclosure from the concrete and weakening its hold in the ground each time maintenance is required, the grid piece on top can simply be removed to reach the PCB case inside to replace the battery/sensors over time. The five larger holes around the outside of the disk are for concrete securing. The grid is designed to fit within the 8 slots to make for a smooth transition and minimalistic look. This grid protection piece will be secured by specific screws and nut inserts found on McMaster.com to order when further along in the installation process. The screws are 18-8 Stainless Steel Hex Drive Flat Head Screw, 82 Degree Countersink Angle, 4-40 Thread Size, 3/16" Long. The corresponding nut inserts are Brass Flanged Screw-to-Expand Inserts for Plastic, 4-40 Thread Size, ¼" Installed Length. The drill bit sizes for these are 5/32", but the prototype 3D printed design below has size 3/32" holes. This is because we designed it to account for the 3D printers not being precise enough. One must take a drill press and make the holes bigger to the 5/32.” Underneath the sloped disk piece below, there are extruded cut out circles around the bottom of the 8 holes for the grid attachment. This is space for the nut inserts to be inserted from below to match the screws from the top. This is so the nut inserts are flush with the bottom, to make for a smoother installation on the concrete. Further along these pieces of the design are meant to be metal or injection molded of some sort to withstand outdoor conditions, and strong enough for use/skateboards, etc. All updated CAD files and parts are found in OneDrive folder.



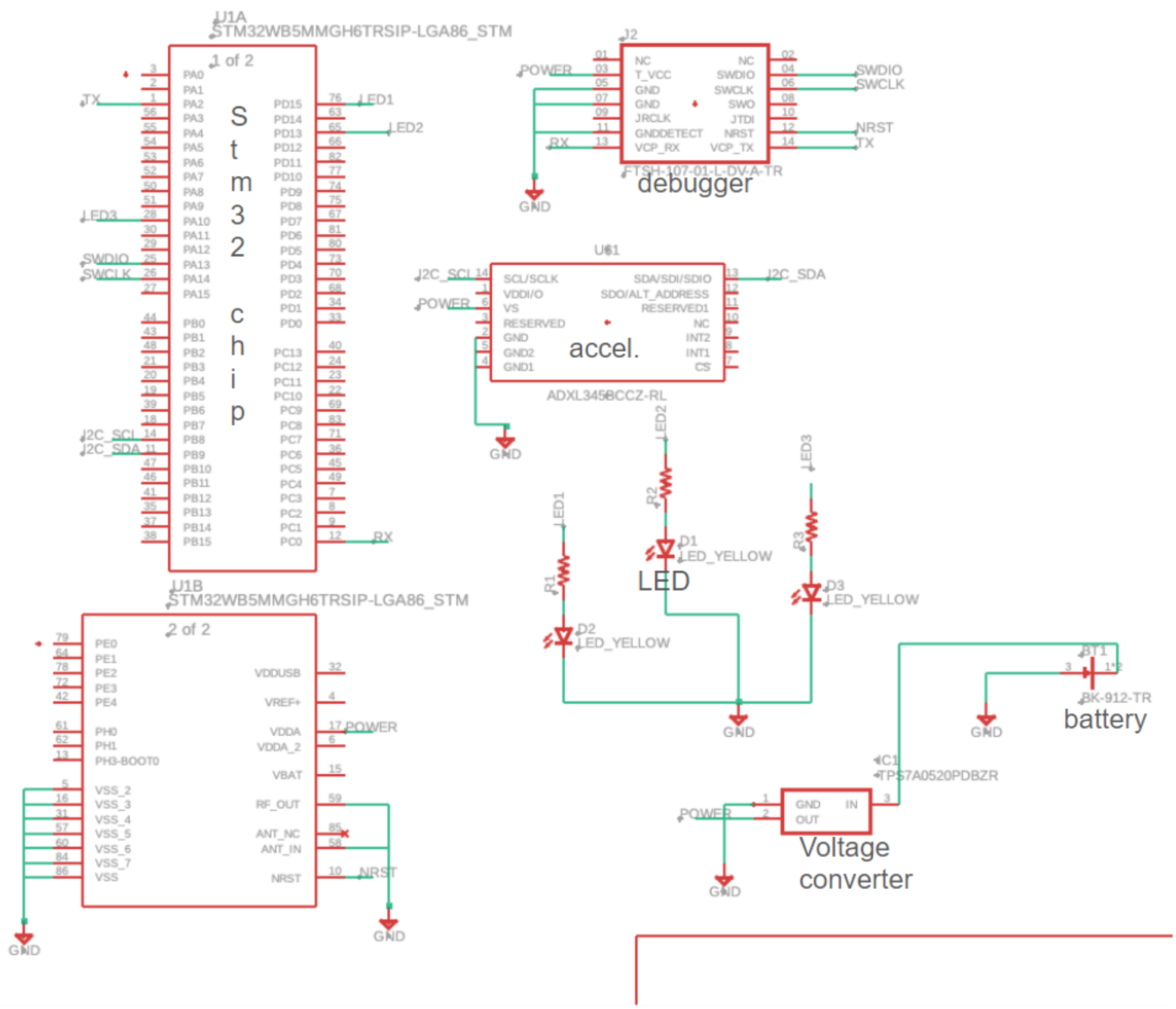
2
1
B
A
.37
.25
∅.40
∅.18
.25
∅10.00
∅.40
∅4.00
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
Noah
2-22-24
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Fillet around .4 inch (5 of them) bolt holes are .25 inch radius fillets.
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
TITLE:
Key Enclosure Top
SIZE
DWG. NO.
REV
A
1
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF Piano Capstone Group. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF Piano Capstone Group IS PROHIBITED.



2
1
B
A
0.00159
0.11
∅0.00464
0.04
0.03
0.02
0.04
0.01
0.04
0.03
0.04
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
TITLE:
Metal Grid Lid
SIZE
DWG. NO.
REV
A
Grid_Lid
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

For the PCB design we used Fusion 360 to create a schematic with the STM32 chip, accelerometer, LED, debugger, voltage converter, and battery (labeled below). Here are the specific parts that are used in the schematic (this cost estimate is only for the components on the PCB and will likely change as this is only the first version):

Name	part #	unit cost	cost for 39 keys
debugger	FTSH-107-01-L-DV-A	3.96	154.44
accelerometer	ADXL345BCCZ-RL	5.942 (for 25)	231.738
LED	150060YS75000	0.122 (for 100)	14.274 (3 LEDs/key)
stm32 chip	stm32wb5mmgh6tr	10.2016 (for 25)	397.8624
linear regulator	TPS7A0520PDBZR	0.298	11.622
battery	BK-912-TR	0.448 (for 10)	17.472
Total cost			827.4084



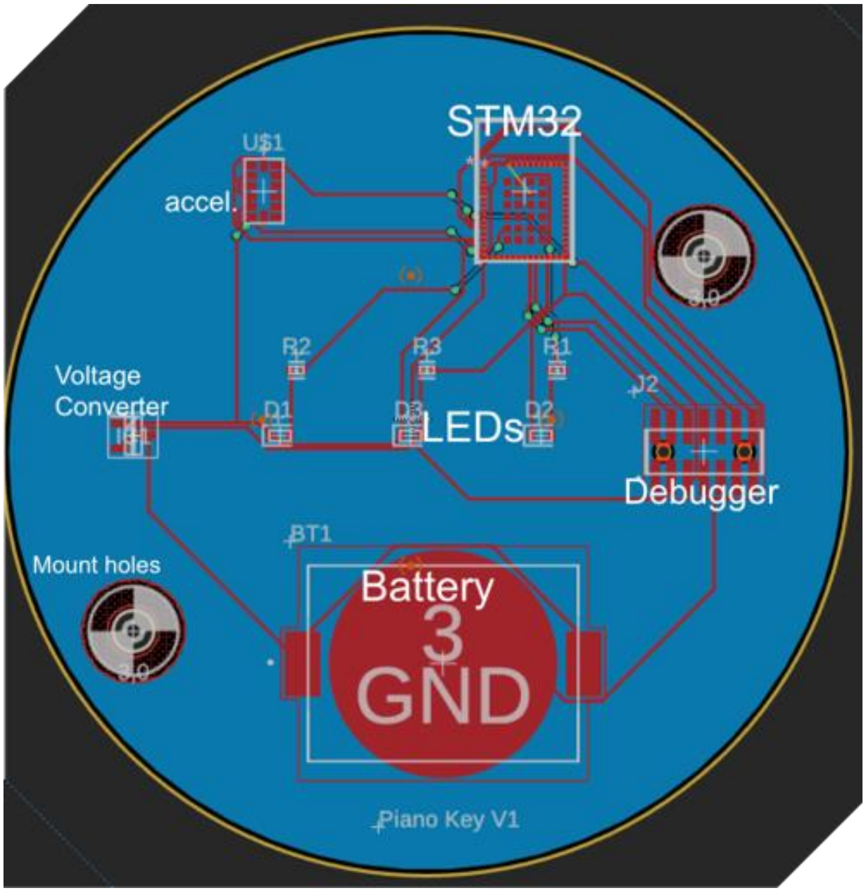
For now, we are using a coin cell battery that connects to the voltage converter in the bottom right of the schematic. In future we should look to a more robust, temperature-resistant battery such as the TLI-1550ES. One of the converter's pins goes to ground and the other one outputs a fixed 3.3V to the debugger, accelerometer (-0.3-3.9V), and microcontroller (1.71-3.6V). The three LEDs are connected to digital pins on the STM32 with resistors in between to allow for current adjustment. For purposes of getting the first prototype out we picked three single-color 0603 LEDs, but ideally the final product's LED's will be RGB. The STM32 communicates with the accelerometer via I2C. Using the STM32CubeIDE we discovered that pin PB8 carries the Serial Clock (SCL) signal and pin PB9 carries the Serial Data (SDA) signal. Therefore, they are connected to the corresponding pins (13 and 14) on the accelerometer. The SWDIO and SWCLK pins on the debugger are connected to the Debug Serial Wire pins (PA13 for SWDIO and PA14 for SWCLK) on the microcontroller. Below are the specific voltage ranges found in the documentation for the STM32, accelerometer, and linear regulator.

STM32	
Voltage range	1.71 - 3.6 V
Input voltage	3.3 V

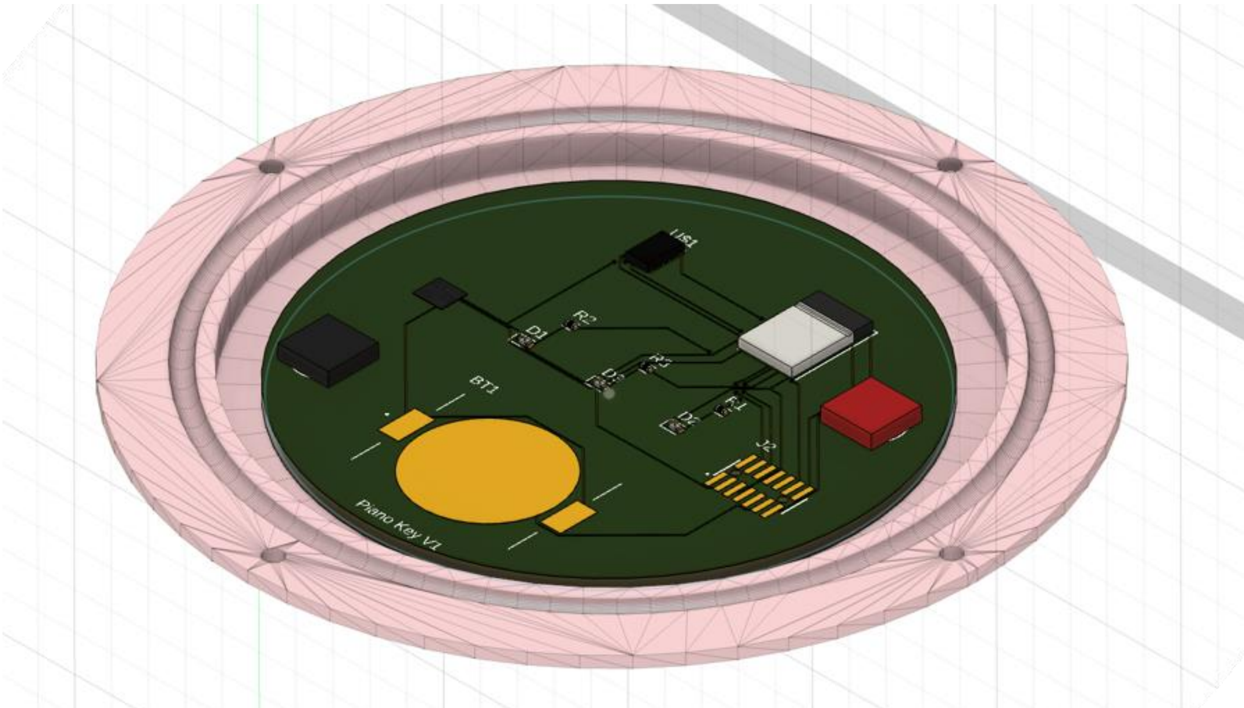
Accelerometer	
Voltage range	-0.3 - 3.9 V
Input voltage	3.3 V

Linear regulator	
Output voltage	3.3 V
Input voltage range	1.4 - 5.5 V

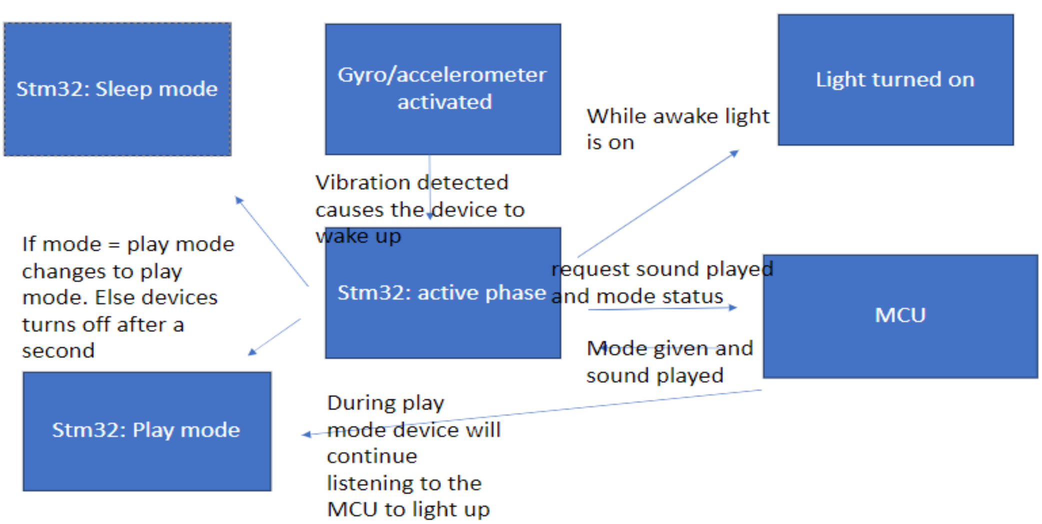
After finishing the schematic, we arranged the parts on the 2D PCB and used the Autorouter to route the board.



We were able to visualize the board in our enclosure before ordering it by importing the PCB case we created in SolidWorks and then inserting the 3D PCB into the design. We ordered the board through oshpark.com.



Software-key Side



The goal of this device is to send data and let the main control unit know when it is stepped on.

When finished it should have three modes; Sleep, Active, Play. Play mode causes the device to light up on instruction from the main control. Sleep mode only runs the Gyro Apon receiving a signal it activates active mode. Active mode starts by lighting the device up and sending a signal. It then checks what mode it should be in before changing to sleep or play mode.

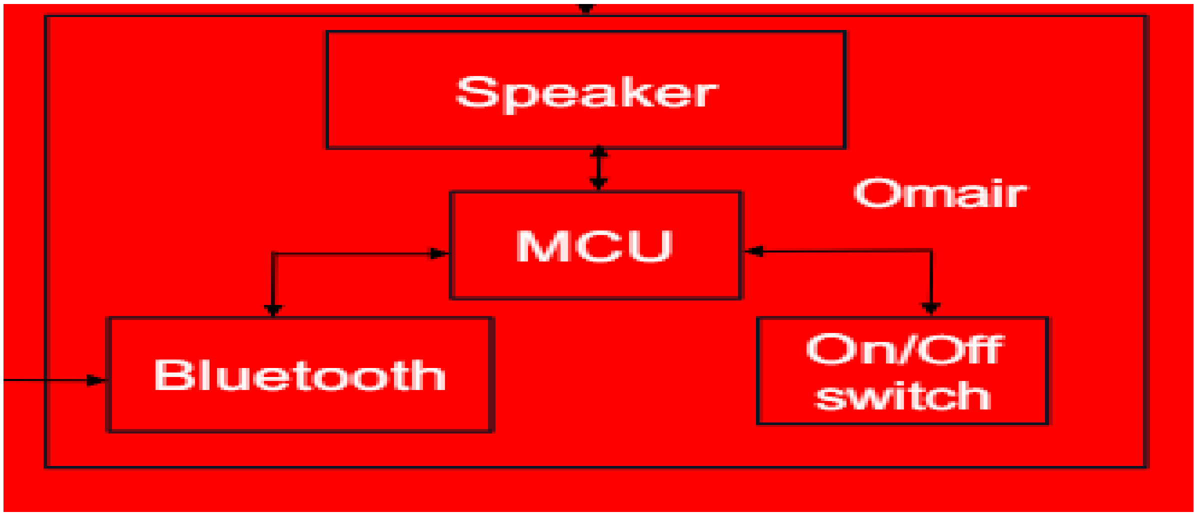
The reason for this method is to reduce the amount of power used. By having multiple stages, the device only activates the perphials that are need. With this implementation the device should be able to go all day without having to be replaced. The only device that would be constantly on would be the accelerometer. It was also discussed about having a working hour when the device would be active. This would allow the city to set hours of the day when foot traffic is at a minimum and the city wants to limit noise. During this mode the device would sleep for that set amount of time. However, it was decided that it would be better to implement this through the main controller as it would allow for limiting noise.

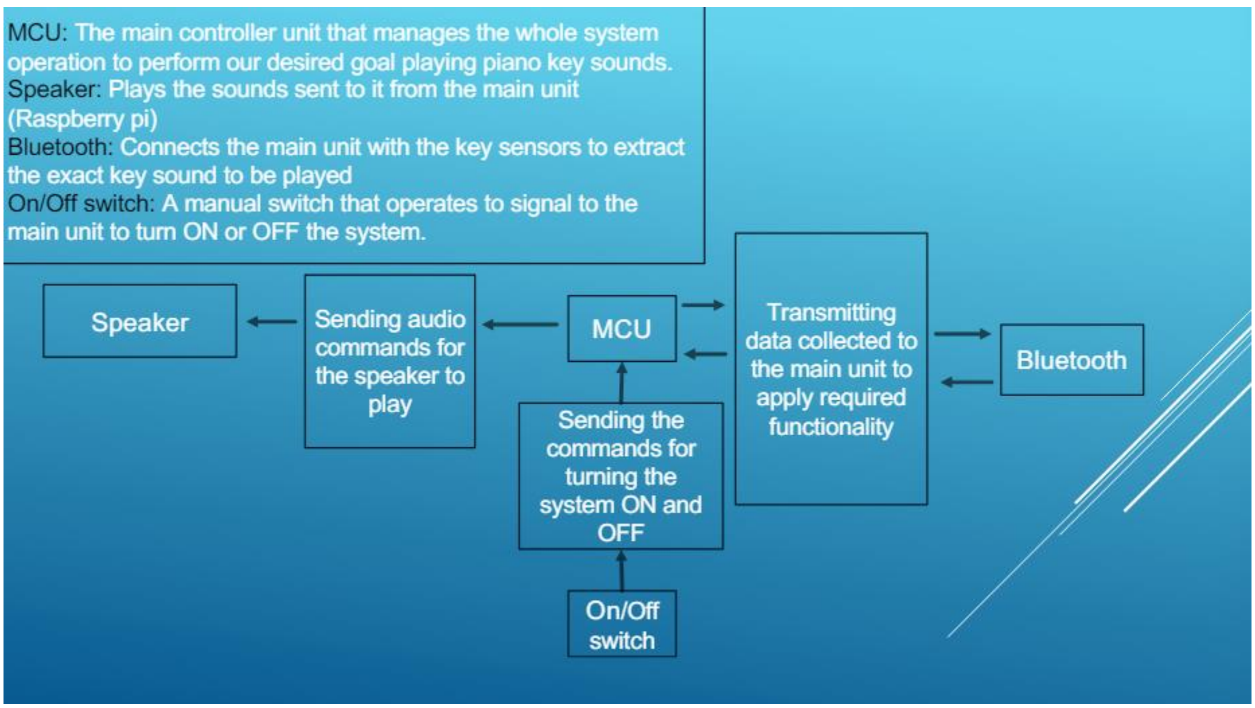
The current implication uses the I2c interrupt to detect when there is a signal from the accelerometer. It then uses the APP_ZIGBEE_SW1_Process() to send a signal to the Main control unit. To do this a sequencer is used. By using a sequencer, memory and power are used more efficiently.

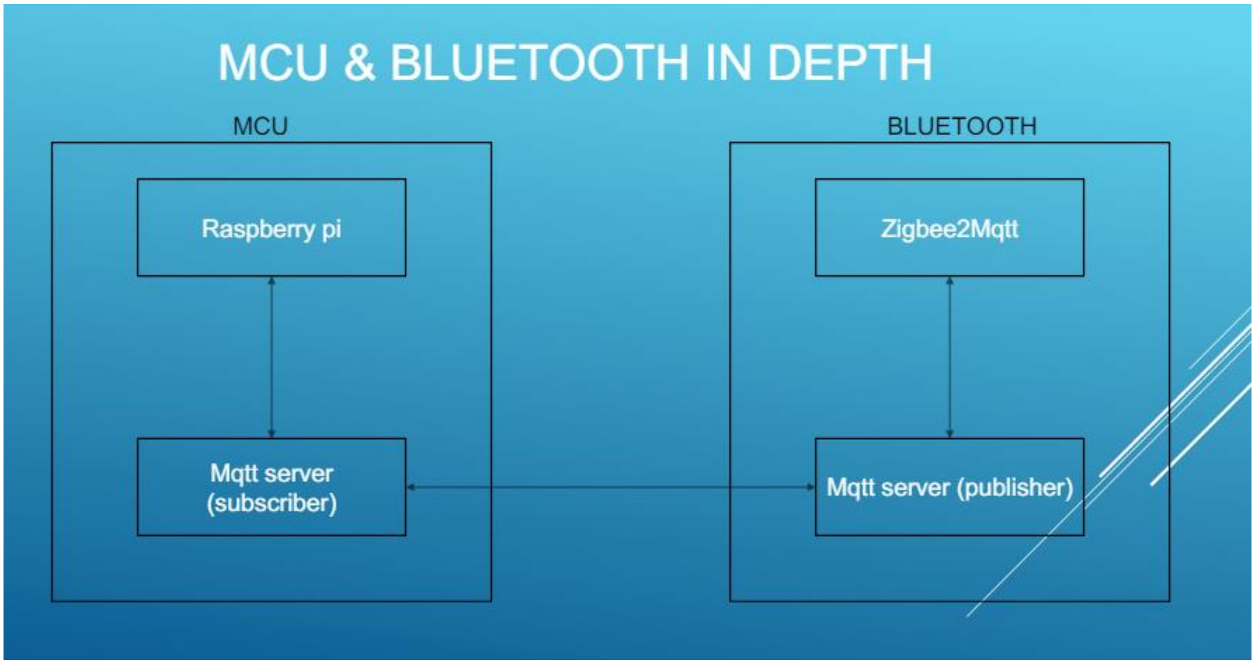
The current iteration is in Active mode only. To be able to go into sleep mode with the current iteration the ZigBee firmware will have to be changed to a different version. In addition, the current implementation of ZigBee only allows for data to be sent from the keys. So, it is unable to activate play mode. In addition, the Zigbee Program only uses the on/off endpoint. Due to time constraints, a magnitude version was not implemented. When implemented the magnitude will allow for the key notes when activated to play at different volumes depending on the force placed onto them. This will be like how regular pianos work. Also, it will allow for songs to be played more accurately.

Main control unit (Software / Hardware)

The goal of the main unit is operating the system to reach the desired goal of having the audio of piano keys to be played out to the user. Omair has worked on this side of the project which consistent of multiple parts. In general, the main unit consists of a raspberry pi model 3 B+, a Bluetooth adapter (Zigbee2mqtt), speakers and a turn ON/OFF switch based on the power supply.


Speaker
Omair
MCU
Bluetooth
On/Off switch

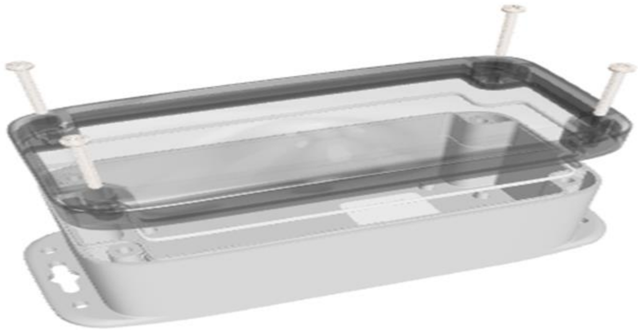

MCU: The main controller unit that manages the whole system operation to perform our desired goal playing piano key sounds.
Speaker: Plays the sounds sent to it from the main unit (Raspberry pi)
Bluetooth: Connects the main unit with the key sensors to extract the exact key sound to be played
On/Off switch: A manual switch that operates to signal to the main unit to turn ON or OFF the system.
Speaker
Sending audio commands for the speaker to play
MCU
Transmitting data collected to the main unit to apply required functionality
Bluetooth
Sending the commands for turning the system ON and OFF
On/Off switch



The purpose of the block is to connect the sensors to the main unit and then output the requested audio (piano key sounds). First, the speakers are connected directly to the raspberry pi via an AUX wire and can be tuned based on the user's choice. Next, On/Off operation is based on the pi management of power where it forces the system to either start or shut.

The Bluetooth section is where our data flow transfer to the main unit (pi), in details, the key sensors will communicate via Zigbee and on the main unit side we will have a zigbee2mqtt adapter where we push the data to the mqtt server in which the pi is waiting as a subscriber and reads the data (key ID, sound intensity) and goes ahead and play the requested piano key sound.

Moreover, into hardware component, we will have an enclosure holding the pi and other electronics required that will be modified to have holes in it allowing for cable management in and out of the case giving access to the pi for speakers to connect and allowing power cables to reach our electronics. For a better visualization an enclosure of the desired goal would be a version of the following enclosure.



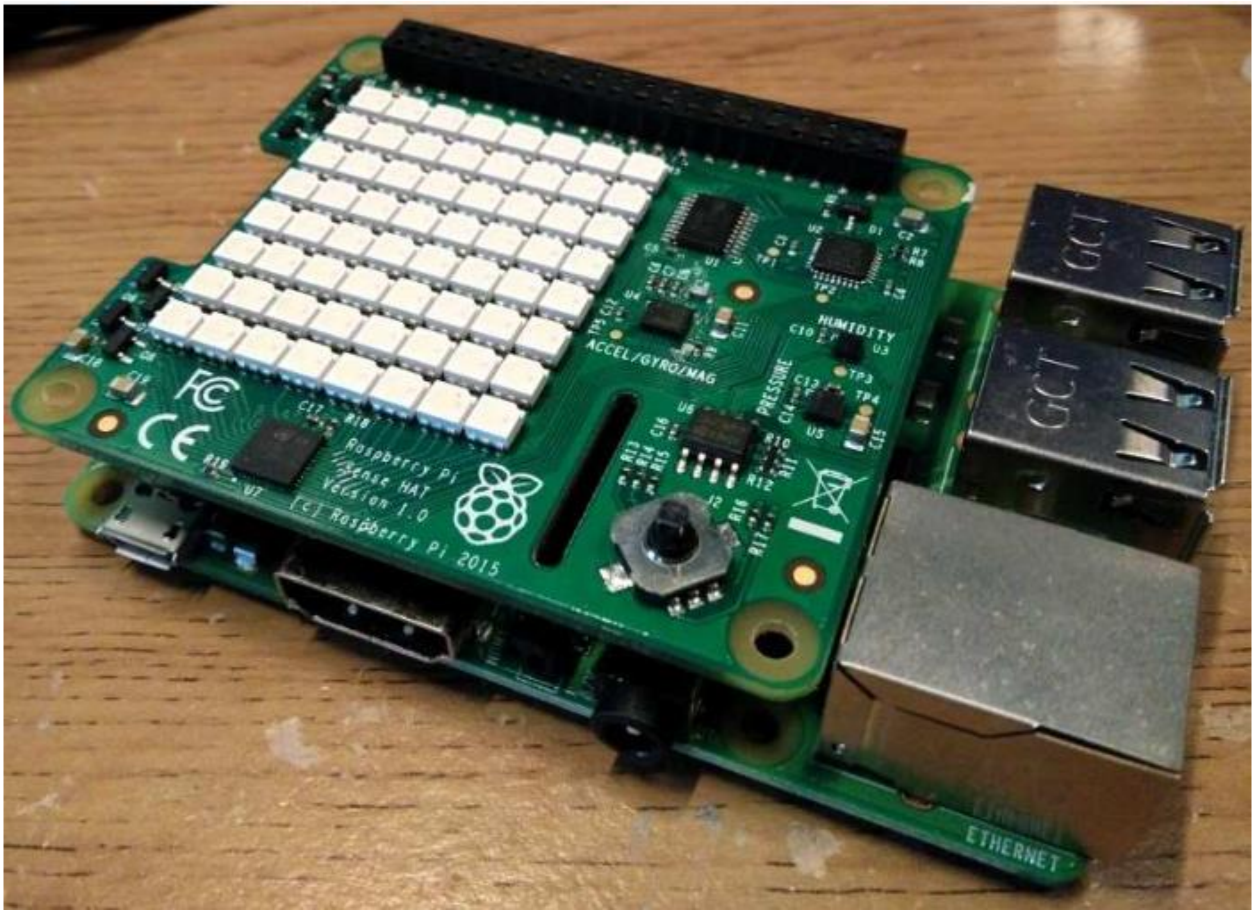
For the Software side, as mentioned above we will be using the raspberry pi to manage the piano keys to be played and such process would be as following: key sensors sending data via Zigbee to the Zigbee2mqtt adapter connected to the pi that then will be publishing such data to the MQTT server where we will have the pi waiting on the subscriber side of the server and pull such data (key ID, sound intensity) and run them through the python script of the pi which will result in having the audio sounds be transmitted to the speakers to play in the alley. For this to work we would have a running docker holding the connection of the keys to the Zigbee adapter that is already connected to the MQTT server. The plan is to have the pi system turn on based on the plugged power source, in other words, if power flows (switched on) the pi system starts to await data from the keys and runs the desired goal.

Demo of the project

Components: ACCELEROMETER-ADXL, STM32, RASPBERRY PI – INTERFACE, ENCLOSURES/PCB

ACCELEROMETER-ADXL:

For the demo we used the sense hat gyro and lcd. This allowed us to quickly come up with a working prototype that could show the full capabilities of the system.



STM32:

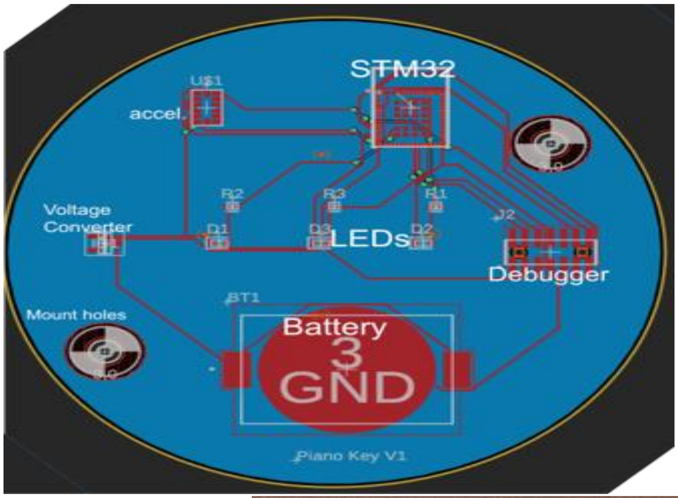
For the final version we plan to use the STm32wb series microchips. They are a two in one package as they have both wireless connectivity and the normal microchip packaged together. Stm32 chips are good at power control making them perfect for a small embedded system. With reduced power consumption the device can be on longer and require less

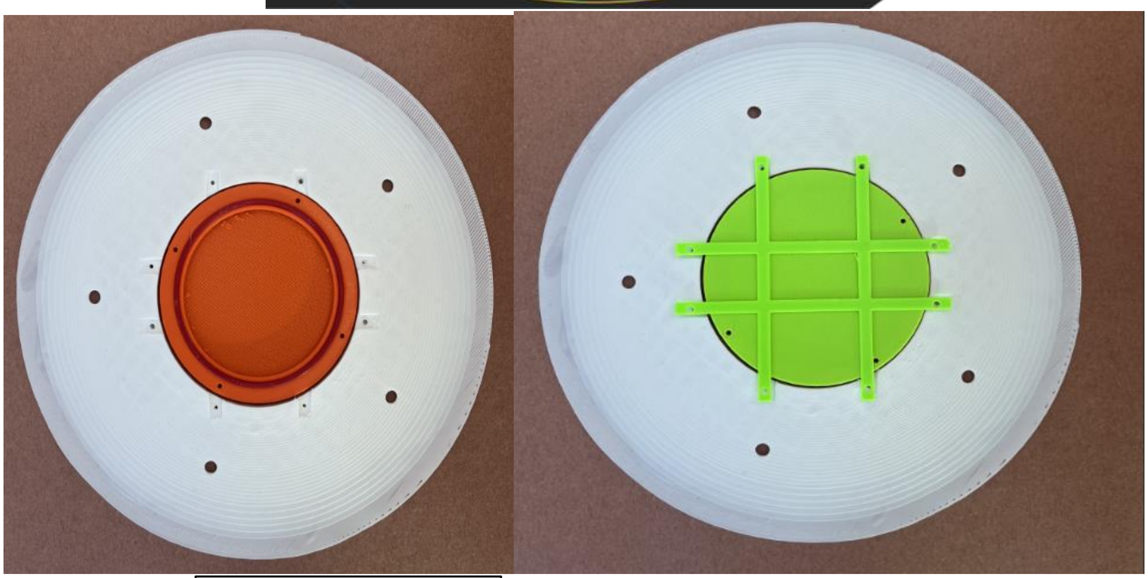
Maintenace.

RASPBERRY PI – INTERFACE:

ENCLOSURES/PCB:

Stm32 based key sensor Enclosure





Main Unit Enclosure

pi based key sensor (for demo purposes)

Final Product:

For our current Prototype we have the main pi (main unit) connected with other pi(s) that are placed on the key enclosures through an MQTT server. We see in the prototype how when the keys (pis) move, demonstrating the action of a button pressed, the main unit sends audio key notes to be played via the speakers. This kind of approach we followed is to demonstrate the system flow since we made the choice to demo our project using (pi)s in the key sensors instead of stm32 chips because we are still in the process of building the Bluetooth connection via Zigbee.

Key Sensor (code snippets important functions)

```
def read_gyro_changes():
    while True:
      if start_publishing:  # only publish when signal from unit recieved
        data = sensor.get_accelerometer_raw()
        dx, dy, dz = abs(data['x']), abs(data['y']), abs(data['z'])
        if dx > 1.1 or dy > 1.1 or dz > 1.1:  # Threshold
            volume = calculate_volume(dx, dy, dz)
            publish_sensor_data(volume)
            #last_x, last_y, last_z = data['x'], data['y'], data['z']
            sensor.clear([200,30,200])
            time.sleep(2)
        sensor.clear()

def publish_sensor_data(volume):
    payload = f"{ID},{volume}"
    client.publish(MQTT_TOPIC, payload)
    print("Published:", payload)
```

Main Unit (code snippets important

```
def on_connect(client, userdata, flags, rc):
    print("Connected with result code " + str(rc))
    client.subscribe(MQTT_TOPIC)
    client.publish(MQTT_CONTROL_TOPIC, "main_on")
    client.publish(MQTT_CONTROL_TOPIC, "start_light_mode")

def on_message(client, userdata, message):
    print(f"Received message: {message.payload}")
    data = message.payload.decode('utf-8').split(',')
    if len(data) == 2:
        try:
            file_id = int(data[0])  # ID to identify the sound file
            volume = int(data[1])  # Volume level
            play_sound(file_id, volume)
        except ValueError:
            print("Received data is not in the expected format: 'id,volume'")
```

Impact

The piano alley should increase foot traffic and enhance the city of Jasper. The goal of the project is to create living artwork. The mural itself has seen an increase in foot traffic. With this known we expect that this might become a local hangout spot and a possible tourist destination. Hence, we should expect an increase in local and non-local traffic into the city. Which in return will have a small economic boost effect. In addition, the foundation could allow for each key encloser to be signed by a backer to raise money for the installation.

Looking ahead

As mentioned before, the plan of the device is to allow it to fully interact with the community. Some additions that need to be made are that the current device uses the default Stm32 Zigbee authentication key. This causes it to be susceptible to malicious intentions. In addition, we have not implemented the Play mode yet due to time constraints. This will increase the interaction value of the installation. It could also be designed in a way that will allow for the songs to be switched around by the user. Power is a big concern for the device in the current iteration. Currently, we have no custom code or design for power. In the future, power modes will need to be programmed onto the board. A trickle charging solution such as solar panels should be implemented along with rechargeable batters to reduce Maintenace. Also, by implementing Zigbee into our main control unit, we can add additional devices to the alleyway. This will allow items to be added over time to increase the capabilities of the alleyway. In addition, it will allow this set up to be moved from one alley to another if necessary.

References

[1] Play22," Keyboard Playmat 71". https://www.amazon.com/Keyboard-Playmat-71-Playback-Adjustable/dp/B073R2FBWY (accessed Dec. 13, 2023).

[2] P. Play, "Grand Floor Piano - Percussion Play," *www.percussionplay.com*. https://www.percussionplay.com/grand-floor-piano/

[3] *Bigpiano*, "*bigpiano*". Available at: https://bigpiano.com/

[4] Rosenberg and J. Zarraga, "Touch sensor detector system and method," Sensel Inc. Apr. 07, 2015 Available: https://patents.google.com/patent/US9001082B1/en

[5] R. Saraceni, "Portable floor piano with folding keyboard,". Aug. 18, 2015 Available: https://patents.google.com/patent/US9111516B1/en

[6] T. Yamaguchi, "Keyboard device for keyboard instrument," Kawai Musical Instrument Manufacturing Co Ltd. Mar. 30, 2023 Available: https://patents.google.com/patent/US20230335082A1/en?oq=US-20230335082-A1

[7] Admin, A. (2023, October 17). *All you need to know about Ada Curb Ramp Requirements in 2021*. ADA Solutions - Tactile Warning Surfaces. https://adatile.com/all-you-need-to-know-about-ada-curb-ramp-requirements/#:~:text=Section%20%C2%A7405%20of%20the,on%20the%20number%20of%20runs.

[8] *IEEE SA - standard for wireless sensor data of power transmission and transformation equipment*. IEEE Standards Association. (n.d.). https://standards.ieee.org/ieee/3363/11263/

[9] *ISO 20108:2017*. ISO. (2023, August 25). https://www.iso.org/standard/67062.html#:~:text=ISO%2020108%3A2017%20sets%20out,are%20specified%20in%20ISO%2020109

[10] *IEEE SA - recommended practice for the design and construction of prefabricated and modular outdoor battery enclosures*. IEEE Standards Association. (n.d.-a). https://standards.ieee.org/ieee/3189/11033/

[11] *IEEE SA - IEEE standard definitions of terms for solar cells*. IEEE Standards Association. (n.d.-a). https://standards.ieee.org/ieee/307/504/

[12] *IEEE SA - IEEE recommended practices for modulating current in high-brightness leds for mitigating health risks to viewers*. IEEE Standards Association. (n.d.-a). https://standards.ieee.org/ieee/1789/4479/

Link for piano note sounds: https://samplefocus.com/tag/piano-note