CPE 191 - 01 : Senior Design

Assignment 8: End of Project Documentation Report

Sight of Touch

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Team 6: “The Ensemble”

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## Elevator Pitch

A multi-sensory system using visual aids and a haptic feedback system for an encompassing musical experience.

## EXECUTIVE SUMMARY

After two semesters of Senor Design, this final report will encompass our team's work and effort to complete a functional deployable prototype. Our team wanted to create a prototype that would address our societal problem, the lack of multi sensory devices. It is in this report where we will provide a detailed description of the entirety of this design process from Fall to Spring and how we were able to successfully implement our design into reality.

Starting with our societal problem we will discuss our Design Idea Contract that will be our main reference for the whole year; this involves features and the measurable metrics that the device must meet like the musical frequency range of 330-784hz. We will then go over the financial aspect of our project that compiles all the expenses from each member. The project milestones will cover the impact of important events over both semesters. The work breakdown structure summarizes hours/tasks done by each member to meet design features. Next we'll discuss how we addressed any risks we faced and the potentiality of risks we could've faced as a team.

The next few sections will cover topics specific to the overall design and the deployable prototype status as of Spring and projections for product placement in the market. In the Design Philosophy we'll go over testing and metrics that led to changes in the design for the second semester. The Prototype Status will cover the testing results and how they lead to changes in our design. The motors results were not what we expected, so changes had to be made to meet our metrics. More importantly this section details how our final Spring prototype meets the Design Idea Contract. For the market forecast we review our previous market assignment and list possible equipment upgrades like addressing the problem with our motors. With upgrades our product can meet the standard of other competitors so we can place our own prototype in our desired markets.

The Conclusion will be a summary of what we have accomplished and learned over the year. The References will include the reference page with all sources used throughout the report. The Glossary will list key ideas and their definition for the casual reader. Appendix A is a User Manual that will explain what is needed to set up the project along with a simple and clear explanation how to use the prototype. Appendix B,C,D will be sections that include data sheets, design diagrams, testing results, flowcharts & pseudo code for areas such as Hardware, Software, and Mechanical. Appendix E will be the contacts that assisted us with our project and Appendix F consists of each team member's resumes listing our skills that we individually provided for the project.

This report truly is the culmination of all our past assignments into one whole document which showcases our team's progress and results of building a multi-sensory device for a unique problem.

***Abstract-***

**Our project's societal problem is the lack of multi-sensory devices on the market. The prototypes goal is to fulfill that gap by creating a device that would incorporate multiple senses while giving the user the best experience. This idea is what we based our metrics on. Project milestones will cover the major steps in our project over both semesters. Risk assessment had us gauge the most common problems our project may have such as parts breaking and our plan to keep working despite setbacks. Our cube shaped device and how our metrics influenced this decision will be covered in the Design philosophy. Finishing the project, our project status will show how we managed to meet all our requirements like constraining motor frequency to 50 -130hz. The market forecast will use our previous experience and knowledge to explain why certain upgrades such as vibration motors are needed to be placed in our desired markets. The conclusion will summarize the main report while the references will list our research and the glossary will define frequently used terms. In the appendices there will be a section for the hardware, software, and mechanical aspects that describe each aspect's design and testing results. A user manual will explain the steps to use our prototype and vendor contacts will list anyone who guided us on our project. This final report will cover both semesters answering many of the questions posed to us over the past year.**

***Keyword Index -***

Light emitting diodes (LEDs), Fast Fourier Transform (FFT), Deaf and Hard Hearing (DHH), Pulse width modulation (PWM), Visible Light Spectrum (VLS)

## I. INTRODUCTION

It has been almost a full year of dedicated work, countless hours, and continuous, sufficient progress that our team has contributed to our senior design project. From the beginning of the Fall semester, our group of four members decided to take upon a project design solution to a very unique societal problem. Throughout these past two semesters, we've individually and cohesively worked as a team to ensure that the device that we produce shall uniquely meet the set design features and requirements. As senior design comes close to an end, it is essential to document the progress, data observations/results, current status, functionality, and task/features completion of our end deployable prototype. Therefore, it is in this paper where we will fully describe in great detail the essential topics involved with our team's deployable prototype that ranges from the initial project design planning to current status of our team's progress to a projected forecast of the manufacturing of the device.

Firstly, we'd like to start of with defining the problem statement we addressed to solve with our deployable prototype. We'll first describe how we defined our initial Fall version and transition into how we modified the problem statement in the Spring semester. It is important to know that the original main construct of the statement we'd like to address is the lack of multi-sensory devices that can be utilized for an alternative, enhanced musical experience. But we'll further explore the reasoning of the main shift of the problem statement redefinition from a singular community to a larger, universal audience.

Secondly, we'll comprehensively review our team's Design Idea Contract which was also defined last semester. This Contract essentially is the overview of our project proposal that contains the deployable prototype's features. Along with each feature there are associated measurable metrics to ensure the design is met. If there were any revisions and/or modifications made in the Spring, it will also be discussed here. Our multi-sensory device essentially has five features, where the four main features were individually completed by a member and further describes how the prototype shall be implemented/designed.

Next, another step that is a part of project design is the financial aspect, ensuring that we have a set budget for necessary spending to complete a functional device. In this section we'll provide the overall budget that our team collectively decided to follow. We'll also provide whether or not this budget was allocated appropriately throughout the year in the form of concise tabular data of the purchases the team attributed to.

Additionally, the following three sections were found to be crucial in planning, organizing, and ensuring that the team would make substantial progress for achieving full implementation of the device's design features. These next three sections are: Project Milestones, Work Breakdown Structure (WBS), and Risk Assessment. With our specific design solution, it consisted of ideally four main features -- each attributed to a sense (hearing, sight, and touch) and synchronization of these three features/senses -- where each group member was assigned one of these features to work on individually and together, if needed. In Project Milestones, the major events that occurred both in the Fall/Spring will be discussed. Immediately the WBS Schedule will be included which will both include the milestones and additional events such as coursework assignments, presentations, tasks. Given that each member is a lead of a feature/sense, in this section the task assignments will also be detailed with the project start/end deadlines. To conclude the section, a summary of total hours completed by each member will be provided. After the WBS, the Risk Assessment section will identify the potential risks and associated mitigations that the team shall take as well as be aware of if anything occurs anytime throughout the semester. This will cover the risks that can occur from a specific feature and the necessary action plan/procedure the individual member/team should do. Despite risks and/or problems happening, it is important that the team makes sure to meet project design tasks/deadlines and this is given by the Project milestones and the WBS.

From the organization and planning of the design, the next section will detail the prototype's design philosophy. In this section, we'll provide a larger overview of what was involved to implement and complete the functionality of the deployable prototype. For example, the hardware/software implementation of the multi-sensory device will be described either in textual and/or figures (schematics, tables, diagrams). This may include detailed reference to the Appendices that will be included towards the end of this documentation report, such as Appendix B - D.

After discussing the design philosophy we will transition into discussing a comprehensive summary of the current status of our team's multi-sensory device. By the Midterm Progress Review presentation, our team was able to *successfully complete and meet* our project design. Therefore, we will further provide how we managed to complete each feature and meet each of its measurable metrics by including the device tests results we gathered. In addition, we'll summarize the entirety it took to ensure that by the end of Spring Term (ideally before Spring Break) the prototype would meet our project proposal.

Lastly, forecast and refine how the device prototype would likely compete in our targeted market: technology/entertainment (music) industry. In order to be successful in this given industry, we'll provide any changes or revisions from our design hardware and software implementation if given the opportunity that our device would be manufactured or produced.

To conclude the report, we will summarize key points discussed from each respective section and its relation to the deployable prototype. Immediately following the conclusion will be the References and Glossary sections of the sources and terminology used throughout the report.

For further reference and additional overview of how the team was able to implement and complete a functional deployable prototype by this Spring semester, there will be appendices included at the end of this documentation report. Appendix A is a user manual that describes the operation of our singular, multi - sensory device. Appendix B, C, and D describes the hardware, software, and mechanical implementation of the device system respectively. Appendix E lists the contact information of any vendors, technical advisors, and or faculty that assisted our project. Appendix F provides the resume of each team member participating in this project design team.

## II. SOCIETAL PROBLEM

Problems arise when there's a lack of substance, a lack or resources, and a lack of answers to a current situation. A societal problem affects the entirety of a community. This can be a specific community or address the entire human race. Sight of Touch project began Fall 2019 addressing a societal problem within a specific community. Declaring a problem to be the lack of integrated devices that accommodate the deaf and hard of hearing (DHH) community. This idea of a societal problem saw promising research and resources, but with further research, by Spring 2020 semester the societal problem got revised. The lack of integrated and multi-sensory devices doesn't only apply to the DHH community, but applicable to every consumer. Thus, the societal problem evolved to address the lack of integrated devices that utilize multiple senses to provide an enhanced musical experience for a universal audience. Revising the societal problem not only grounds the problem but sets a clear vision as to what is the problem by exposing the lack of substance, resources, and solutions.

Starting Fall 2019 semester the idea of Sight of Touch began with the idea of expanding current technological devices utilized by DHH community. The DHH category used within the initial problem statement included people who are deaf, hard of hearing, and those who use aids to enhance their ability to hear such as cochlear implants. Research mainly focused on the expansion of music-based products for this group. Questions the group sought to research, and answers included: "How do

DHH people interact with music?", "What are current products on the market that are used?", and "Is there a specific target age group that would benefit the most?". Search results indicated that DHH people have a deep relationship with music. The lack of the hearing sense does not stop this community from the musical creative arts. Ways DHH people interact with music is by applying their other senses. Using sight and touch senses allows most DHH people to interact with music.

Keeping in mind everyone's interaction with music varies from person to person, music brings positive reinforcements for both adolescents and adults especially those in the DHH community. For example, adolescent DHH children benefit from the use of instruments in the classroom. Children who are exposed to "arts, culture, communication … foster creativity, enhance instruction, and create a learning environment in which children thrive emotionally, socially, and academically" [1]. The study identified the effects hearing loss has on people including adolescents that can lead to self-social isolation and/or depression. Incorporating music allows adolescents to create an assimilation between words, actions, and touch, allowing them to create a story that can be told. Stories told or acted out by using songs and instruments. Another example is the use of nursery rhymes. Most nursery rhymes are taught with the accompaniment of movement – to act out the story – and instruments – creating a relationship to rhythm and for DHH children the feeling of an instrument to associate with an action. "Music is a powerful tool to enhance the patterns and rhythms of sound as they relate to language structures and literacy sequences" [1]. Language structures can then relate to cultural boundaries because the variation of sound develops their own vocabulary terms. For example, the sounds of drums introduce different types of drums (i.e. congas or bongo) and their corresponding cultures highlighting the use of different sounds from instruments deeply relating sounds to languages and cultures.

Mentioned before, the Fall 2019 societal problem focused on the DHH community. Technological advancements have made it available to aid many DHH people with the evolvement of cochlear implants (CIs). Over 600,000 implant devices have been registered around the world, leading to an increase in social engagement, by allowing CI users to understand 90% of continuous speech [2]. Technological advancements like CIs truly contribute to the improvement of health for many DHH people.

As music positively described contributes to health and wellness of DHH people and with the technological advancements of CIs for many users, the next stream of research involved looking at the technical interaction between a DHH person and music. Sources revealed the use of sight and touch were key aspects for DHH people to interact with music. As exemplified earlier with adolescent children creating an assimilation with music, by using instruments and acting out a story or nursery rhymes. DHH can rely on the use of sight and touch senses. With that said, although CI users can hear, they "experience greater difficulties in recognizing melodies or discriminating between different instruments in comparison to normal-hearing listeners" [2]. This results in the lack of rhythmic detection using CIs, leading users to have difficulty to listening to musical pieces with multiple voices or instruments [2]. This leads to the use of visual aids.

For DHH people sight is a key sense used to perceive the world around them. Consider the use of video games. Video games are a sight-based technology. Games clearly show the environment or even story of the game whether you can hear the narrative or music. They use subtitles and have storylines to help the user follow along within the game. Although video games aren't made specifically for the DHH community, they are a great example of an integrated multi-sensory product. Games include visual aids, sound, and touch. Visual aid is the core of the video game as its output onto a screen, sound typically outputted from the computer speakers or console in use, then controllers supply haptic feedback. The touch sense implemented from video game controllers use vibrating motors or a haptic feedback system. Depending on a game – say first person games, the vibration of the controller helps indicate the moves, location, or surroundings the player is in. Haptic feedback is a great tool that utilizes an additional sense – touch – to give the player an enhanced experience to the video game.

After taking a look at how using multiple senses contributes to an enhanced and personal experience, research then began to look at current products that use multiple senses for the DHH community. Products include backpacks and necklaces that use vibration motors. The motors provide feedback to the song currently being played. Some relied on bass others relied on amplifying the vibrations that would come off a speaker but not play the sound aloud. Other tools included visual videos to songs that had a person signing the lyrics and including subtitles at the bottom of the video. Although all these tools are useful and currently implemented the societal problem became clear. There's a lack of accessible and integrated devices that utilizes the two senses -- sight and touch to enhance and provide a sensational musical experience for an individual, specifically in the deaf/hard of hearing community.

Coming back from Fall 2019 into Spring 2020, new discoveries and research revealed, this societal problem isn't only specific to one community or group of people. This is a problem affected by various people. The updated societal explores the lack of integrated devices that utilize multiple senses to provide an enhanced musical experience for a universal audience.

Key improvements to the now refined societal problem is defining key words and exploring current resources all people have, to listen to music, and the lack of developed integrated devices for an enhanced musical experience.

Starting off with defining music and universal. Music taken from a book titled *Keywords in Sound*, music is defined as "organized sound" [3]. This definition best suits the Sight of Touch project because the design is built on a note by note basis. Musically, the project is based on a range of musical notes, specifically frequencies – to be discussed later on. Universal describes the inclusion of all people without the discrimination or exclusion of a person's background and mental or physical attributes. By updating the societal problem to be all inclusive the project reaches a greater audience with no borders – the same way music communicates to a wide range audience without boundaries.

The concept of music is not only an auditory sense. Music is an experience – whether a person listens to music, feels music, plays an instrument, or uses visual aid imagery, music is boundaryless and so is the audience of this societal problem. Although research from Fall 2019 focused on the usage of music within the DHH community, common trends revealed music's positive stimulus to those who aren't DHH. Therefore, the design no longer focuses on a specific community, but a universal audience – children, elderly, those with classified disabilities, or even those who want an alternative experience with music.

Global universal benefits of music include the sense of community and belonging. A person doesn't need to be an expert in order to create or appreciate music. Take children for instance. They create sounds with toy instruments or follow the cadence of a poem, things individual items can create a melody or rhythm, thus making music. Music is helpful as it's also used for music therapy. Benefits from listening to music include reducing pain and anxiety, stress relief, memory improvement, and development of strong neural activity [4]. Other positive musical contributions include reduction of negative effects from people with conditions of depression, deafness, and schizophrenia. A Turkish study revealed musical therapy supports the wellbeing of patients diagnosed with schizophrenia [5].

There are numerous studies backing up the idea of music's positivity to a person's health and wellbeing, so the next level of study was the way people used music. Humans hold five senses – sight, touch, hearing, smell, and taste – all of which contribute to how we as humans perceive the world. The more senses used for a particular experience the more enhanced that experience is. Musical applications such as visualization create a relationship to what's being heard to what can be seen. Even bridging together, a touch to sight.

Adding to research from Fall 2019, Spring 2020 research supported the idea that there's a lack of integrated devices incorporating multiple senses. The only difference this time - the research includes people of all backgrounds. Majority of the products on the market use two senses sight and touch or sight and hearing. For instance, movie theatres. Cinemas today spend a large portion on great seating, high end movie screens for a better quality, and top-notch sound quality, but for someone with a classified disability or a person who wants more out of a movie are stuck with the use of two senses or even one sense. IMAX cinemas are enhanced to provide a multi-sensational experience, but prices are expenses that not everyone is suited to afford. Video games are a great multi-sensory technology that includes a large universal audience. Games provide sight, touch, and sound. The downside? Not everyone plays video games nor have the time to explore what console they want to invest in.

Unlike video games, music has a long history and relationship with people of all backgrounds. Music has a universal audience. An average 51% of the United States population listens to music on a daily basis [6]. Over half the U.S. population experience music in some form, the key is how to enhance this experience in a way that reaches a universal audience the same way music does. The solution is by solving this societal problem: the lack of integrated devices that utilize multiple senses to provide an enhanced musical experience for a universal audience.

## III. DESIGN IDEA

Given the problem statement, our team constructed a Punch List that is composed of the main features and its specific measurable metrics to serve as a guideline for our device design. This was initially created in the Fall Semester (can be shown in Table I) and was slightly revised this Spring semester with small modifications (can be shown in Table II). It is in this section which we will describe each essential feature and how each shall be achieved.

Table I
Fall 2019 Punch List [7]

| Features | Measurable Metrics |
|---|---|
| Design will offer multiple user interaction/experience. | 1-2 people using the device. |
| To provide an auditory input that will drive the other features, haptic feedback and visual translation. | Music notes will be played with a frequency between 320hz - 850hz and be scaled by ¼ for the output of the haptic feedback device . |
| To provide an output of haptic feedback sensation for when music is translated. | The output feedback of the haptic device will operate from 80Hz to 230Hz; with the constraint that the hand sensation has a frequency range of 80Hz - 250Hz. |
| A visual translation of musical frequencies to a specified color. | Base range of frequencies according to wavelength Range for Visible Light (Rainbow Colors): 400-700nm<br>(See Color-Frequency Table) |
| Synchronization of features where there will be a timing delay between both the haptic feedback and visual aid after a range of frequencies are played. | Synchronization between visual aid of lights and haptic feedback to be 10ms or better. |

Table II
Spring 2020 Punch List [8]

| Features | Measurable Metrics |
|---|---|
| Design will offer multiple user interaction/experience. | 1-2 people using the device. |
| To provide an auditory input that will drive the other features, haptic feedback and visual translation. | Music notes will be played with a frequency between 330hz - 784hz and be scaled by 1/6 for the output of the haptic feedback device . |
| To provide an output of haptic feedback sensation for when music is translated. | The output feedback of the haptic device will operate from 55 Hz to 130Hz; with the constraint that the hand sensation has a frequency range of 80Hz - 250Hz. |
| A visual translation of musical frequencies to a specified color. | Base range of frequencies according to wavelength Range for Visible Light (Rainbow Colors): 400-700nm<br>(See Color-Frequency Table) |
| Synchronization of features where there will be a timing delay between both the haptic feedback and visual aid after a range of frequencies are played. | Synchronization between visual aid of lights and haptic feedback to be 10ms or better. |

To provide a sensational musical experience for a universal audience, the multi-sensory device brings the 3 senses: sight, touch, and hearing together. These senses can be associated with the features: visual aid, haptic feedback, and audio respectively. The feature of synchronization synchronizes these 3 mentioned features for that enhanced musical multi-sensory experience. Additionally, in the list we stated that the design will offer a multiple user interaction/experience with the metric of at least 1-2 people using the device. Thus, there are 5 main features that encompasses the team's Design Idea Contract which can be seen in Tables 1 and 2.

Due to the integration of multiple senses, each feature in the design has its own metrics to ensure that it constitutes to the design's purpose Ultimately the 3 sensory features are to be synchronized to allow the audible sounds aligned with the visuals and haptic feedback features. Thus, the design features and its measurable metrics will be described as follows. The audio feature will be the driving input as it will be outputted visually and through the touch sensation. In the Fall semester, the audio (music notes) were played at a frequency range between 320 Hz - 850 Hz and scaled by ¼ for the output of the haptic feedback system. The touch sense provided the output of haptic feedback sensation to translating the musical notes from a frequency limit of 80 Hz to 230 Hz, with the hand sensation frequency range of 80 Hz - 250 Hz. Conversely, the visual aid feature will provide a visual translation of the musical frequencies to a specified perceivable color within the Visible Light Spectrum (VLS). Essentially, these colors are mapped to a specific audible/musical range of frequencies. In the Fall semester, the visual aid features were ideally represented through individual LEDs. The feature of synchronization shall integrate the audio, visual aid, and haptic feedback where there will be a timing delay between both the haptic feedback and visual aid after a range of frequencies are played to be of 10ms or better. Synchronization like mentioned earlier will elicit the user's experience with music to be improved through the participation of multiple senses. Last semester the main goal was to ensure that the metrics would be met for each feature, thus the design implementation for the feature of multiple user engagement wouldn't be fully implemented -- but was modified and met for Spring semester.

Therefore a rough sketch diagram for Fall Semester can be displayed in the image below. Fig. 1 [9] ideally represents the synchronization features of the audio, haptic feedback, and visual aid features. The audio will be playbacked through the computer device from a software program which would output the visuals (colors/LEDs) and touch sensation which is driven by the hardware device Arduino and vibration motors. This shows a visual display of the Design Feature Set implementation for last Fall.

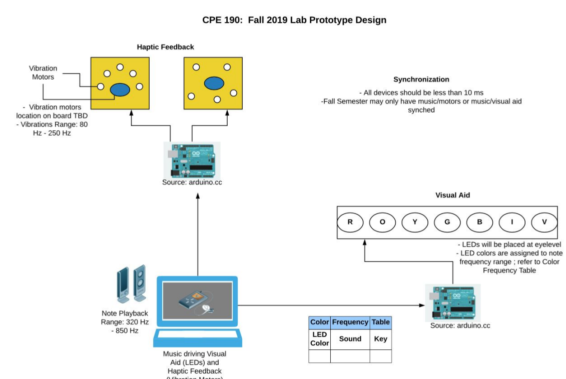


Fig. 1 Fall 2019 Lab Prototype Design Schematic [9]

The image below [10] shows the final hardware and software setup of our team's design last Fall Semester during the Senior Design Showcase. It can be implied that features of the design were met and measurable metrics were achieved and distinctly follows the schematic image above. The multi - user aspect is done through a potential user(s) can place their hands on top of the board to feel the notes being played, additionally the LEDs are ordered in the VLS spectrum for the display of the musical notes.

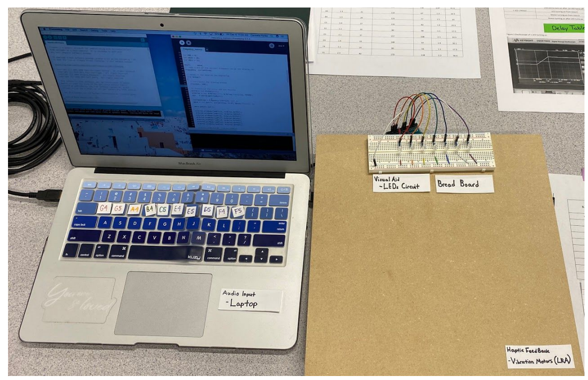

Fig. 2 Fall 2019 Design Showcase Implementation [10]

In the beginning of the Spring semester there were no new modifications made to the Design Idea Contract (Punch List) although revisions were made/finalized due to the device testing schedule and action plans. There were only two slight modifications made and this was specific to the audio and haptic feedback features. The main changes were as follows:
Audio Feature: music notes transitioned from a frequency range of 320 Hz - 850 Hz (Fall 2019) → 330 Hz - 784 Hz (Spring 2020) with the additional revision to be scaled by ⅙ for the output of the haptic feedback device. This modification was made due to the results of the device testing for the vibration motors not fully meeting the initial measurable metric. Thus, the haptic feedback feature was also modified: to operate from 80 Hz - 230 Hz (Fall 2019) → 55 Hz - 130 Hz.

With these two main modifications the other features (visual aid, synchronization, and multiple-user interaction) were not at all modified. Although, the design implementations / executions to the overall build was more enhanced for the Spring. This can be presented in Appendix B[11] which represents the end deployable prototype schematic of the multi-sensory device.

For example, the visual aid was transitioned from individual LEDs to a larger scale of LED panels -- to visually represent the musical notes through detectable colors as well as textual form (if applicable). The implementation of the visuals are portrayed through two LED panels that are displayed in the middle of the clear cube, supporting the visual/sight feature of seeing.

Additionally, the device is implemented in a cube shaped form that will allow for a multiple user interaction/experience with music. This idea was actually originally constructed also in the Fall but we fully implemented it in the Spring. This build is designed to address the audience aspect of potential users of the device as well as allowing the features of haptic feedback and inclusivity. Where the vibration motors are to be also placed on the panel boards for 1 - 2 people touching / interacting with the touch sensation of the sounds. Thus, building the device in a cube form encompasses the senses of seeing, touching, and feeling the musical notes where one can have a unique and inclusive experience with music.

An additional modification made this Spring Semester was previously discussed in the first section, which was the problem statement. With this newly revised layout and modifications for the end deployable prototype we did meet and address the societal problem. From Fig. 3, through this design, synchronization of features, and incorporation of multiple senses, multiple individual(s) can have a unique, alternative experience to visualizing and feeling a musical note -- touching the basis of the Punch List requirements. This will be further discussed in Section IX: Deployable Prototype Status in such detail of how and to what extent our device prototype at the Spring semester meets the design idea. Next we will move onto discussion of the funding involved throughout the year to implement the features started from the design idea.

## IV. FUNDING

Here are the components that were purchased from the first semester of Fall 2019 to Spring 2020. Not all of the equipment shown here was used in the project. Some of the items were used for testing purposes and/or comparing different products. For example the LRAs, we purchased 12, 6 were used on the final project, 3 broke and 3 are left over. The ERM motors were purchased to compare the vibrations to the LRAs. A total of 3 arduinos were purchased, 2 of which were used for the final project and an extra for spare and in case of risks. The 100pcs of LEDs were used in our first semester, where we decided to connect single LEDs to each note. The N-channel MOSFETs were used to test the vibrational motors, in hope to get better vibrational frequencies. The 16x16 LED panels were incorporated in our second semester. We decided to include this in our second semester, since it would enhance the visual experience of the user. The acrylic board was to build a 8x8 see through cube. This would allow us to include all of our components inside the cube, making it more appealing and easier to hold. In order to hold the sides together, we used Gorilla super glue. The leg tips were purchased to reduce the vibrations coming from the panel from our first prototype. White foam board poster was to build the poster for our demonstration. Finally the gyroscope was purchased to measure the frequencies that were being emitted from the vibrational motors. All of our components came out to be a total of about $500 USD for both semesters.

Table III shown below, has the breakdown of the items purchased in quantities, price and totals.

Table III
Overall Funding & Purchases for both Fall 2019 - Spring 2020 [12]

| Item | | | Quantity | Price (USD) | Total (USD) |
|---|---|---|---|---|---|
| Vibrational Motors (LRA) | | | 12 | 7.69 | 92.28 |
| Vibrational Motors (ERM) | | | 3 | 7.16 | 21.48 |
| 2 Arduinos + 9V Power Supp | | | 1 | 46.21 | 46.21 |
| 9V Power Supply | | | 1 | 6.99 | 6.99 |
| CHANZON 100pcs Colored LED's | | | 1 | 8.60 | 8.60 |
| 1 Arduino UNO + 1 9V Power Supp | | | 1 | 31.89 | 31.89 |
| WEIMeet MOSFET N-Channel | | | 1 | 7.99 | 7.99 |
| WESIRI 16x16 WS2812B Panel | | | 4 | 30.16 | 120.64 |
| LED Purple Diode | | | 1 | 8.61 | 8.61 |
| Printer Cable (for Arduino) | | | 2 | 5.99 | 11.98 |
| EDGELEC 100 pcs LEDS RGB Tri-Color | | | 1 | 9.69 | 9.69 |
| Acrylic Board 18x24 | | | 1 | 12.37 | 12.37 |
| Acrylic Board 8x10 | | | 2 | 3.78 | 7.56 |
| Gorilla Super Glue | | | 1 | 5.97 | 5.97 |
| Leg Tip Clear (4pk) | | | 1 | 2.38 | 2.38 |
| Leg Tip White Rubber (4pk) | | | 1 | 2.38 | 2.38 |
| White FoamBoard Poster (30x40) | | | 1 | 8.49 | 8.49 |
| Gyroscope (3pk) | | | 1 | 16.00 | 16.00 |
| | | Shipping | | 11.84 | 125.6 |
| | | | | | |
| | | | Total | | 547.11 |

## V. PROJECT MILESTONES

For two semesters our group has worked together to create a prototype that would meet the expectations that we laid out, for a topic that we all agreed on. Since the beginning of the class there are many events that we would consider remarkable and important. Though there are a select few events that we believe were the critical milestones that if we could not complete them, we would not be here now. To us these events were our milestones first completing our Fall proof of concept, Senior design showcase, completing spring testing, construction of the Spring prototype, and lastly the final documentation report. Each of these events is the culmination of many hours of work and research that lead to a tangible result that we could present. Also, each of these milestones taught us important information that we haven't considered beforehand giving us even more knowledge about our own project. Going all the way back to Fall semester we will start with the Fall proof of concept.

The end of Fall semester required that we had a proof of concept to show at the Senior design showcase. This meant that we needed a device that would demonstrate each of our prototype's main features. At the time our punch list was made up of 5 main features. [7] As a group we wanted to follow a simpler version of our ideal design, we envisioned the cube with each panel displaying a sense to be the final project. With the time we had back then, we agreed that having one panel with all the sense on it would meet the requirement. Thus, we began thinking on how we wanted to meet each sense and where our justification would come from. For the lights we had already begun on code that would play computerized pitch of the frequency we entered. This would be the backbone for the Fall and spring design. The program displays the frequency in a waveform, prints the frequency, and even plays the pitch of said frequency. Building upon this for the visual component we would have different colored leds light up when a key was pressed. The sound portion of the metrics required that our notes were within a specific frequency range 320-850hz. [7] Alexis verified our programs frequencies by first creating notes on her iPad. Then she analyzed the created notes with a software called WavePad that would apply the FFT to find the frequency. Though we had notes at the time, for Fall we decided the pitches would be fine for a proof of concept. For the haptic component of the project Christian and Alex worked to get vibration motors to work. We agreed that using the Arduino and vibration motors would be the best method as we were already powering LEDS and wanted our software to control the hardware. Christian worked on the PWM calculation and tabulating the correct value to get the desired voltage. Using the data sheet with the specific voltages calculated we had assigned specific frequency ranges to each note. For the multiple users we used a panel that could fit two hands. Then finally for the delay that had to be less that 10ms, Alex used an oscilloscope to test the startup time. Having the laptop hooked up the Arduino the software would run and whenever a key on the keyboard was pressed the hardware started. The Arduino controlled the leds and vibrations motors, which would both happen at almost the same time. This would give the impression of multiple senses being displayed as soon as the key was pressed. With all the concepts complete we were satisfied as a group that our design showcased the main features of our project. This design is what we used in the Fall showcase and was the centerpiece for our final fall instructor meeting. This part was completed on 12/2/19 just in time for the next milestone, the Fall showcase.

The Fall Design Showcase was a great event that we believe was very useful to us. Though there is not much time in between milestones this event was more so an experience for us. Seeing all the other groups' projects and everyone dressed up to impress the public was a very fun event. However, the most important aspect from this event is what we learned. We were able to see other groups current prototypes and talk to them about what their plans were for spring. What changes are they going to do? Were they going to continue the current design, or did they learn of problems with the design? Besides talking to other groups, we also got to talk to the public. We met a couple of people that gave us insight into the problem that we never considered. One person commented if the device could translate the music as it played, or another person commented if we knew about any standards for converting music into sense already as he had created his own standard in his previous work. Including outside critique, we also received outside resources. One person that came up to us during the showcase currently worked at a recording studio and offered his contact to his boss. He said that we may be able to have access to their recording studio for testing our audio or recording our notes. So even though we ourselves didn't progress that much from the previous milestone the experience itself was we believe to be a great experience and one we will all remember when we think of senior design.

Moving into Spring semester the next big part of our project was to test our features and construct our deployable prototype. As we worked for a majority of spring semester when we finished our testing, we considered this another major milestone. The significance of completing the testing means that our current prototype meets the punch list thus clearing the major hurdle of having a "complete" project. Our testing completed when all our features meet our punch list even with the new hardware and design that we wanted to implement for the prototype. The music had the same testing as last semester using WavePad to verify the frequency of the notes, but Alexis created new notes for our device to play so this means she had to retest these new notes. Ensuring that the new notes still meet the same frequency range will be critical as the motors are based directly on the musical frequency. For the visual aid we had implemented the use of LED panels that would be a more noticeable visual feature than leds. Carmela worked hard on verifying the wavelength of each color. Using the color table, she created last semester and the WhatAColor app. She would take pictures of the leds on the panel and verify the RGB color and wavelength to the table. Thus, ensuring we were displaying the correct color for each note. The motor testing was also completed though we did have some troubles. Since the beginning of construction as a group we have had problems with the motors. Initially it was motor performance due to Arduino limitation, but now we were having troubles completing the frequency testing. Christian and Alex were having trouble completing the testing and then soon realized we would not be able to fulfill what we promised earlier. We used the data sheet to predict performance, but Alex misread that information. So, the scaling had to be changed and thankfully the professor approved the frequency ranges to be changed and to adjust the motor frequency scaling. This led to our new punch list that has a different musical frequency range and a 1/6th motor scaling. For the synchronization, the same test was done on our new hardware and setup. Testing the same as the previous semester involved using an oscilloscope to measure the hardware's startup time and the time it takes for each device to startup working together. With all the features meeting our new punch list this gave us the green light to work on our build. This was a relief for us as the problem with the motor cut very close to the deadline of needing to complete the project.

On to the build this is another major milestone for the sole reason that upon completion this meant the end of our physical building and that means for the rest of the class it would just leave assigned reports. The build was complete on the same day as testing completion. Both tasks were working together as we completed testing, we were happy to implement the feature onto the final prototype. Construction began with our design; we still wanted a cube since it helped with the multiple user feature. Almost all sides of the cube would have hardware that displayed a sense. Two sides with led panels for visual aid and two panels with motors for haptic feedback. Along with the shape we had changed material for the case. In Fall we had used recycled wood planks. After our accelerometer testing, we noticed that plastic panels we had gotten in Spring had a better feel than the wood. The plastic also made it easier to see the LED panels in our design. The placement of the hardware, opposite to each other was important as it helped fulfill the multiple user aspect. Two people could use the device if they put our prototype between them. Construction wasn't bad as Alexis had gotten some panels cut out to eight by eight size. We used eight inches as our basis since it could fit two of our hands on a panel comfortably. Since Alexis' father also had a plastic glue majority of the design was complete at her house. We only had the top left open to allow us to access for the wiring. Also, one side had to be opened to allow for the wires to come out. With the container done we had to place the hardware and wires down. Once that was complete and the wires were grouped for easy use all that was left was the software. That was done quickly as we had figured out the software during testing. Completing the physical prototype was one of the biggest milestones of the project. With it complete we were able to make our prototype video and move on to the last major assignment in the class, the end of project documentation.

The final report is the last major milestone. It will be the culmination of both semesters as almost every section is based on previous assignments in the class. The final report showcases all the work we have done for our project as well as the research done for our societal problem. Compiling all aspects of the project like cost, hardware, resources, and references nothing should be missed in this paper. When the final report is complete it will signify the end of our senior design class, which may be the biggest milestone in the whole class.

## VI. WORK BREAKDOWN STRUCTURE

In all the fields of engineering, project management is key for a successful project. Before execution of project implementation, it‘s essential to develop a clear and detailed understanding of how a group will accomplish and develop a laboratory prototype. For example, our project is structured by smaller milestones that will eventually lead to our final prototype. Our first milestone would be to choose a societal problem. Once we had a societal problem chosen, we had to get it approved by our instructor. He gave us better advice and a better understanding of what had to be done. With every design, we have to prove each of our features with data. Which leads to our next milestone for the fall semester. Measurable metrics for all features. We were all responsible to measure our own feature (haptic feedback, audio, lighting, and synchronization) components with real data collected by the prototype. With the data collected, we had to write a report and present our measurable metrics to the class. Once we had our measurable metrics confirmed and approved, we were ready to start our first build stage of our prototype. This had to be finished by December 2, 2019 in order to demo our final project for this semester. During winter break, we were all brainstorming on how to improve our prototype for the Spring 2020 semester. The first week of Spring Semester, we had to have a problem statement revision. That means we had to have a plan of what our second semester of senior design would look like. In a couple of weeks we would have to do a device test plan of our somewhat modified feetures. On February 4, 2020 our team had to do research on our market review as well as presenting to the class. During the switch to our new schedule due to the shut down of our campus, we had to finish the build ahead of schedule and make a video of our midterm progress review. Like all engineers, we had to evaluate our ethics skills. First our instructor posted lectures of ethics examples and then everyone had to take a quiz about multiple scenarios. Finally our final milestone and one of the most important documentations is the end of project documentation. This is by far the heaviest graded assignment for this semester.

All of these milestones would not have been possible if our team would not have put in the time and effort in the project. Our team as of March 12, 2020, has a total of 846.85 hours worked on the project. The project at that time was at 81% complete. By the time we are done with the end of project documentation the team would have worked over 900 hours. Our team decided to break our work by feature list. Eached picked a feature that everyone felt comfortable doing. Alexis, focused on the music/visual aid. Carmela, focused on visual aid. Alex, did the synchronization/vibration motors. And Christian focused on the vibrational motors. Alexis tasked were; creating the audio file (Piano), playing the audio file, play file with frequency range, translating file as well as writing output to a file, hardware, incorporating a piezo speaker, link spread, microcontroller, mount hardware to a panel for presentation and testing the audio frequencies. Looking back at the weekly reports from the first semester to present. Alexis worked a total of 98.15 hours on her features lists. This includes all the features she worked on (Music, vibration motors, visual aid and programming). For group meetings, she has a total of 32.75 hours. For the assignments, she worked a total of 110.35 hours. This includes all the writing assignments from both semesters, presentations (Powerpoints), formating, research. Alexis also contributes 16.75 hours of outreach to other professors or the community. Moving to haptic feedback, Christian was responsible for this feature. His feature tasks were; ERM/LRA, determining vibrational motors, test freq., hardware, test motor drivers, test power supply, microcontroller, make motor vibrate, assign freq. To certain ranges, input number to audio file, scale audio input, fall design, mount motors and microcontroller on board, test motor layouts and material. He worked a total of 85.5 hours on his features lists. For the assignments from both semesters, he worked a total of 80 hours. He also met with the team for a total of 27 hours. Moving on to visual aid, Carmela was responsible for incorporating a visual experience to the user. Her feature tasks were; hardware, LED's, assign values, color frequencies table, assign colors and set frequencies for each LED, microcontroller, program LEDs to light up, make LED's light up with audio file, fall design, create row of 7 LED's, mount design board, incorporate and build new components. She worked a total of 71.5 hours to complete her features list. For all the assignments, starting from the first semester, she worked a total of 151.75 hours. She also met with the group for a total of 32.75 hours. For the synchronization feature, Alex was responsible for these tasks; hardware, laser rotator sensor, oscilloscope, testing, test accuracy of LEDs given audio file frequency, test accuracy of motors given audio file frequency, software, drive the LEDs with audio file, drive, motors with audio file, test the timing delay for all devices used. Alex, worked a total of 78.85 hours on the feature tasks. For all the assignments from the beginning of senior design, he worked a total of 84 hours. He met with the team for a total of 30.5 hours. The assignment portion includes the end of the year documentation.

Looking at Table IV. We can see a Summary of the features that each team member worked on and the total hours spent working on each feature.

Table IV
Summary of Project Statistics [13]

| Summary of Project Statistics (Fall 2019 - Spring 2020) | | | |
|---|---|---|---|
| Team Member | Features | Hours Worked | Total Hours |
| Alexis | Music | 35 | 260 |
| | Haptic Feedback | 7.5 | |
| | Visual Aid | 55.65 | |
| | Assignments | 110.35 | |
| | Group Meetings | 32.75 | |
| | Team Leader Report | 2 | |
| | Outreach | 16.75 | |
| Christian | Haptic Feedback | 85.5 | 197.5 |
| | Assignments | 80 | |
| | Group Meetings | 27 | |
| | Team Leader Report | 2 | |
| | Outreach | 3 | |
| Carmela | Visual Aid | 71.5 | 264 |
| | Assignments | 151.75 | |
| | Group Meetings | 32.75 | |
| | Team Leader Report | 2 | |
| | Outreach | 6 | |
| Alex | Synchronization | 9 | 195.35 |
| | Haptic Feedback | 39.85 | |
| | Visual Aid | 30 | |
| | Assignments | 84 | |
| | Group Meetings | 30.5 | |
| | Team Leader Report | 2 | |

Table V, shows the individual hours each team member works on, in order to finish the prototype.

Table V
Individual Hours [14]

| Individual Hours for Fall 2019 - Spring 2020 | |
|---|---|
| Team Member | Hours |
| Alexis Lozano | 260 |
| Christian Anaya | 197.5 |
| Carmela Flores | 264 |
| Alexander Tan | 195.35 |
| **Total Hours for Both Semesters** | 916.85 |

## VII. RISK ASSESSMENT

When designing a project, it is essential to plan out every milestone and every step, but when dealing with projects and planning deadlines in advance, we cannot assume that everything will go as planned. We have to take into account the many risks that could affect or slow down the build of the project and figure out mitigations to overcome these hurdles. When assessing our risks, we decided to talk about the risks that could arise from each feature and then talk about any other risks that could arise from natural causes or problems outside of our control.

The first feature assessed is the auditory feature. Some of the risks in this feature is the lack of software to accurately measure the frequency that;s in the frequency range. If we can't prove our frequencies with measurable metrics, we will not be able to prove that our audio is playing at our desired frequency range.

Another software risk is with the use of software taking audio files as input. One of our hardwares being used is an Arduino and software, knowing that this software does not work with the audio file. This would alter the entire set up of the project and more configurations would have to be incorporated which could be expensive to purchase or difficult to use. Another risk would be that the files are not correctly formatted. If the audio file is not formatted properly, the software we use may not accept it which would then over cast on the vibration motors and the synchronization. The last risk for audio is the hardware. Hardware includes the speakers and use of different programs on multiple computers. Audio will play different notes aloud as they are being transmitted through the microcontroller to vibration motors and LEDs. It's a risk assuming that the audio will play automatically aloud from software to the computer. Some of the mitigations for this portion of feature are: beginning work packages as soon as possible, graphing a Fast Fourier Transform, using MATLAB., making sure everyone in the group has downloaded the appropriate software and is tested on each computer, go through arduino libraries to see if an arduino input file is supported.

Our second feature to assess is haptic feedback. Some of the main risks are hardware malfunctions, limited resources, and human errors. All of our motors were purchased from the same vendor, Precision Microcontrollers. They have been in the business of making vibrations motors and include a very detailed performance of their product. Even though they are well known for their vibration motors, mass producing many motors have a higher risk of getting faulty motors or drivers. This could have a negative impact if we are trying to measure the frequencies output, we would get faulty reading.

Getting faulty products could lead us to our next risk, which is having a limited resource. All of the motors are shipt from their warehouse which is located in England. If we wait to test our vibrational motors too late, we could run out of vibration motors. Depending how close we are to deadlines, this could mean we use less vibration motors due to shipping delays or simply change our whole scope of the project.

A big risk when building circuits are human errors. Not knowing the limitations of the hardware and/or knowing how to use the hardware properly could lead to burnt circuits, motors, laptops, or anything attached to the circuit.

In order to mitigate the risk that could arise from building the vibrational motors are: purchase extra motors and study the hardware before attempting to build the circuit.

For our third feature, we will talk about the visual aid. The risk can vary from hardware or software design implementation, quantity and performance effectively of LEDs. A hardware design risk of LEDs could possibly be the setup and wiring connection of components. More specifically a hardware risk may include: no presence of a current limiting resistor, blown off LED, wiring connections that may result in no source of light and/or electrical hazards (power outage, burnout), too much heat, as well as the external voltage power applied.

Additional potential risks from software is the association may include not finding a compatible software that would serve the features to be in sync with the microcontroller to produce LED output and sound frequency mapping to a color can't be done. Some risks may include damage to external computer parts if software programs are not compatible to devices and storage availability for devices.

Some possible mitigation to limit the risks of happening, we could run the LEDs with low current avoiding any burn outs or blow outs. A possible mitigation plan to reduce the hardware potential risks is to have all team members, specifically the member responsible for the visual aid feature, to be aware of the basics in circuitry and power/currents involved. Starting to work early on the packages, can mitigate many of these risks because we would have time to study and find other solutions.

For our final feature we have Synchronization of audio, haptic feedback, and visual aid. Most of these risks are related to the oscilloscope and feature dependency. Since this feature relies on the other main features if there are problems with those features it can impact the timing for this feature.

Another risk with having the same input to multiple devices is working with powering the device. Considering the arduino to control the feature if it could supply enough power to both devices. This could lead to many sub risks, which include blown out circuits or even having current come back to the source which in our case is the laptop. That can be a very expensive risk. Since the oscilloscope will be hooked up to the hardware circuits of each feature there is a possibility of shorting or breaking any electronics when testing the timing.

The main mitigation strategy that involves the oscilloscope is to complete the project early or try to create our own oscilloscope using the microcontroller. The main way to mitigate the risk of having multiple inputs and using an oscilloscope is being careful when setting up the devices and having multiple copies of components. In the case if some components burn out, we can purchase more or different microcontrollers that would allow us to have extra, in case one blew out.

Those are some of the risks that our team identified according to our features lists. But looking back to what happened in Fall 2018 year with the wildfires, causing a campus closure for two whole weeks. This put everyone at a high risk for this semester since speculation was that the planet was getting hotter and therefore expected more wildfires. In order to mitigate a disaster like the wildfire in Fall 2018, the professor handed out an alternative schedule for assignments and projects. We would still be held accountable for turning in all the assignments. This means that we as a team would have to speed up our build process, so we could finish ahead of time and focus on the final assignments. Table VI (on next page) shows the risk assessment chart. It's an overview of the most significant tasks identified for the project design. In order to create our chart, we referred to the Work Breakdown Structure and went through each feature/element and identified if there is an associated risk.

Table VI
Overall Risk Assessment Table [15]

| WBS # | Feature | Task Element Description | Risk | Level | Impact | Probability |
|---|---|---|---|---|---|---|
| 1.1 | Music | Audio File | Compatibility with SW | 3 | 4 | 0.5 |
| 1.2 | | Hardware | Connectivity between computer to microcontroller | 2 | 4 | 0.3 |
| 2.2.1 | Haptic Feedback | ERM/LRA | Malfunction with motors | 3 | 4 | 0.5 |
| | | Hardware | Limitations of individual component | 3 | 4 | 0.5 |
| | | Microcontroller | Inability to provide enough power | 3 | 4 | 0.5 |
| 3.1 | Visual Aid | Hardware | Circuitry Setup (LEDs, resistors, power) | 2 | 4 | 0.3 |
| 3.3 | | Microcontroller | Inability for SW compatibility to associate LED color to frequency | 3 | 4 | 0.5 |
| 4.1.2 | Synchronization | Hardware | Measuring oscilloscope | 1 | 5 | 0.1 |
| 4.1.2 | | | Electrical Error when testing oscilloscope | 3 | 5 | 0.5 |
| 4.2.1 | | Testing | Electrical error when testing with individual feature with oscilloscope | 3 | **4** | 0.5 |
| 4.2.2 | | | Electrical error when testing with multiple feature with oscilloscope | 3 | **4** | 0.5 |
| 4.3.1 | | Software | Compatibility with software when driving both devices with a different computer | 2 | 3 | 0.3 |

# VIII. DESIGN PHILOSOPHY

Making sure to understand the societal problem lends its hand to creating the design idea then to the design philosophy. Breaking down each aspect of the design down to each minute detail reveals a story and connection. A design idea reflects a product's end-goal. Describing how the design of a product could approach a solution to the problem, but the design philosophy takes a closer look into how each aspect of the design connects to the societal problem. In an attempt to solidify there is a societal problem and how integrating multiple features working synchronously will impact the societal problem positively.

Stating the societal problem there is a lack of integrated devices utilizing multiple senses for an enhanced musical experience for a universal audience. This means, current devices lack a universal targeted audience and lack the focus on incorporating music or any entertainment aspect by incorporating multiple senses. Designing the project focused on how the team can build such a device that has a universal audience, utilizes multiple senses and works synchronously. As a result, the team designed a product that uses sound, visual aid, and haptic feedback. Sound is relative to the hearing sense, visual aid to sight, and haptic feedback to touch. The main glue to these features is synchronicity. All three features work together, delivering an enhanced experience with music.

The thought process or philosophy stems from each feature seen individually and as part of a collective whole.

Sounds surround us everywhere we go. Whether it's the siren of a firetruck, chirping of the morning birds, or even our own footsteps as we walk. Sounds are inescapable. Once sounds are repeated, creating a pattern, a rhythm develops. Rhythms lead to songs, outputting a cadence catchable to the human ear. Patterns created by the repetition of sounds have evolved throughout time and culture. Stories of ancient ancestors creating drums or string instruments have evolved from every culture. The ancient stories or history of music is not only a way to mark a place in history, but a form of communication. Communicating what words cannot. The philosophy of this design and the goal of music – classified as "organized sound" – is to allow a free range of communication. A communication that can't be used with words, but self-expression and creativity. For example, movies. During a movie the intensity of a scene is not intensified by the word's actors say, but the background music. If the music is slow, pierced with screeching violins playing, then the audience is marked with a sense of suspense. In the form of a movie, music is accompanied with a visual aid – the actual movie. In a similar fashion, the Sight of Touch design philosophy sets music to collaborate with visual aids through an assignment of color.

Music, specifically sounds, target the hearing sense. If hearing is not a person's strong sense or they want to add a heightened exposure to sound, having a visual aid to assist offers an inclusive experience. Like watching movies there's a correlation to what is heard and seen. Adolescent children create assimilations between songs and acting out the words to the song. In the same sense, this project creates a relationship between musical sounds and a color. Exemplified within this project is the piano. The piano is a melodic instrument, meaning the sounds that come out of a piano bounce off one another to create a fluidity in what is heard. Technically speaking the music is analyzed down to frequency – a numeric value. Frequency is the measurement of a vibration through a set time. Visually speaking, frequencies look like a wave – a sinusoidal wave. Analyzing music down to a frequency gives the first taste of how music can be translated into something that can be seen.

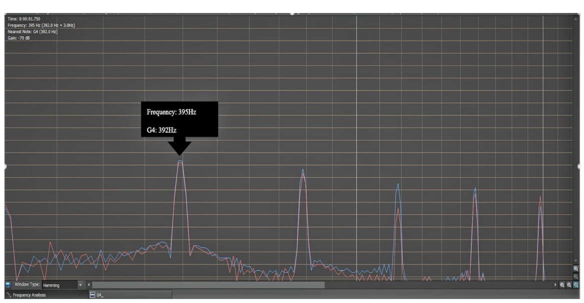


Fig. 3 WavePad G4 Note Gain vs Frequency Waveform [16]

From the figure above the frequency wave of a piano specifically of a G4 note, overtime forms a wave. This wave is a visual portal to what music can look like.

Relating a frequency wave to the use of visual aids in the project, colors add a sense of depth to a sound. By creating a Visual Aid Color - Frequency Table in Appendix B Table B-V, each color and note based on the piano (within the set frequency range) are assigned together. Configuring the note to color relationship wasn't a blind assignment, it's based on research between music and colors that's been studied for many years. Although there is no standard table of correlation, there is an agreed base point to the associations. As a result, the colors used are based within the visible light spectrum, specifically the color of the rainbow.

When it came to pair the two features together the software and hardware needed to make sure the relationship was obvious to any user. Software – seen Appendix C Figure C3, reveals the use of an Arduino library, "Fast LED", allowing colors to be assigned and controlled then output onto a device. For the deployable prototype the colors are output onto a 16 by 16 LED matrix panel. The LED's are coded a color value based on the Red-Green-Blue (RGB) color schematic. The Color Frequency Table sets up a range of RGB, Hex, and Wavelength values allowed to be used within the project. Those values are mainly set for testing purposes, but gives room to programming color values that will fully allude to the correlation of the notes it's assigned to.

Programming the colors to a note, begins to transform a story to a language, communicating what's heard to what can be seen. Taking this form of communication, the project adds another sense – touch. By adding a feature of touch, the design rises to the next level. The music and colors don't just “paint a pretty picture”, for a user to just witness, but transpired into what can be felt.

People who play instruments, understand there’s a natural resonance when playing an instrument. Especially for a pianist. Hitting a key on a piano reciprocates a natural vibration sensation to the hand because of the hammers and strings inside the piano and the hood. The same is likely to occur for various other instruments when played. Since the Sight of Touch project aims for a universal audience, people who aren’t as familiar with playing live instruments will be able to grasp the sensation though this design.

Now, that a correlation is built between notes and color, the next step is correlating the haptic feedback system. Integrating a haptic feedback system to the design, brings the feature list full circle, back to music’s frequencies. The set frequency range for music is scaled down by $1/6^{th}$ as the output goal for the vibration motors. By having a direct scale from the notes to the vibrations, the design draws a close link to those frequencies that are heard, the frequencies seen as a wave form, then assigned to a color, and now touch. Still keeping in mind the idea for a universal targeted audience. For a consumer who may not be able to hear, they can still fully interact with the device by using their sight and touch senses. A product user, with special needs is able to access this product and hear, see, and feel an entirely new experience. The book *Musical Communication* describes music “as a powerful means of communication… provid[ing] a means by which people can share emotion, intentions, and meanings even though their spoken languages may be mutually incomprehensible” [17].

As music is such a grand form of communication, it was logical to create a device emphasizing this and emphasizing the way people communicate with their senses can be transformed to an experience in its entirety. Including a haptic feedback system brings to life something 2 dimensional to 3 dimensional. Scaling the motors by $1/6^{th}$ was primarily based on testing and the corresponding outcomes. In order to deliver appropriate vibrations, research led to purchasing Linear Resonant Actuators (LRAs). These motors are able to support complex waveforms and provide a detailed tactile output – further discussion of the LRAs is in section III Design Idea and Appendix B. The motors are physically circuited to a panel, in a conveniently accessible way for the user to place their hand and feel the music being played. As if they had their hand on a real piano, but this time they will witness the touch they feel to a color they see and a sound they hear. Bringing the design philosophy to be concluded with the glue of the project – synchronicity.

To be able to get the outcome or experience described above, all features are to work simultaneously. The idea of witnessing a live instrument is the goal. Whether the user has played an instrument or never touched one, this impression of an enhanced experience works when all feature sets are all synchronized at once. Otherwise, playing a musical note then outputting a color, not assigned to the not just played causes confusion to what the project is. The project design besides being a new musical experience, is a basis, a foundation to a set of universal correlations/assignments between what is heard, seen, and felt. As mentioned before, assigning color to a note is not new, but there are variations. Not having some form of universal basis for a note to color assignment or note to haptic feedback can lead to confusion for many users, especially those seeking an alternative experience or form of entertainment when it comes to music.

This design philosophy looks closely to the relationship between people, music, and the way they interact with music. Aimed as an all-inclusive design, juxtaposing human senses to music, and technology, the societal problem becomes less of a problem and more of a reason to vehicle to enhance technology to be universal and engaging.

# IX. DEPLOYABLE PROTOTYPE STATUS

The focus of this Spring semester was on ensuring that our team followed the device test plan to complete build of the device prototype. This device testing plan describes in detail the testing necessary for each specific feature with the assigned team member module leader, and more importantly the expected date the testing ideally should be done. Additionally, as a team we had the intention to finish and have a working, fully functional deployable prototype done by the end of March; also have it completed by the Midterm Progress Review. The whole purpose of the testing procedure is to confirm and validify the theory to an idea within a specific timeframe. In this procedure, each member followed the schedule and tasks to ensure that not only the tests would be done, but as well as meeting our team's design idea contract. Despite the unexpected risk, specifically the COVID-19 virus outbreak, we planned accordingly to test and have a deployable prototype that meets our design specifications. With this intention and goal in mind, as a result of the Midterm Progress Review we received credit for the completion of each feature meeting its associated measurable metric, but also for the Deployable Prototype Review assignment.

In other words, the status of the deployable prototype as of this Spring term is *complete*, 100% meeting our Design Idea and we will support this by quantifiable proof with the device test results for each feature. We'll also detail/summarize how the finished prototype performs and meets the design contract. This multi-sensory device is composed of ideally four main features which include audio, haptic feedback, visual aid, and synchronization. Each feature was tested/completed by a given member and followed to meet the measurable metric requirement.

## *A. Audio Feature*

Firstly, the audio/music feature is the integral part of the device as it is the foundation for enabling the other senses/features to be outputted. This feature was functionally complete at the end of Fall semester, but was slightly enhanced and improved by the end of this Spring semester. The definition of music in our design implementation is gathered from individual notes. With the measurable metric of music being frequency, one big adjustment we discovered we had to do during the testing process was the modification to condensing the frequency range of the note(s). Additionally the notes were scaled down to ⅙ in accomodation for the motors,which we will discuss shortly. The note range of the device would now operate at 330 Hz - 784 Hz. The audio feature was done by using a software application called WavePad Sound Editor which utilized Fast Fourier Transform(FFT) to analyze the frequency of the individual note. There were a total of 10 musical notes that fell within a specified sound frequency range and ideally replicated the sound of a piano. In other words, when a note/key is played, the range is played in a compilation. Each note was recorded by the iPad application *The Piano* and was uploaded to WavePad for analysis. For example, the following image, refer to Fig. 3 can depict the testing analysis for a note, specifically G4 through the FFT feature. This shows the waveform of the note's translated amplitude and frequency, outputting the peak frequency (note's pitch) which is in our desired metric.

Ultimately through this application , Alexis, the team member assigned for this feature, was able to follow the similar procedure for each note and ensure that it would meet within the audio frequency range. These results can be shown in Table B-II: Audio Analysis and Testing Results in Appendix B.

As it can be observed from the table, each note was compared to the design defined frequency range with the individual value obtained from WavePad analysis. Each note met the audio's feature - measurable metric requirement. With this confirmation, continued testing was implemented and included in the software program input of the audio file(s), to be integrated with the other features. Thus, the performance of the audio is provided that the file recordings are the input to drive the haptic feedback and visual aid feature(s).

### B. *Haptic Feedback Feature*

The feature haptic feedback was the next crucial aspect of the design and included moretrial/error testing and detailed analysis. The main goal for the vibration motors was modified to operate from 55 Hz to 130 Hz and was scaled down from ¼ to ⅛ in relation to the audio feature. As mentioned before, this was slightly different from the Fall semester due to the testing problems and observations we as a group faced, specifically Christian and Alex. It is good to note that this modification made no drastic alterations to the overall design and thankfully approved by Professor Tatro. The reasoning to this motor scaling adjustment was due to misinterpretation of the vibration motor performance table and the limitations of the Arduino Uno as well as the receiving results that didn't necessarily verify the haptic feedback metric.

From the approval of modifying the motor scaling, Alex and Chrisian then went on the approach of validating the new motor frequencies. The approach they took involved using an accelerometer to obtain the gravitational force of the motor as this was the best device/method to determine frequency. After obtaining the frequency it was then applied to FFT to get more of an accurate frequency reading. This process involved using: MPU chip and an oscilloscope for getting raw voltage/current outputs and translating it into MATLAB for vibrational frequency analysis; MATWORKS which is a MATLAB forum specifically was also used for additional assistance.

An example of the testing result gathered from MATLAB can be shown down below where the data from Arduino is applied into MATLAB for FFT analysis.

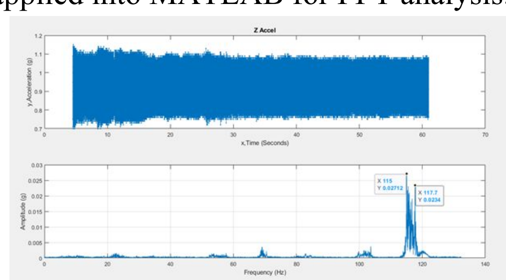


Fig.4. MATLAB of vibrational frequency : 155 Duty Cycle [18]

The frequencies gathered from this testing procedure were then compared to the expected results from the vibration motor datasheets as well as the ranges from the design contract. The table results in Table B-III:Table for Accelerometer Values for Haptic Feedback Feature and Table B-IV:Table for New Duty Cycle Values for Haptic Feedback Feature are found in Appendix B; here it shows the data results for the haptic feedback feature.

It can be observed that from these data results, the motors were operating and performing at a specified frequency range that falls within the improved ⅛ scaling. From this it can be integrated to perform with the audio and visual aid feature accordingly.

### *C. Visual Aid Feature*

The visual aid feature provides the visual translation of the musical note frequencies which is assigned to a perceivable color within the VLS. As stated, the spectrum has a color wavelength range of 400 - 700 nm where 380 - 740 nm is detectable to the human eye. With this feature it provides a sensory enhancement to visually see what we hear, specifically the musical notes. This Spring this feature was mainly enhanced by the transition of using individual LED's to an LED panel -- WS2812B 16X16 panel. To ensure that the measurable metric for this visual aid feature would be met, Carmela - the task module leader worked on creating/modifying the Color-Frequency Table. This table can be shown in Table B-V of Appendix B and defines the relationship between the audio feature of musical notes and the colors of the VLS, as well as the color wavelength, color RGB/HEX values. The colors included are red, orange, yellow, green, blue, indigo, and violet; with each color having assigned a specific note range.

In addition, the basic testing results for the LED panel can be shown in Table B-VI in Appendix B.

It can be seen that the voltage and current was tested from the 3 sources: Arduino, multimeter, and the LED panel. From the expected values of the Arduino and how much voltage/current it can take in, the values obtained from the multimeter met these expectations, as well as fell within the range of the expected WS2812B values. These constraints would be insightful for the other design features/testing procedure to the device prototype as a whole.

The testing procedure for LED color verification was similar to the Fall which described as follows: to retrieve RGB values of each color utilizing *What A Color?* phone application due to the RGB constraints obtained from an online wavelength converter tool [19]. Additionally, wavelength alone was not sufficient enough to verify the color being emitted from the LED, thus the use of the phone app was implemented to meet the metric. These results can be shown in the table in Table B-VII of Appendix B [20].

Based on these results, each color met its RGB constraint which was derived from the Color - Frequency table. Additionally, the following images are screenshots of the colors orange and indigo with its RGB value meeting the color verification.

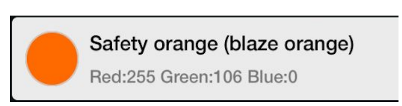


Fig. 5. Screenshot of RGB Value for Orange using What A Color? Application [21]

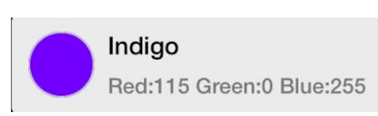


Fig. 6. Screenshot of RGB Value for Indigo using What A Color? Application [22]

There was a lot of discrepancy and difficulty in the beginning stages of this testing but what we learned was that the LED declarations in the software program would most likely determine the color display on the LED panel, thus it was crucial to have the Arduino statement defined to accurately represent the color from the VLS. Furthermore, for the color-verification process it was necessary to also have an ambient,dark setting when taking the image to be able to retrieve an accurate RGB reading or have dark toned materials around the panel.

From these results, the visual aid feature of color/LED assignment was verified (status complete), meeting the measurable metrics of falling within the VLS color wavelength range which were based off of the RGB conversion. The cohesion of the audio-visual aid features provide the performance of the device to represent in color/text form of the note being played, such that the color emitted onto the LED panel would correspond to a musical note, shown by the test results above.

### *D. Synchronization Feature*

Lastly, the feature of synchronization ties the audio, haptic feedback, and visual aid features together. This was completed through both software and hardware implementation with a delay of 10ms or better. With this feature the device is fully completed meeting the requirements. On the hardware perspective, Alex was assigned for this feature to ensure that the components of each feature would synchronize at an appropriate time with minimal delay. His approach was similar to the testing completed last Fall but with the new hardware material included in the Spring, improved testing was necessary. Testing involved the need of an oscilloscope to time the delay for the device to begin after a key was pressed; this involved the measurement of the hardware's power pins. Two tests were required such as testing the LED panel and the LED panel with the motor and the results can be shown in Table BVIII of Appendix B[23].

From this it can be inferred that the results were within the Punch List requirement of less than 10ms. The following images are data gathered from Alex's testing where it shows the oscilloscope results for the panel and the motors.

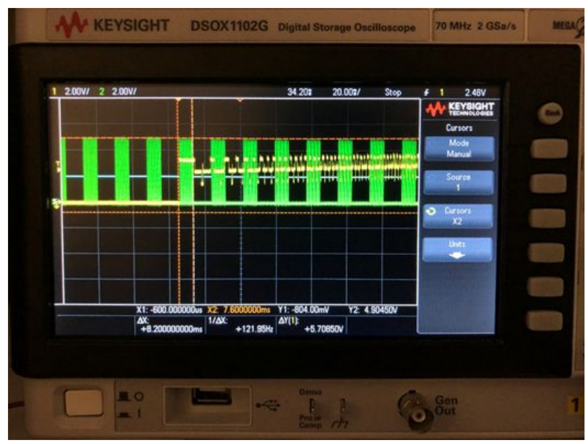


Fig. 7. Oscilloscope of motor and panel turning on [24]

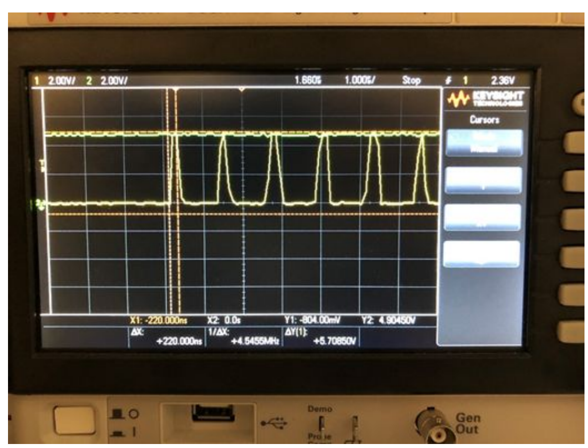

Fig. 8. Oscilloscope of LED panel data in and 5V pins [25]

Additionally with the synchronization feature and to have a full, sensational performance, the software program needed to be implemented accurately so that the audio, haptic feedback, and visual aid can communicate effectively. The software implementation was done through both Processing and Arduino. It was discovered along the synchronization testing process that 2 Arduinos were needed for the device to have sustainable power and for the two software programs to communicate amongst each other utilizing a serial method in Processing to send a signal to Arduino over a COM port. With 2 Arduinos it also enabled the program code for the LED panel and the motors to be outputted at a minimal delay.The program application follows that whenever a laptop key would be pressed it the musical note plays with the output of both the visual aid (VLS colors/text) and haptic feedback features (vibrations).

Meeting the synchronization feature implies that the other main features of the design testing was also successfully met, as was described throughout this section. Therefore, from these multiple testing results for the audio, haptic feedback, visual aid, and synchronization, the desired project design idea was achieved. Our overall design idea contract was significantly based on features and associated metrics to ensure that it would function for the ultimate purpose of being a multi - sensory device. The multi-sensory aspect of the design idea is achieved by synchronization which is driven by the audio. Furthermore, the device was built in a cube shaped form to allow for a multiple user interaction/experience with music; which is another design feature. Through this design layout of a cube, it also addressed the societal problem where it can be applied for a variety of purposes to a universal audience.

In our end prototype, the implementation of the motors are placed on two sides of the panel, where ideally 1-2 people can interact with the touch sensation of the musical sounds being played. The visual aid feature is portrayed through two LED panels that are displayed in the middle of the clear cube; this supplements the visual aid feature of seeing the notes heard/played. The audio feature is inputted from the laptop device that runs the Processing and Arduino programs.

The following image depicts our group presenting the functionality of the multi-sensory device prototype. Alex and Christian are the two users sampling the cube prototype; meeting the multi-user feature. It can be implied that they are feeling the vibrations of the music note which was completed through the haptic feedback feature. In the picture it also shows the visual aid feature being successfully implemented; the musical note that is being played is F4 as the textual display of the note is outputted on the LED panel with its associated VLS color, violet.

Fig. 9. Team Six and the Multi-Sensory Deployable Prototype [26]

The final deployable prototype of our group meets the design idea contract with a status of completion. Through meeting the features by device testing we were able to provide an alternative experience to visualize and feel a note designed in a single-integrated, multi-faceted device.

## X. MARKETABILITY FORECAST

Now that the prototype is complete, we are looking forward to the market that our product will reside in. In our market review we noted some markets that we believe our device would fit into. The medical, educational, and most prominent entertainment market are the focus of our project. We will briefly go over the markets again and their demographics, with a description of the target audience we can move forward. With an understanding of the user we can start working on what upgrades are needed to make the prototype more successful. Then we will briefly mention any issues with the project before we conclude on what would be the ideal prototype to manufacture. Now to go over the main markets for our project.

The most important market is the entertainment market with a focus on the music industry as our device is focused on playing music. The music industry in America is around 22 billion dollars in 2019 including concerts and touring. [27] With so much money in just one aspect of the total market, this is truly one of the most important markets for our product. As we shifted towards a more recreational and entertainment-based focus this allowed our prototype to be used by a much larger audience. Since everyone loves and can listen to music, we wanted to make this our target audience. A quick demographic breakdown of our target audience shows that most of the people that purchase music are from the ages 25-34 years old. The gender for each is 46% female and 54% male. This trend is also very close to the global trend. Though there is a difference between users who buy physical media to digital media. [28] With the rise of people buying more digital media than physical. This is most likely due to ease of access and increased suppliers of streaming services. Going back to the music industry, which the project heavily focuses on, we will go into the statistics of music listeners in the US. In a survey 51% of the population listen to music every day. 65% of those are adults from 18-34 years old. The sources and their opinions towards music change per age. As younger listeners are more passionate about music than younger ones. How they access music also varies per age. The younger audience prefers streaming while the older audience uses the radio. [29] Looking at the total audience it seems one key factor is they want to use something they are comfortable with. Though they vary in passion it would seem both groups like their music and will listen to it if it is easy to do. Now that we have covered our main audience, we can briefly cover our other markets.

The medical and education markets are markets we also did research on. Both are massive markets, but we would only be able to focus on a small portion for each. Music therapy and an interactive way to teach music would be the target purpose for both the medical and educational markets. In our research most of the music therapy was for an older audience that focused on relieving mental illnesses. While we didn't find much research on the educational use of our product. We believe that its use would cover teaching music to the kids, but it could also be used to teach STEM concepts as it is a technological project. This would be more focused on the arts or extracurricular portion of the educational budget. As these markets deal with both ends of the age spectrum, we need to be very general in our improvements to the project. For these markets though they do focus a specific demographic we believe the teachers, nurses, and doctors would be the target audience as they would be overseeing or teaching without prototype. We believe the greatest improvement to our device for these users would be ease of access and set up. That is why we are going to consider this topic the most when we go into the improvement section.

The improvements we believe would be the most impactful for manufacturing is to condense our project. There are numerous hurdles with the software that is needed to set up the project. Currently required for this project is Arduino, Processing, and numerous files in the correct location. Within Arduino we have multiple windows that need to be set up before the prototype works as intended. We haven't figured out how, but one major improvement would be to consolidate all the software. Or create a unique software that can run the project with less set up required. As of right now I would think most of the target audience would have trouble setting up the prototype. Even with a user manual that will be included later, the steps needed are too much to ask of any one user. We think if this aspect of the project could be streamlined it would be massively beneficial for our prototype. Another benefit would be to have our product use similar components. If the internal workings like the wires and DC converter were uniform, we think it would be a more professional appearance. This however is a cosmetic concern that doesn't affect the performance or experience with our device. For hardware that needs change we could include better motors and microcontrollers. With better motors the feelings for each note could become more distinct and resemble the actual musical frequency closer. The improved microcontrollers directly relate to the motors as it was our current microcontrollers limitations that led to a weaker motor performance. Both can be improved which we believe would then improve the user experience with our device. Especially for any user that has a weakened sight or hearing sense the improved tough would be very beneficial for them particularly. The three improvements we mentioned are the major's ideas we had even after the project. We will not briefly mention the issues that need to be addressed.

Issues we have will directly relate to some of our problems mentioned earlier. We had issues with the motors and the microcontroller. The microcontrollers limitations for providing both voltage and current was the downfall for our motor part of the project. Though we were able to get a unique frequency for each note, it was not at the frequencies we thought they would be at. We had to change the scaling which led to slight changes in our project. We think with a better microcontroller and inclusion of an external power supply and a MOSFET based circuit the motors could be improved greatly. Another issue we had was getting the project to work all in one software. We use both Arduino and Processing to control our project. This is due to the unique library in Processing that detects and displays frequencies. If we had more time maybe, we could get the whole project to work in Processing which would make the project easier to use.

With the massive market of entertainment and the very general topic of music we think our project could be used by many people. Even though we are very proud of our work so far, there are some areas that need to be addressed before being placed in the market. Unless the user is one who is very tech savvy or passionate about the multi-sensory experience our prototype provides, we doubt that our current project would appeal to the intended audience. We want our project to be a fun and unique musical experience that anyone can use. Through the barriers to set up the project just do not allow for that. Though if those changes are made, we know our project would be great and can provide as much fun as we had making it.

## XI. CONCLUSION

Sight of Touch project spanned over 9 months of rigorous work, beginning with a societal problem and ending with a completed deployable prototype. Within the last 9 months the project endured plenty of obstacles leading to an odyssey, solidifying this project design as a solution to the claimed societal problem. Both individually and cohesively, the group worked on this project to not only meet specific requirements but ground an idea to a real-life usable product.

The project begins with a societal problem. Fall 2019, saw a societal problem to be the lack of accessible and integrated devices that utilizes the two senses - sight and touch to enhance and provide a sensational musical experience for an individual, specifically in the deaf/hard of hearing community. This problem focused on a specific community and their interaction with music. Research revealed the deaf and hard of hearing community (DHH), are immensely exposed to music. Further research of the involvement of music within this community led to understanding the benefits of music. Music's positive benefits include an increase in holding the attention of adolescent children, exposure to languages and cultures, a decrease in stress and anxiety, and in one study exemplified in the report listening to music contributes to the well being of people diagnosed with schizophrenia. Working through the Fall semester constantly researching the societal problem for sources and some outreach, it was concluded the societal problem needed refinement. For the Spring 2020 semester, the societal problem was revised to no longer focus on a specific community. The new problem statement states there's a lack of integrated devices that utilize multiple senses to provide an enhanced musical experience for a universal audience. This new statement no longer confines a problem to a specific commonality but relates to a general public. Like the way music has no bounds, the new societal problem follows the same path leading to a project design that also has no limits as to who can use it. Concluding to the refined problem statement derives from the commonality between DHH music users and people who have full use of their hearing. Grounding the idea that music is universal, thus, so will the design. Whether DHH or have full use of the hearing sense, there is still a lack of integrated devices built for a universal audience and uses multiple senses simultaneously. Along with refining the problem statement, two keywords are also defined. First, music is defined as "organized sound" taken from the book Keywords in Sound and universal is the inclusion of all people no matter their background, physical, and mental attributes. Both keywords that lend help to designing the integrated device.

In the course of 9 months, a contract was enacted, setting the tone and requirements for a proper completion of both a laboratory prototype and deployable prototype. Outlined in Table II is the Design Idea Contract more known as the Punch List. The list provides a set of focal points for the project. These focal points include five features and their goal metric needed to be met for both laboratory prototype and the deployable prototype. The first feature is single or multiple users – once the device is on and running either a single individual or two people can use the device. Next is the key motive for the project – music. Music as "organized sound", through metrics is broken down to a frequency range between 320hz – 850hz, which is scaled down by 1⁄4th for the output of the haptic feedback feature. Next is the haptic feedback feature, where feedback output will operate from 80Hz o 230Hz. The last two features are visual aid and synchronization. Visual translation of the musical frequencies would be a wavelength range for visible light, 400 -700mm. Synchronization acts as the glue between for all these features to work cohesively and deliver an enhanced musical experience by providing synchronicity between visual aid of lights and haptic feedback to be 10ms or better. These requirements were the basis of the Sight of Touch project specifically for Fall 2019. Within the testing stages in Spring 2020, these features and key metrics seemed to continue to be confirmed by testing, but a refinement was needed due to limitations on testing. The change occurred between the music and haptic feedback scaling. For Fall 2019 the scaling was $1/4^{th}$ and for Spring 2020 the scaling adjusted to $1/6^{th}$. Thankfully not the features themselves weren't affected between Fall 2019 and Spring 2020, but to match the $1/6^{th}$ scaling the numerical values of the measurable metric. Therefore, the audio feature now ranges between 330hz – 784hz and the haptic feedback output is set to operate from 55hz – 130hz. These metrics not only set a testing goal, but also lend to research the types of products needed for the build.

Purchasing needed products were all funded by group members. Although the group spoke to sources, the team didn't seek, nor was offered anytime type of special funding. With that said, products purchased were purchased based on their ability to successfully deliver a detailed output and price. Between Fall 2019 and Spring 2020 the total cost for all needed parts totaled to $547. This amount is over the initial goal set by the group in Fall 2019, but the amount covered all necessary equipment, including backup material, all in which went into completing the laboratory prototype and deployable prototype.

After laying the foundation for funding, crucial steps for the Sight of Touch project completion include Project Milestones, Work Breakdown Structure and Risk Assessment.

With the ups and downs involved in developing this project there are also key milestones. These milestones were turning points. Determining whether a design idea projected to solve a societal problem could be solidified with testing and presentations. For Fall 2019 key milestones include agreeing on a societal problem, devising a Punch List, Technical Review, and presenting the laboratory prototype to peers at the end of the semester. These milestones were all stepping stones, shedding light to whether the project and the team were focused and right on track for a successful deployable prototype. Spring 2020 saw similar milestones, including a refined and completed societal problem statement, completion of testing and testing accurately reflecting the completion of meeting measurable metrics set by the Punch List, Midterm Progress Review, and the completion of the deployable prototype. This Spring 2020 semester heavily focused on testing. Testing involved many details and time, once that was completed, the group was finally able to fully build. This was a large milestone especially when the test results in large part met the measurable metrics set by the Punch List. Another large milestone in the Spring, was completing the deployable prototype. Due to unforeseen circumstances – COVID-19, the team had to quickly adjust and fast-track building the device, along with reporting such circumstances, all prior to the Sacramento State campus closing. Working on  a fast pace, the group was able to complete the build and documentation all prior to the campus closing.

Working through such unforeseen circumstances requires a work effort needed by each group member. In a Work Breakdown Structure guideline set for both Fall 2019 and Spring 2020, each member is delegated as a member lead on a feature. Luckily this project contains four key workable features, the group has four members and each member then has a feature. Alexis was in charge of the audio feature, Carmela – visual aid, Christian – haptic feedback, and Alex – synchronization. Throughout both semesters the assigned feature was managed by the individual member for both semesters. With the goal of reaching 10 – 15 hours per week per member, the average weekly hours per member was 10. This meets or exceeds the plan requirement set by the syllabus, leading to an overall amount of 220 hours over two semesters.

Having each member assigned to a specific feature, allows them to have a sense of responsibility and awareness of how to plan out their duties for the feature. This includes understanding the possible risks. Although not all risks can be forecasted like COVID-19, some can be identified from past projects and experience. Software risks that could happen include having programs working only on one member’s computer. To reduce this risk any program or application used to function the device was tested on at least one other member’s computer. Other software risk was the possibility of a random deletion of code whether it was not saved or lost due to an automatic update. Reducing this risk had members creating code save the entire code/program every time it was edited and saved onto Google Drive. On the other hand, hardware risks dealt with the actual use of hardware. For example, the vibration motors and LEDs, LED panels, and Arduino’s. To help prevent these negative risks, the group ordered multiple parts and made sure to review the company provided datasheets before physically using the part within the project build. Of course, there are outside risks that would affect the project, outside of the team’s control, but the team made sure to not keep parts on campus and planned days where it would be needed to take the project on campus. This way of planning contributed to proper mitigation and reduced the effects of unforeseen risks.

Planning the project as thoroughly as possible led to the success of completion. Including the philosophy of why the design is set the way it is. Circling back to the societal problem, the goal of  the project is to use multiple senses by integrating features working together that'll produce an enhanced musical experience along with the focus of a universal consumer. In order to do so, designing audio (hearing sense), visual aid (sight), and haptic feedback (touch), the project gives the consumer various outlets to combine multiple senses, no matter their background, physical or mental attributes. This philosophy pushes the design idea further by accounting for any type of user while answering to the societal problem.

Closing the Spring 2020 semester was the completion of the deployable prototype. Completing the prototype means, with a rigorous set of testing on each feature, each measurable metric set by the Punch List was confirmed by these results. Each feature and design outlined from the beginning of Spring 2020 semester including all the revisements made fully meets the desired design idea. Thankfully, all completed before the closure of Sacramento State.

Now with the deployable prototype completed, there is room on the market for an innovative device, but with needed improvements. Improvements required for the current deployable prototype to achieve a marketable device includes refining the circuitry. The current device uses two Arduino's and results in multiple wires being exposed. Also, the software can be simplified into using a single application rather than two different applications – one addressing the LED Pixel Panel and another addressing the audio and vibration motors. Making these two key alterations to the current prototype is a solid contribution in efforts to getting the current completed prototype (according to the Punch List) to a marketable device ready for release as an engineering prototype.

In all, between both Fall 2019 and Spring 2020 semesters, idealizing, developing, building, testing, and refining has all led to a successful deployable prototype despite unexpected events.

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[35] A. Tan, “Extract Arduino folder,” April. 2020

[36] A. Tan, “First Arduino sketch,” April. 2020

[37] A. Tan, “Arduino Library window,” April. 2020

[38] A. Tan, “Processing download website,” April. 2020

[39] A. Tan, “Processing first sketch,” April. 2020

[40] A. Tan, “Processing library Arduino window,” April. 2020

[41] A. Tan, “Processing minim library window,” April. 2020

[42] A. Tan, “Current Frequency Code example,” April. 2020

[43] A. Tan, “Final Led Code example,” April. 2020

[44] A. Tan, “Correct Arduino setup,” April. 2020

[45] A. Tan, “Wrong Arduino setup,” April. 2020

[46] A. Tan, “StandardFirmata Example,” April. 2020

[47] A. Tan, “Final Software Window,” April. 2020

[48] A. Tan, “Plug in power cord,” April. 2020

[49] A. Tan, “Plug in LED cord,” April. 2020

[50] A. Tan, “Arduino select one COM,” April. 2020

[51] A. Tan, “Arduino compile button,” April. 2020

[52] A. Tan, “Arduino upload results,” April. 2020

[53] A. Tan, “Plug in motor cord,” April. 2020

[54] A. Tan, “Second COM port,” April. 2020

[55] A. Tan, “Processing run button,” April. 2020

[56] A. Tan, “Processing pop up window,” April. 2020

[57] A. Tan, “Prototype Working,” April. 2020

[58] A. Lozano, “Spring 2020 Modified Device Testing Plan,” Mar. 2020

[59] A. Lozano, “Audio Analysis and Testing Results Table,” Mar. 2020

[60] A. Tan, “Accelerometer Values” Dec. 2019

[61] A. Tan, “Revised Duty Cycle Values” Mar. 2020

[62] C. Flores, “Spring 2020 Modified Color-Sound Frequency Table,” Feb. 2020

[63] “Colour.” *Colour* , 2007, www.cs.mcgill.ca/~rwest/wikispeedia/wpcd/wp/c/Color.htm .

[64] “WS2812B Datasheet.” *WorldSemi,* cdn-shop.adafruit.com/datasheets/WS2812B

[65] A.Lozano and C.Flores , “LED Matrix Panel: Hardware Testing Results,” Mar.2020

[66] A. Lozano “ Programming Flowchart between Processing and Arduino”, April 2020

[67] A. Lozano “Processing Libraries”, April 2020

[68] “Minim” , WordPress. [Online]. Available: http://code.compartmental.net/tools/minim/

[69] A. Lozano “Arduino Libraries”, April 2020

[70] A. Lozano “The Piano Application”, April 2020

[71] C. Anaya “Single Acrylic panel”, April 2020

[72] C. Anaya “Shorter back panel”, April 2020

Glossary

LEDs - Light Emitting Diode: A Diode with two terminals that when given current will emit a bright light. Color is usually due to the bulb but in some cases like RGB LEDs it is controlled by the energy gap between in the semiconductor.

FFT - Fast Fourier Transform: It is a mathematical method for taking a function of time to a function of frequency. This is done by grouping the common frequencies in the time domain.

DHH - Deaf and Hard Hearing: Those who have hearing loss that prevent understanding speech by hearing. Or those who have had hearing damage that lowers their ability to hear or communicate. For hard hearing it is those who cannot hear sounds of 25 decibels or less.

PWM - Pulse Width Modulation: It is the concept of having a reduced or average power by sending a discrete signal. This is done by sending a maximum amount but it is rapidly turned on and off. The percentage for long of the time the signal is on is the duty cycle.

VLS - Visible Light Spectrum: The portion of the electromagnetic spectrum that is visible to the naked eye.

## Appendix A. User Manual

This will be a complete user manual so that hopefully anyone that gets our project will be able to set it up and then use the device. We will break the manual into multiple sections. First, we will go over what is needed to set it up, then we will break up the set up into two parts. Just like cooking with dry and wet ingredients there is the physical and software set up. However, the software set up is very extensive so we will try to be as clear as possible. After that we will go over how to use the device.

Required Supplies:

Alright this section will not be too bad. There are only a couple of supplies needed to start. The first thing needed of course is our device. You will need one sight of touch project. The next thing you will need is a laptop or computer that has at least two usb ports. The two ports are needed to power the sight of touch device. With the computer you will also need a working and consistent Internet connection to download the necessary software. The last thing you will need is an AC wall socket. This is needed to power the sight of touch project but can also be used to power your computer/ laptop. Also, for the computer set up. It is critical you have a monitor, mouse, and keyboard. The keyboard being the most important as these are keys, we will be pressing to play the notes. Now that we have our supplies lets begin setting up the project!


Fig. A1.(left) Laptop [30]                Fig. A2. (right) Power Outlet [31]

Fig. A3. Sight of Touch Prototype [32]

Set up (Software):

Alight starting from scratch we will need a couple pieces of software and do a couple of steps. For starters we need both Arduino and Processing to run the project.

1) Step one download Arduino from the home page here https://www.arduino.cc/en/Main/Software

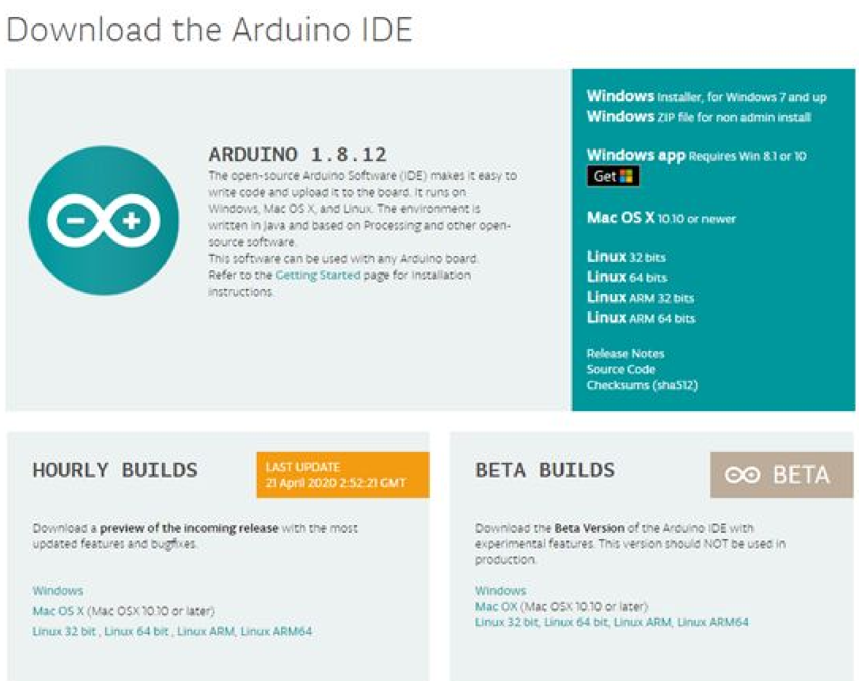



Fig. A4. Arduino download page [33]

Make sure to get the proper version for whatever device you are working on I got the Windows installer zip file.

2) To download make sure that you click on the version you want then on the next page hit "just download" unless you feel inclined to donate.


Fig. A5. Arduino continued download page [34]

3) Next is to download it onto your actual computer. I went for the zip but if you didn't you should be able to run the Arduino.exe file. Since I downloaded the zip first, I must extract the file

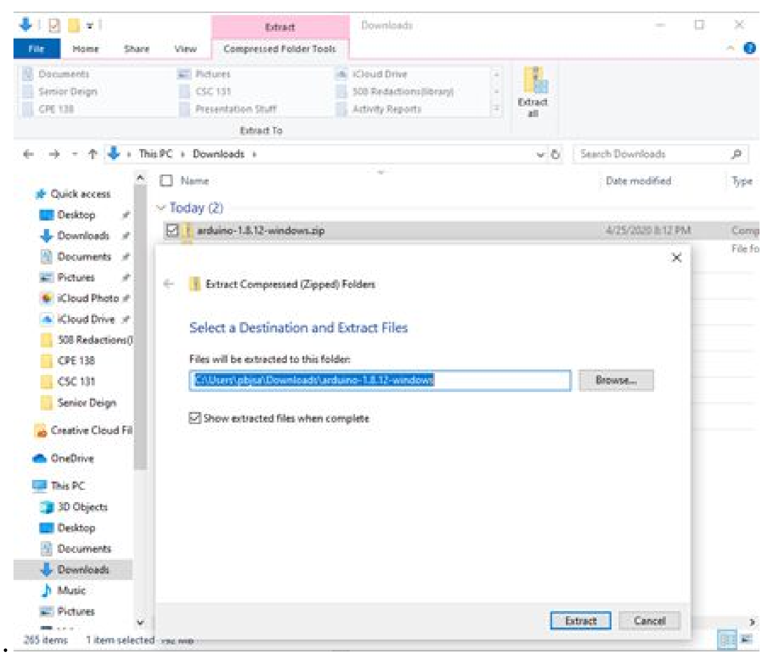



Fig. A6. Extract Arduino File [35]

4) Once that is done you can open Arduino and should have a window like this.

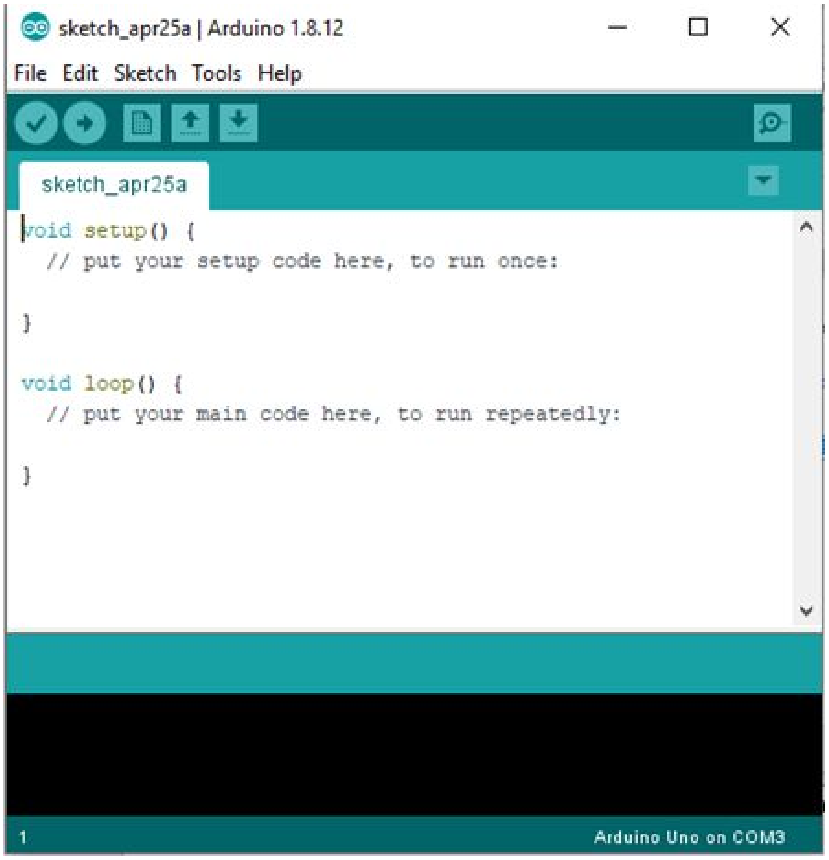



Fig. A7. First Arduino sketch [36]

5) We will need to download a library for Arduino to control the LED panels. To do this go to sketch -> include Library -> manage library. From here you should get a screen like this. Click on the search bar and type FastLED. We want version 3.3.3. If you see the same library as below install it. We can close out of Arduino now we will open it later in a couple of steps.

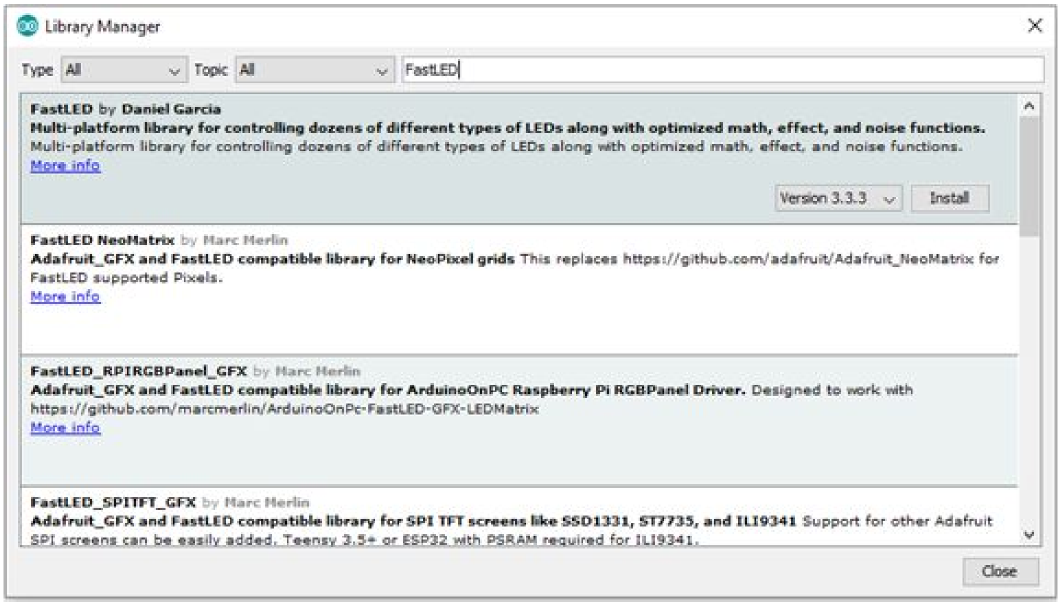



Fig. A8. Arduino library page [37]

6) Now we will install processing. This can be done at this page: [https://processing.org/download/](https://processing.org/download/)


Fig. A9. Processing download page [38]

Make sure you get the correct version. When you click it will take you to a donation page and immediately download the zip file. The donation is up to you. For the zip file we will repeat step 3 and extract the zip file. After it is done downloading click on the processing.exe to open the software environment. It should look a little like this

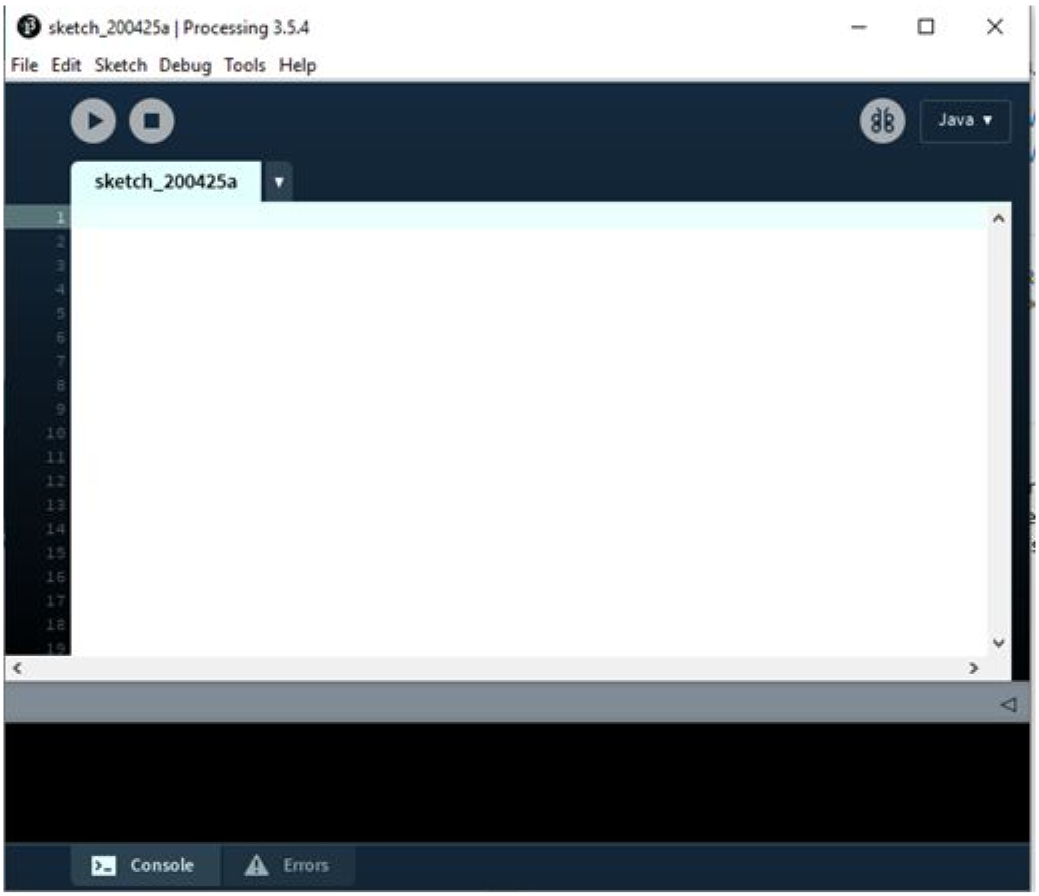



Fig. A10. Processing's first Sketch [39]

7) In the processing window go to Sketch -> import library -> then add library from there you should get a screen like this.

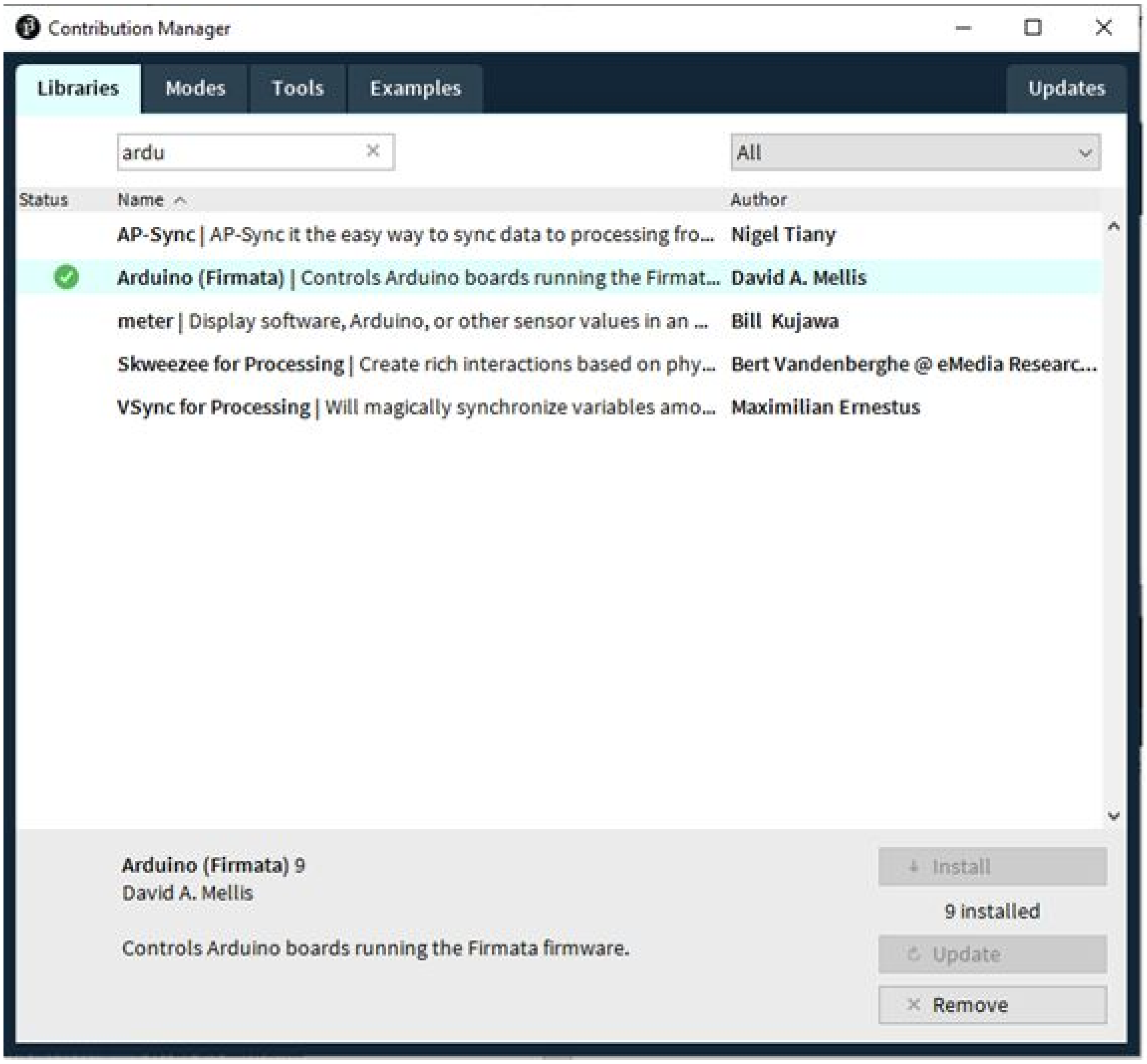



Fig. A11. Processing library window [40]

Search for a library by typing Arduino. We are looking for the Arduino (firmata) library that will allow both devices to talk to each other. As seen above click on the library and install it in the bottom right. It should now look like mine with a green check.

8) We will repeat step 6 but now we want to download the minim library that is needed for the frequency detection. Here is what the menu should look like.

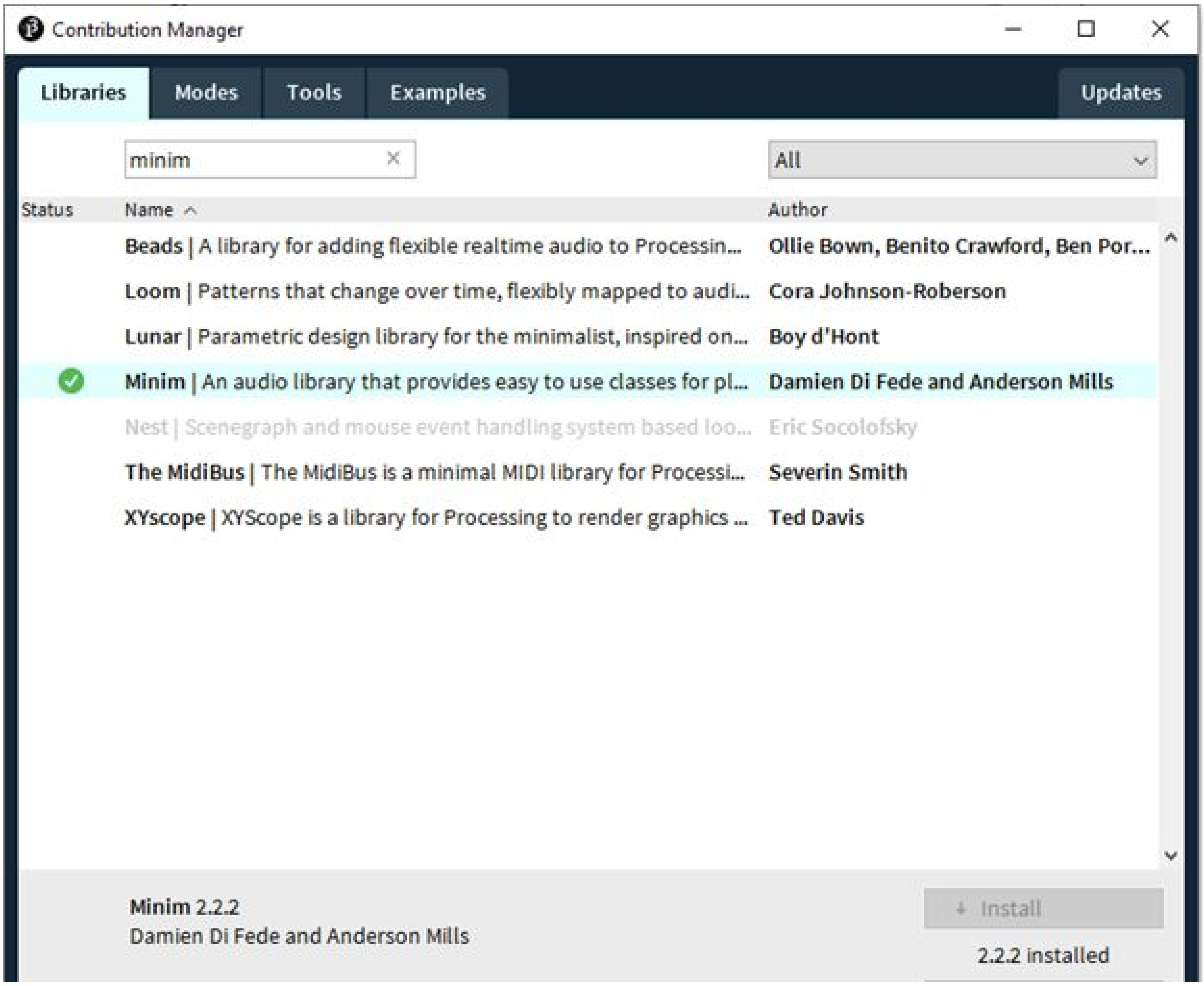



Fig. A12. Processing Minim window [41]

9) Perfect now that we have our environments working let’s add the code. For processing we need to get the code that runs the device. From the Senior Design Project digital folder that will be provided open the folder and click on the Current Frequency Code folder. Inside you will see Current_Frequency_Code.pde click on that file and open it. Disregard the data folder for now. It should look a little like this.

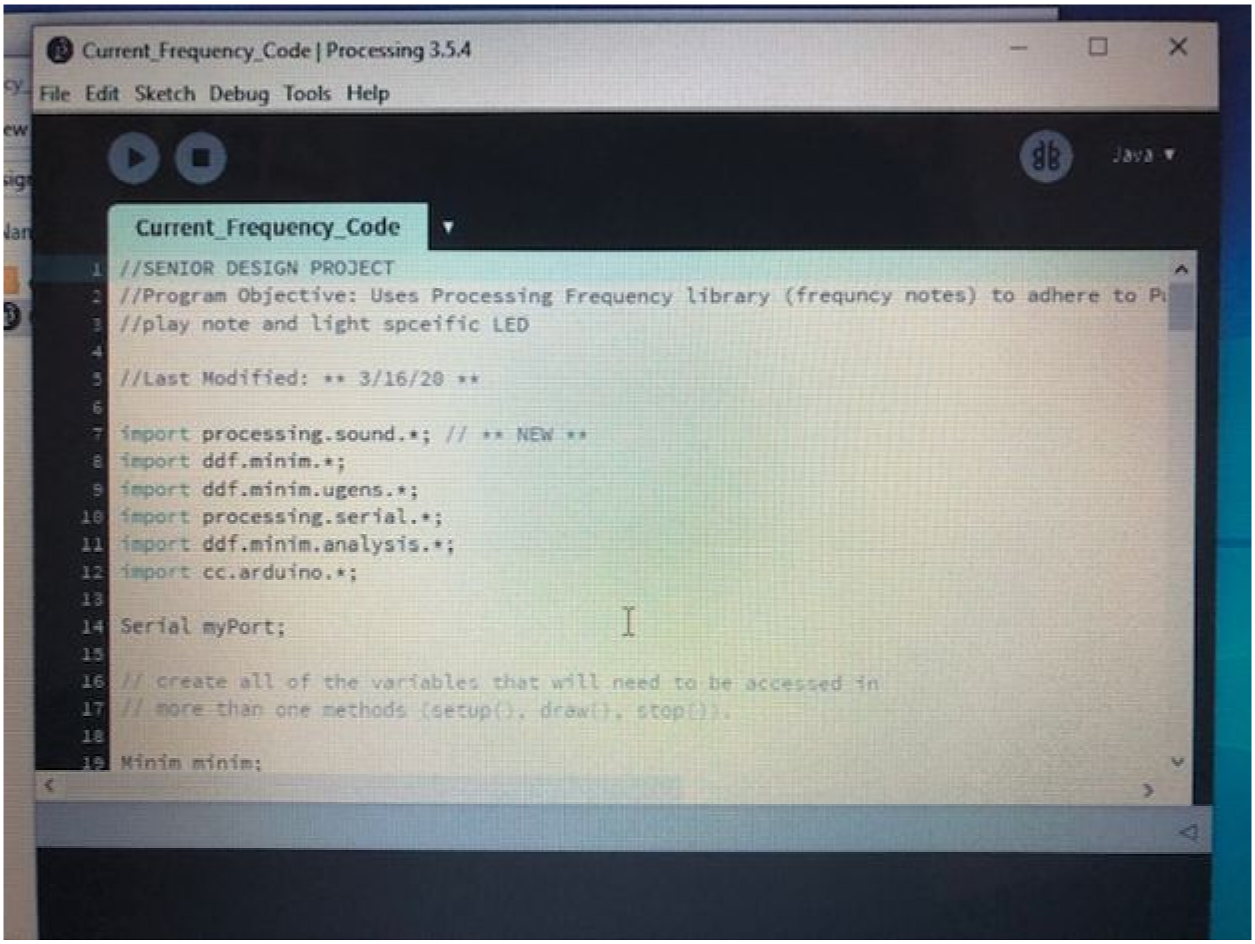



Fig. A13. Current Frequency Code [42]

10) Alright now that the processing code is in its place, we just need to update the Arduino code. In our Senior Design Project folder there should be one more folder called FinalLedCode. Open that folder and open the FinalLedCode.ino. It should look a little like this.

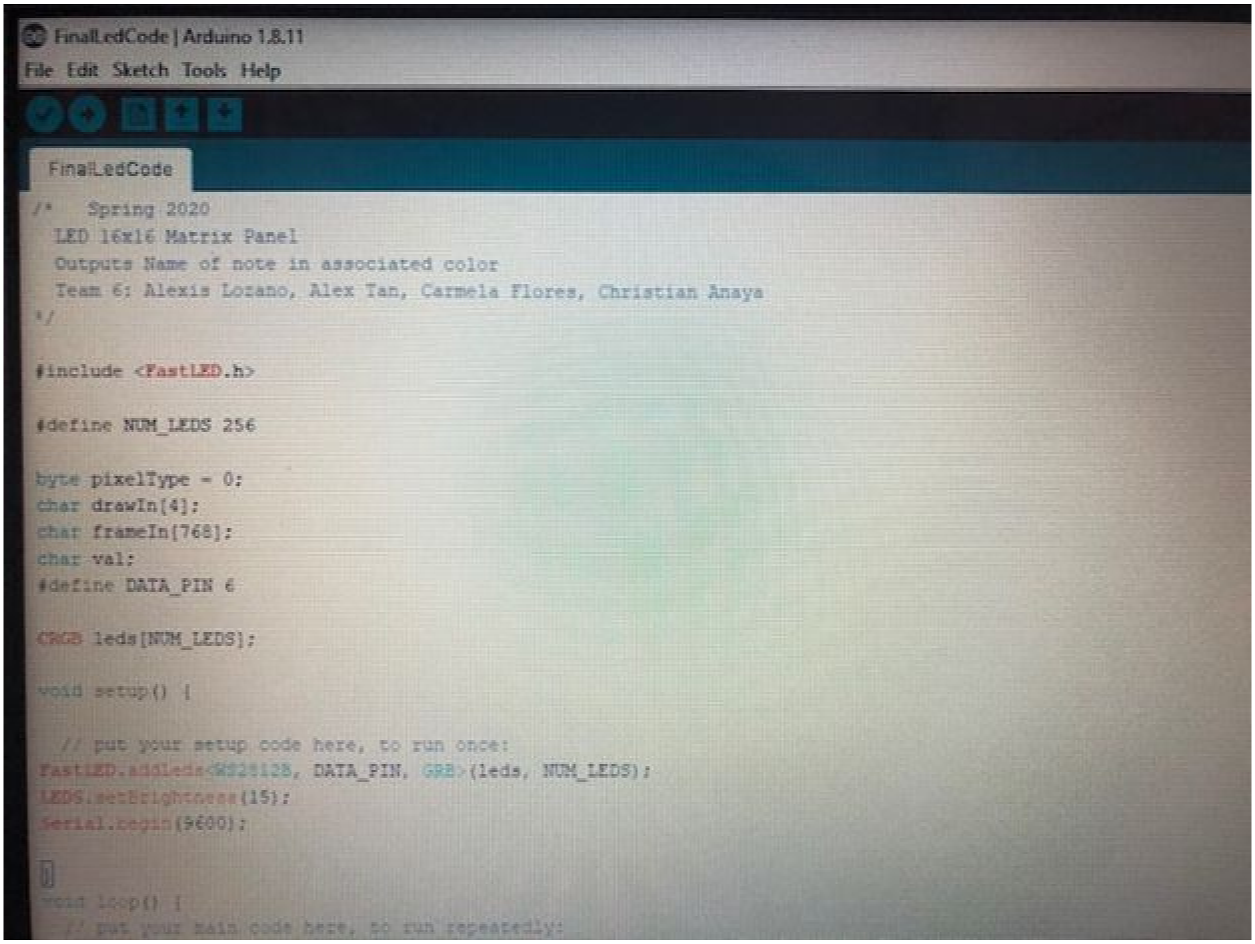



Fig. A14. Final Led Code [43]

11) Next we need to open a new Arduino window however this is a tricky part it needs to be its own process, so they don't share the same com port. To do this if you type Arduino in the Search bar in the bottom left for PC or look for your Arduino file that you downloaded for other computers. If you right click and open another instance of Arduino.exe it will open it on a different com port. You know it will work if you see two Arduino symbols. We want something like the left image not the right image. This is CRITICAL if this isn't done correct the project won't work!

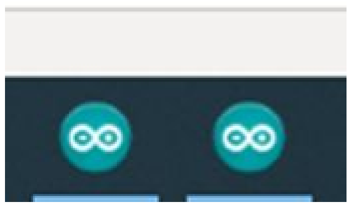
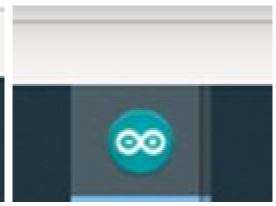



Fig. A15.(left): Correct Arduino setup (left) [44]

Fig. A16.(right): Wrong Arduino setup (right) [45]

12) If you follow the steps correctly one Ardunio should be FinalLedCode and the other arduino program should be empty. This one needs to be updated with an example library code. Go to File -> Examples -> scroll down until you see the Firmata list. We want to open the StandardFirmata. It should look like this.

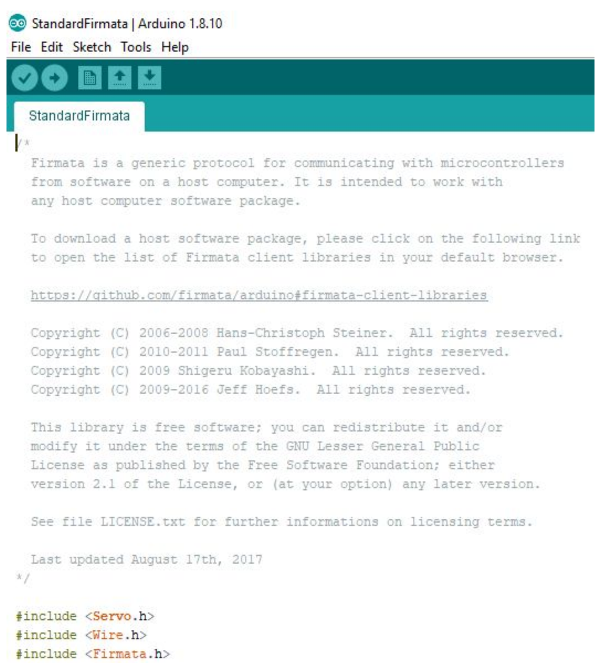



Fig. A17. Standard Firmata in Arduino [46]

13) Your Desktop should now look like the picture below. With one processing window with Current_Frequency_code, one Arduino window with FinalLedCode, and one Arduino window with the StandardFirmata library example. With all the software set up we will proceed to the hardware Section where we plug in the wires and compile all the code to run it!

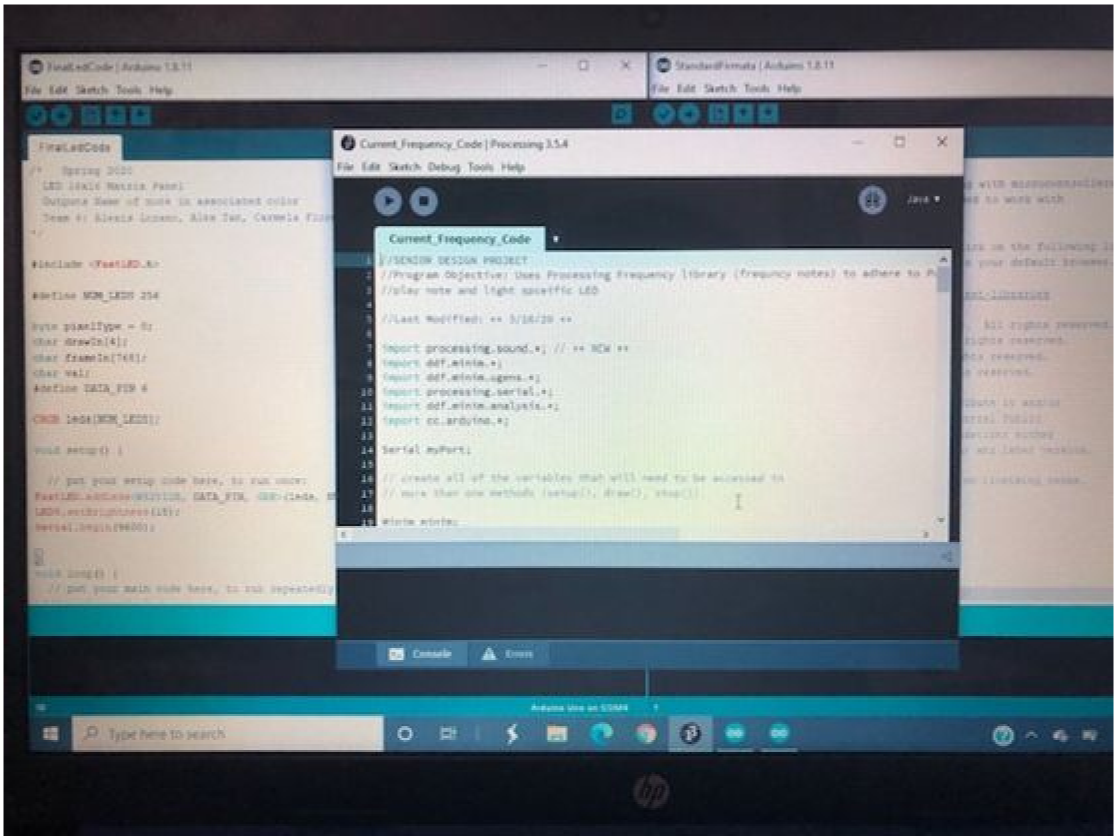



Fig. A18. Current Window [47]

Set up (Hardware):

1) First plug in the power cord into the wall

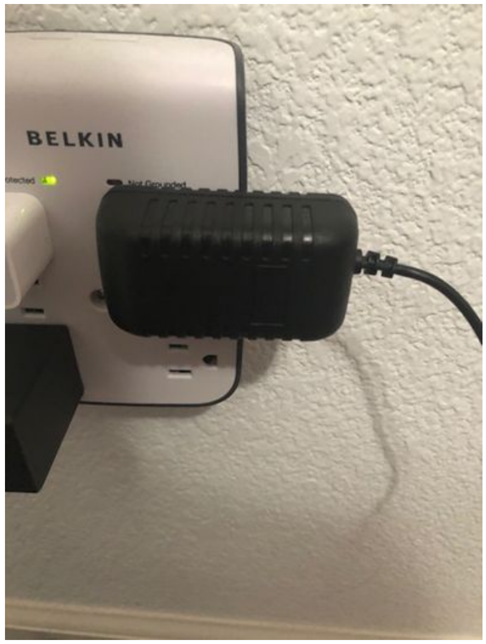



Fig. A.19. Plug in power [48]

2) Next plug in the cable with the lights tag into one of the usb ports.


3) Fig. A20. Plug in LEDs [49]

4) We then want to send our code to the Arduino. To do this we need to go to the FinalLedCode Arduino window and make sure that the proper COM is selected. Click on Tools -> Port -> and select the port that is shown. Since this is the only one plugged in right now it should show one COM select it.

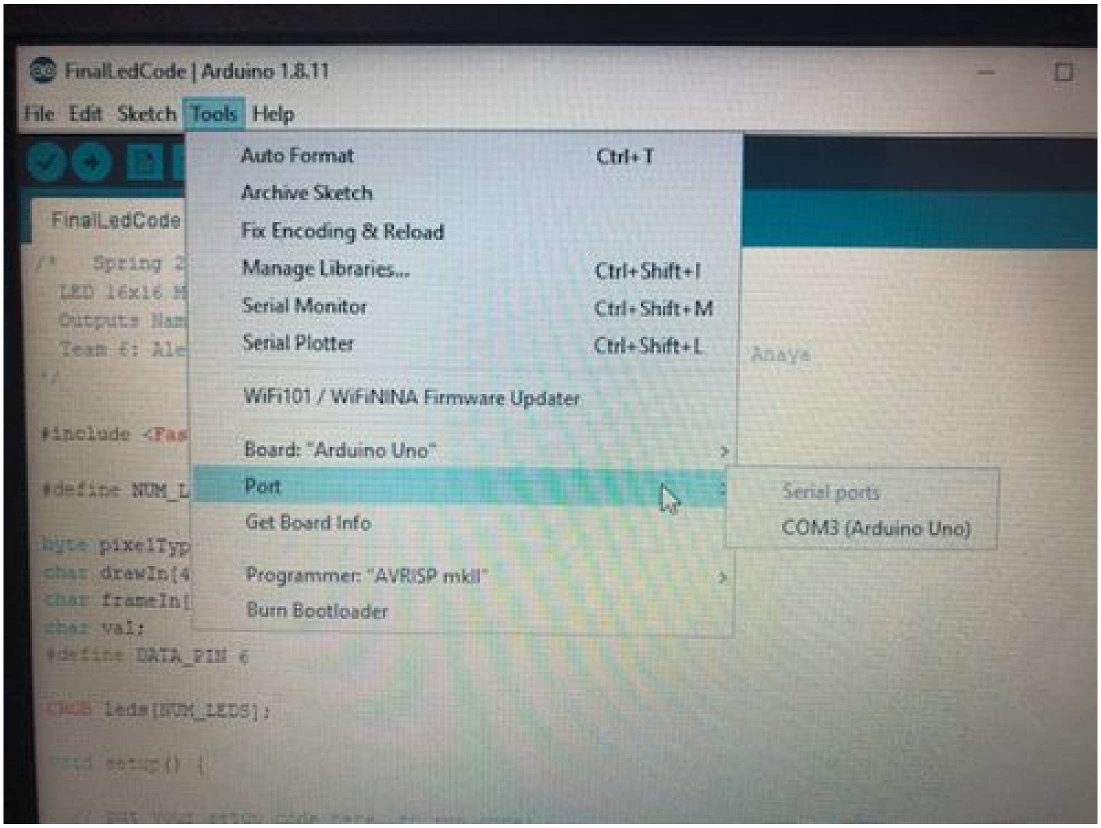



Fig. A21. 1st COM port [50]

5) Now we need to verify and run the code. To run the code after verifying, click on the sideways arrow. The pictures below will show the verify button and what happens when the code is done running.

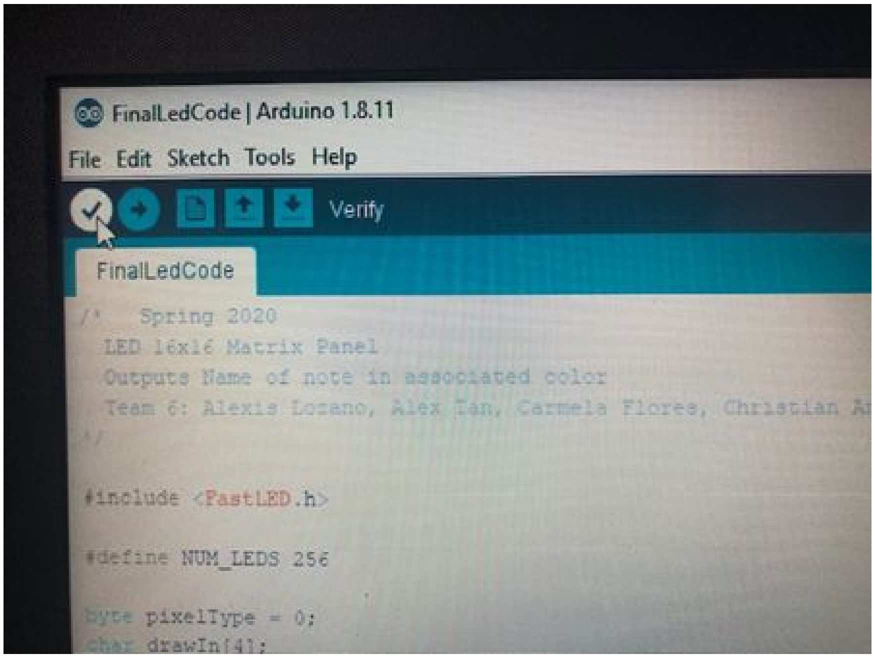



Fig. A22. Compile [51]

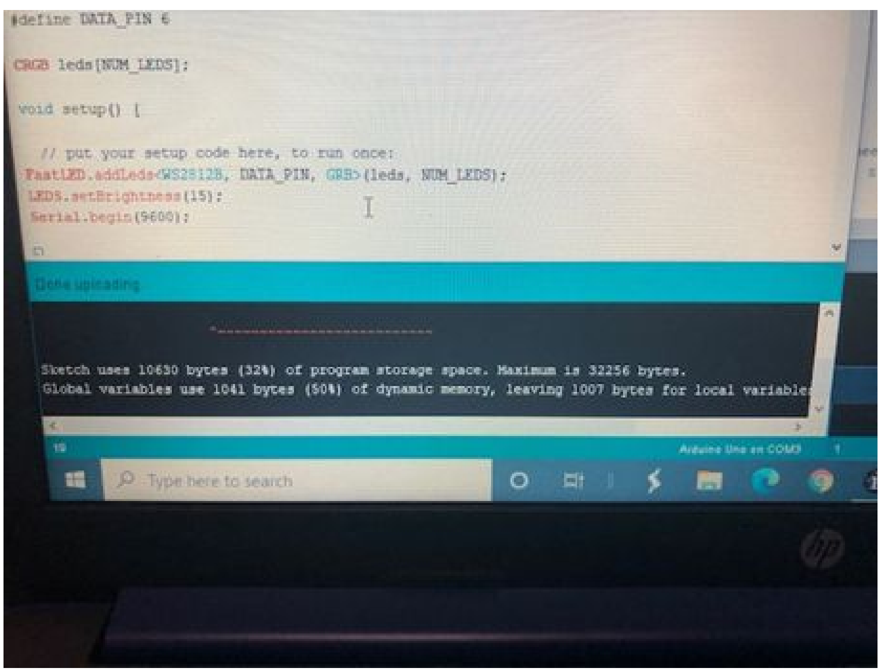



Fig. A23. Run Results [52]

6) Now plug in the motor cord into the second usb port.


Fig. A24. Plug in motors [53]

7) Now we need to do the motor code. Go to the StandardFirmata Arduino window. Then do the same thing as step 3. BUT!!! We want to make sure it is on a different COM port, so make sure yours is like the picture below. Go to tools Port and select the different port.

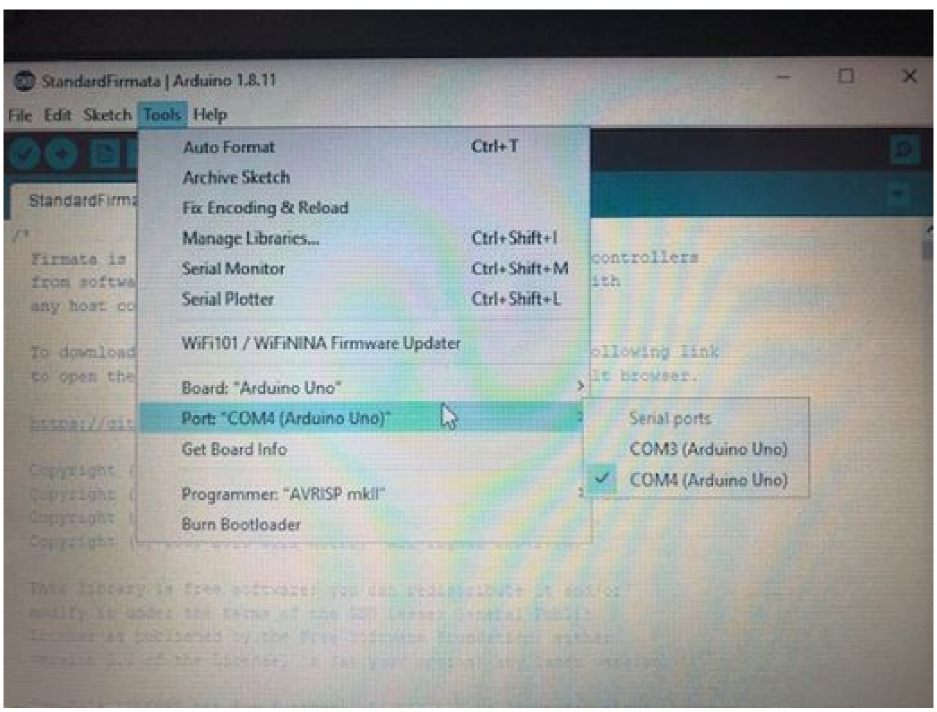



Fig. A25. Second COM port [54]

8) Follow step 4 again and compile and upload this code into the other Arduino.

9) The next step is to run the code in Processing. After you hit the play button in Processing you should see another window pop up. Click on it now and the project should be up and running.

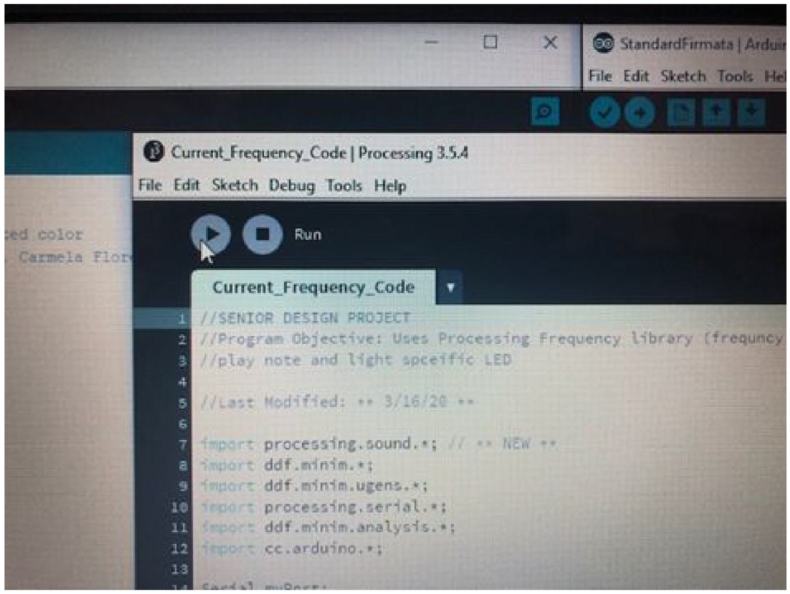



Fig. A26. Processing Run button [55]

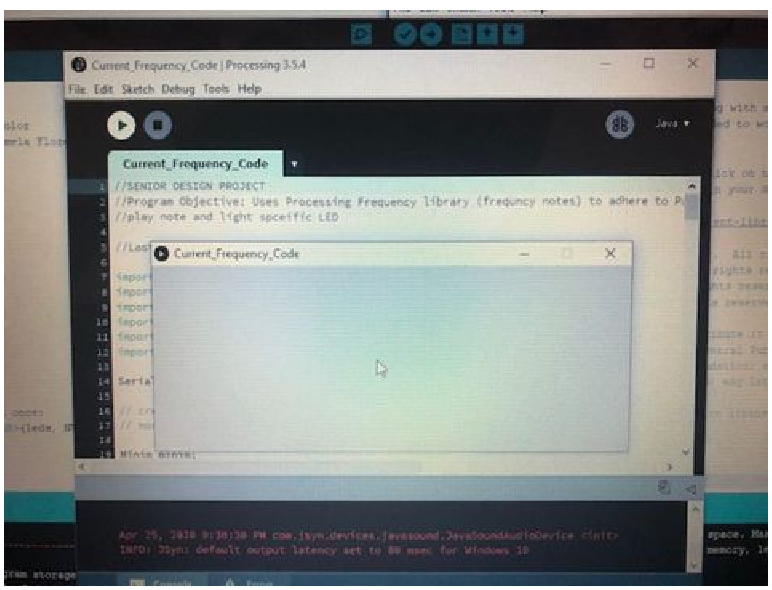



Fig. A27. Processing run window [56]

Using the Device:

Now that you clicked on the new Processing pop up box if everything is working correctly and you followed the steps above it should be functioning. To use the device, press the keys on your keyboard. The keys starting with Q and going left to right each key will have a note assigned to it. Press each key to hear a noise, see a note, and place your hands on the side to feel a vibration! Now that you're up and running, try playing a song while enjoying the device, it's all up to you. We hope you have as much fun as we have had building it, thank you so much for using our device!

Fig. A28. Prototype working [57]

**Appendix B. Hardware**

The hardware utilized in this multi-sensory device includes laptop/speakers, Arduino Uno microcontroller, breadboard, LED WS2812B 16 x 16 panels, and LRA and ERM Vibration motors, and a power supply. The laptop device serves as providing the audio input feature for the musical notes. It allows the user to press any key on the top row of the keyboard which is programmed to an associated note key to output to the Arduino boards for the haptic feedback and visual aid features. There are 2 LED panels built inside a clear sided panel so that the colors can be visible and distinguished as designed. The vibration motors are placed on two sides of the clear cube so that the user(s) can place their hands on the device. In this section, we'll provide the device testing plan schedule as well as the results for each feature: audio, haptic feedback, visual aid, and synchronization.

The following image shows a visual schematic of the end hardware deployable prototype design.

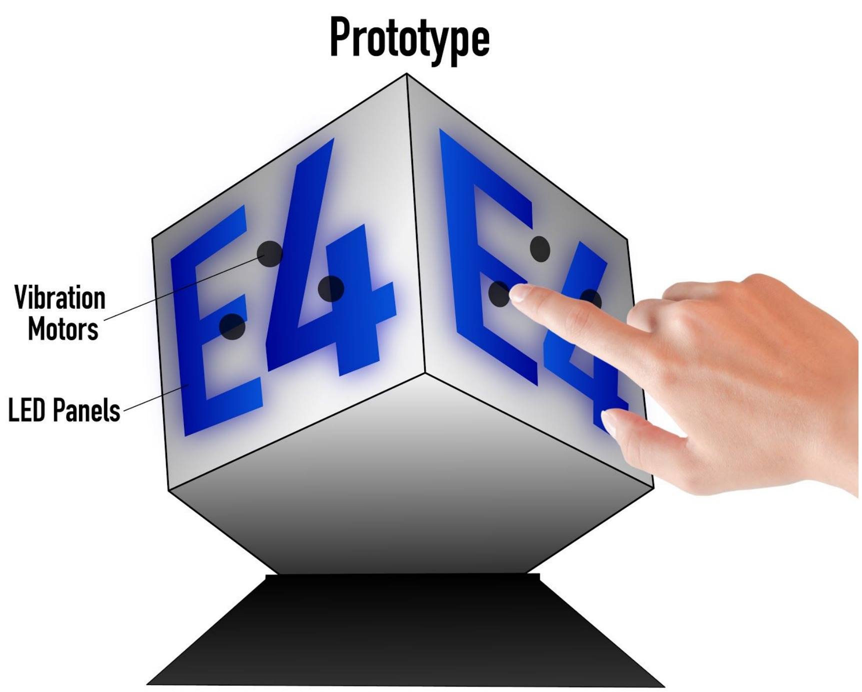



Fig. B1. Spring 2020 Deployable Prototype Schematic[11]

Table B-I

Hardware Device Testing Plan Schedule (Modified) [58]

| Module Leader | | Feature | **Completed Date** | |
|---|---|---|---|---|
| **Alexis** | **1** | **Music** | | |
| | 1.1 | Record New Audio Files | **2/16/20** | |
| | 1.2 | Process each file in WavePad | **2/16/20** | |
| | | | | |
| **Carmela** | **2** | **Visual Aid** | | |
| | 2.1 | Adjust Color Table | **2/14/20** | |
| Alexis | 2.2 | Test Visual Aid - LED strips | **2/14/20** | ** No Longer Planned for Use |
| | | Voltage, Current, Power | | |
| Alex | 2.3 | Test Visual Aid - Panel | **3/17/20** | |
| | | Voltage, Current, Power | | |
| Alex & Alexis | 2.4 | Visual Aid Program | **3/13/20** | |
| | | Confirm, software works with LEDs | | |
| | | | | |
| **Christian** | **3** | **Haptic Feedback** | | |
| | 3.1 | Vibration Motor Testing | **3/11/20** | **** Began 2/7/20** |
| | | Accelerometer | | |
| | | Voltage, Current, Power | | |
| Alex | | Meeting with Prof. Burnside | **2/26/20 - 3/11/20** | |
| | 3.1.1 | Vibration Motor Testing Revised | **3/21/20** | |
| Alex & Alexis | 3.2 | Vibration Motor Program | **3/13/20** | |
| | | Confirm software works with Motors | | |
| | 3.3 | Collected Data to reassure used values are scaled | **3/16/20** | |
| | | | | |
| **Alex** | **4** | **Synchronization** | | |
| | 4.1 | Delay Testing | **3/17/20** | |
| | | Visual Aid & Vibration Motors | | |
| Carmela & Alexis | 4.2 | Program LED & Motors together | **3/11/20** | |
| | | Program to work on multiple computer sources | | |
| | 4.3 | Debug Program Errors | **3/16/20** | |
| | 4.4 | Temperature Testing for all Components | 3/21/20 | |

Table B-II
Audio Analysis and Testing Results [59]

| Note | Note Listed Frequency (Hz) | Measured Note Frequency (Hz) | Assigned Frequency Range per Note (Hz) | Meets Requirement? |
|---|---|---|---|---|
| E4 | 329.63 | 334 | 330-335 | YES |
| F4 | 349.23 | 354 | 335-360 | YES |
| G4 | 392 | 393 | 380-405 | YES |
| A4 | 440 | 443 | 430-455 | YES |
| B4 | 493.88 | 497 | 485-510 | YES |
| C5 | 523.25 | 524 | 511-530 | YES |
| D5 | 587.33 | 592 | 580-595 | YES |
| E5 | 659.26 | 660 | 630-670 | YES |
| F5 | 698.26 | 703 | 671-720 | YES |
| G5 | 784.26 | 773 | 770-784 | YES |

Table B-III
Table for Accelerometer Values for Haptic Feedback Feature [60]

| Motor Test (one motor on board with breadboard chip) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Note | Duty cycle | Gyro X | Gyro Y | Gyro Z | Temp C | Accel X | Accel Y | Accel Z |
| Solo | 0 | -3.5 | -2 | 0 | 19.53 | 0.01 | 0.01 | 1.06 |
| G4 | 61 | -3.63 | -2.08 | 0.17 | 20.53 | 0.01 | 0 | 1.07 |
| * | * | -3.61 | -2 | -0.01 | 20.53 | 0.01 | 0 | 1.07 |
| * | * | -3.57 | -2.26 | -0.24 | 20.53 | 0.01 | 0 | 1.08 |
| * | * | -3.69 | -2.15 | -0.02 | 20.53 | 0.01 | 0 | 1.07 |
| * | * | -3.64 | -2.34 | -0.16 | 20.53 | 0.02 | 0 | 1.07 |
| * | * | -3.86 | -3.14 | -12.63 | 20.53 | 0.02 | 0 | 1.06 |
| * | * | -3.57 | -2.66 | -0.41 | 20.53 | 0.02 | 0 | 1.06 |
| * | * | -3.6 | -2.35 | 0.11 | 20.53 | 0.02 | -0.01 | 1.07 |
| * | * | -3.59 | -2.05 | 0.22 | 20.53 | 0.02 | 0 | 1.06 |
| * | * | -3.67 | -2.32 | 0.05 | 20.53 | 0.02 | 0 | 1.08 |
| * | * | -3.76 | -2.15 | -0.06 | 20.53 | 0.02 | 0 | 1.07 |
| * | * | -3.3 | -2.06 | 0.17 | 20.53 | 0.02 | 0 | 1.07 |
| Avg | | -3.624167 | -2.29667 | -0.98538 | 20.53 | 0.016667 | -0.00083 | 1.069167 |

Table B-IV
Table for New Duty Cycle Values for Haptic Feedback Feature [61]

| New Values | | | | |
|---|---|---|---|---|
| Note | Musical Frequency | Frequency Range | Vibrational Frequency | Duty Cycle |
| G4 | 380-405 | 63.3-67.5 | 63.52 | 67 |
| G5 | 770-800 | 128.3-133.3 | 130.3 | 150 |
| A4 | 430-455 | 71.6-75.83 | 75.25 | 77 |
| B4 | 485-510 | 80.83-85 | 83.75 | 91 |
| C5 | 511-530 | 85.1-88.3 | 87.95 | 82 |
| E4 | 320-335 | 53.3-55.8 | 55.9 | 61 |
| E5 | 630-670 | 105-111.6 | 105.7 | 124 |
| D5 | 587.3 | 97.88 | 97.85 | 110 |
| F4 | 335-360 | 55.83-60 | 55.9 | 61 |
| F5 | 671-720 | 111.8-120 | 115 | 125 |

Table B-V
Visual Aid Color - Frequency Table [62]

| **Visible Light Spectrum** | | | | | **Color** | **Sound** | |
|---|---|---|---|---|---|---|---|
| **Wavelength Interval (nm)**[63] | **Wavelength Interval (nm)** | **Frequency (THz)**[63] | **RGB Value** [16] | **Hex Value** [16] | | **Sound Frequency Range (Hz)** | **Key** |
| 625 - 740 | 620 - 625 [64] | 405-480 | (255,99,0)- (181, 0,0) | #ff6300 - #b50000 | Red | 380 - 405<br>770 - 784 | G4<br>G5 |
| 590 - 625 | 590 - 620 | 480 - 510 | (255,223, 0)- (255,99, 0) | #ffdf00 - #ff6300 | Orange | 430 - 455 | A4 |
| 565 - 590 | 560 - 580 | 510 - 530 | (210,255, 0) - (255,223, 0) | #d2ff00- #ffdf00 | Yellow | 485 - 510 | B4 |
| 500 - 565 | 522 - 525 [64] | 530 - 600 | (0,255, 146) - (210,255, 0) | #00ff92- #d2ff00 | Green | 511 - 530 | C5 |
| 440 - 485 | 465 - 467[61] | 620 - 680 | (0,0,255) - (0,234,255) | #0000ff - #00eaff | Blue | 330 - 335<br>630 - 670 | E4<br>E5 |
| 420-450 | 430 | | (106,0,255) - (0,70, 255) | #6a00ff - #0046ff | Indigo | 580-595 | D5 |
| 380 - 440 | 400 | 680 - 790 | (97, 0, 97 - (0,0, 255) | #610061 - #0000ff | Violet | 335 - 360<br>671 - 720 | F4<br>F5 |

Note: E4 and G5 sound frequency ranges were modified in Spring 2020 to accommodate haptic feedback vibration motor constraint of ⅛ scaling.

Table B-VI
Visual Aid LED Matrix Panel: Hardware Testing Results [65]

| | **Arduino Expected Values** | **Measured Values with a multimeter** | **WS2812B LED Matrix Expected Values** |
|---|---|---|---|
| **Voltage** | 5 V pin | 4.29 V | +3.5V ~ +5.3V |
| | Voltage from Pin 6 | 0.58 V | |
| **Current** | 20 mA from Pin 6 | 0.14mA | 15360 mA = 15.35 A |

Table B-VII

Visual Aid Feature Testing Results [17]

| Note | RGB Value Constraint | Color | What a Color? App | | In Range? |
|---|---|---|---|---|---|
| | | | Color Name | RGB Value | |
| G4<br>G5 | (255,99,0)-<br>(181, 0,0) | RED | Candy Apple Red | (255, 0,0) | Y |
| A4 | (255,223, 0)-<br>(255,99, 0) | ORANGE | Safety Orange<br>(Blaze Orange) | (255,106,0) | Y |
| B4 | (210,255, 0) -<br>(255,223, 0) | YELLOW | Golden Yellow | (254,225,0) | Y |
| C4 | (0,255, 146) -<br>(210,255, 0) | GREEN | Lime(web) (x11) | (0,255,0) | Y |
| E4<br>E5 | (0,0,255) -<br>(0,234,255) | BLUE | Blue | (0,8,255) | Y |
| D5 | (106,0,255) -<br>(0,70, 255) | INDIGO | Indigo | (115,0,255) | Y |
| F4<br>F5 | (97, 0, 97)-<br>(0,0, 255) | VIOLET | Violet(RYB) | (99,0,208) | Y |

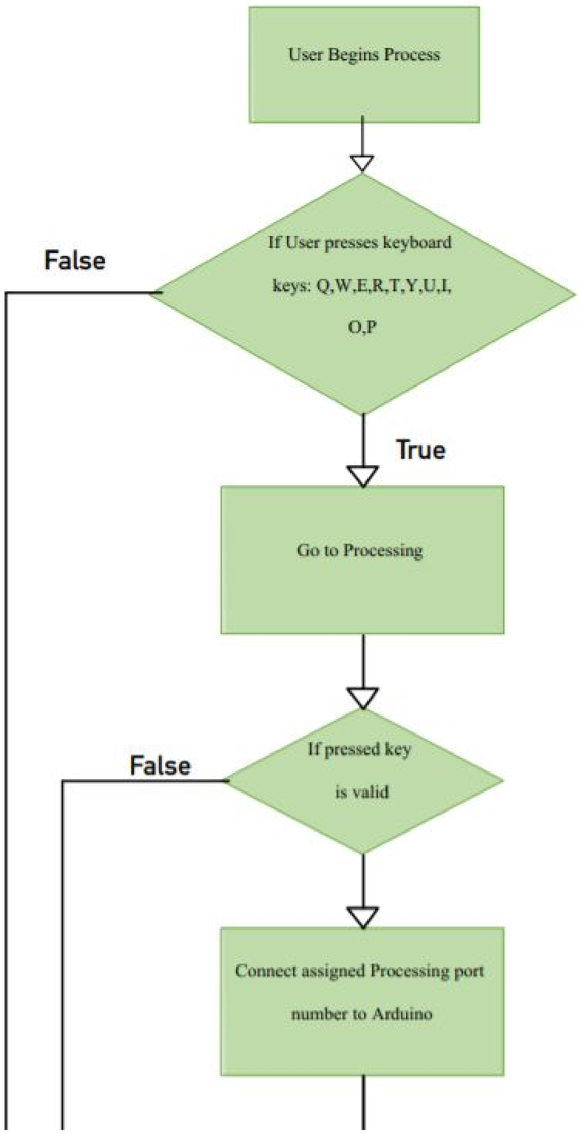
Table B-VIII
Synchronization Timing Results [20]

| Delay Test Table | | |
|---|---|---|
| Delay Test Description | Delay Test | Delay Time |
| 1 LED | Power on | 99 us |
| 2 LED | 1st LED to power on | 4.7 us |
| | 2nd LED to turn on after 1st LED turns off | 4.6 us |
| 1 LED 1 Motor | LED turning on from time 0 | 2.6 us |
| | Motor turning on from time 0 | 6.6 us |
| | Motor turning on after LED turns on | 4 us |
| LED Panel | LED Panel Turning on | 7.7 ms |
| LED Panel and motor | One motor then the LED Panel turns on | 6.2 ms |

## Appendix C. Software

Software used within the project were dependent on two applications, Processing and Arduino IDE. Both Processing and Arduino IDE work together to make the audio, vibration motors and LED panels to function in unison. Whenever a user presses a keyboard key, they see an immediate output. In the background, once the key is pressed, it sends a signal to Processing. Processing evaluates that input and falls to the appropriate if- statement. Within that statement, Processing uses a function called Serial Port. This port is assigned a numerical value and is the bridge connection to Processing and Arduino applications. Arduino software, similar to Processing, consists of if-statements, focused on sending an output to the LED panels. Once the serial port finds its match the LED panel outputs the current note in its assigned color. Back in Processing, once the serial port call sends, Processing outputs the vibrations from the vibration motors. All of these processes work fast enough within 10ms, it provides an appropriate sensation of synchronization.

Below is the general software flow between Processing and Arduino, specifically when operated by a user.


User Begins Process
If User presses keyboard keys: Q,W,E,R,T,Y,U,I, O,P
False
True
Go to Processing
If pressed key is valid
False
Connect assigned Processing port number to Arduino

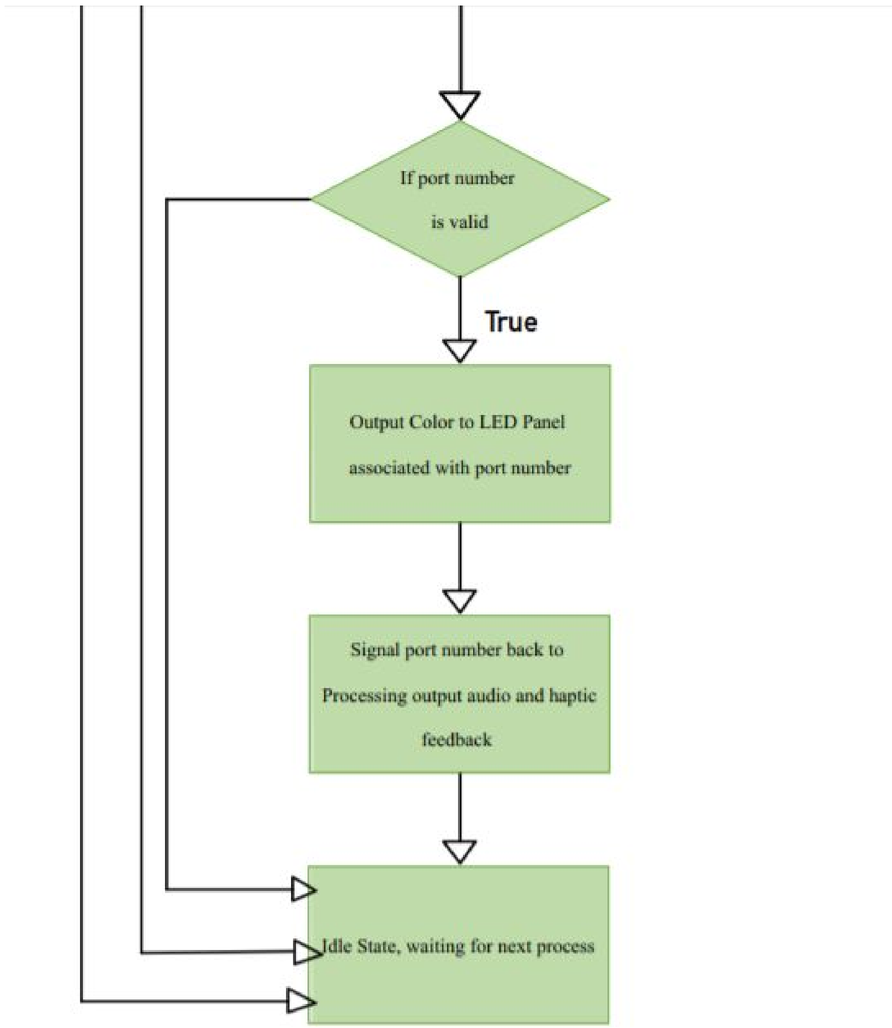



Fig. C1 Programming Flowchart between Processing and Arduino [66]

Processing application is used to open the audio files, play the files and set the vibration motors to vibrate simultaneously as the note will output through a set of speakers running from the computer or laptop connected to the circuit. The figure below shows the Processing libraries needed to run the functions mentioned above.

```
import processing.sound.*; // ** NEW **
import ddf.minim.*;
import ddf.minim.ugens.*;
import processing.serial.*;
import ddf.minim.analysis.*;
import cc.arduino.*;

Serial myPort;

// create all of the variables that will need to be accessed in
// more than one methods (setup(), draw(), stop()).

Minim minim;
AudioOutput out;
BeatDetect beat;
Arduino arduino;
SoundFile file; // ** NEW **
```

Fig.C2. Processing Libraries [67]

The Minim library is the main tool used within Processing to open and play audio files. Features included in the library allow audio recording, sound synthesis, an audio generation of a frequency spectrum, and is able to playback a variety of files. The last option provides flexibility and reduces the amount of risk associated with the confinement of using one type of audio file [68].

Below is a figure showing the libraries needed to be included in the Arduino coding program.

```
#include <FastLED.h>

#define NUM_LEDS 256

byte pixelType = 0;
char drawIn[4];
char frameIn[768];
char val;
#define DATA_PIN 6
#define DATA_PIN2 3
CRGB leds[NUM_LEDS];

void setup() {

  // put your setup code here, to run once:
FastLED.addLeds<WS2812B, DATA_PIN, GRB>(leds, NUM_LEDS);
FastLED.addLeds<WS2812B, DATA_PIN2, GRB>(leds, NUM_LEDS);
LEDS.setBrightness(15);
Serial.begin(9600);

}
```

Fig.C3. Arduino Libraries [69]

Libraries in Arduino are mainly focused on the use of the LED matrix panel. In order for the panel to be used, a library called FastLED is needed. This allows the programmer to directly assign and communicate with each LED using Red Green Blue (RGB) values. Another necessity to control the LED panel, is referencing the model of panel used. Figure C2, shows the declared FastLED library at the top and towards the bottom is a declaration of the panels. The LED panels used were 16 by 16 matrix panels, model WS281B. Seen above FastLED calls the "addLeds" function declaring WS2812B panel model, the data pin the panel is connected to, and GRB function. Like, RGB color scheme, GRB (Green, Red, Blue) are a set of color values ranging from 0 -255 per color. Adjusting the color and values between 0 -255, outputs an assortment of hues. In this case the panel was not built with an RGB base but GRB. By calling GRB, in the declaration, this allows the programmer to still code the color ranges as RGB, but the Arduino library declaration will call the GRB function to resort the values in proper GRB form.

Another source of software used for this project was for the audio feature. The notes were created using an application called "The Piano" created by Impala Studios. Figure below is the opened application. The application is based on the sounds of a Grand Piano. All notes were able to be recorded within the application, providing an ease of access for other team members.

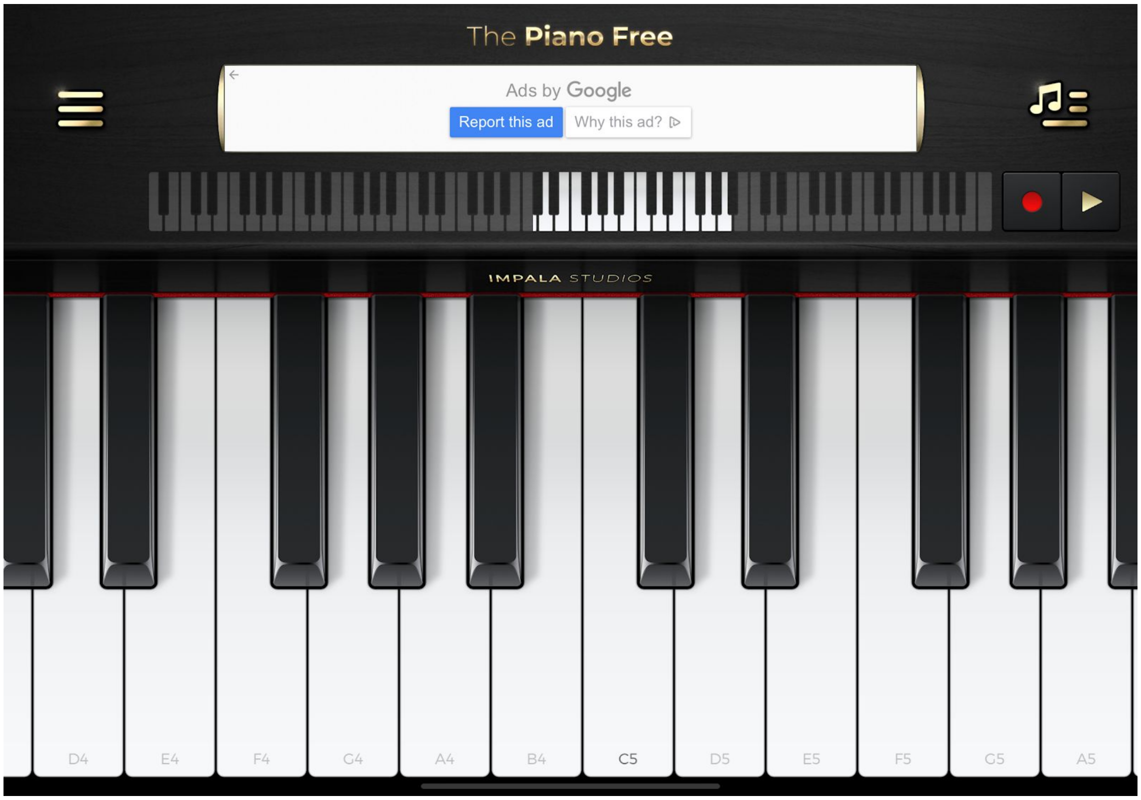



Fig.C4. The Piano Application[70]

Testing the recorded audio, the files were uploaded to a software called WavePad Sound Editor part of the NCH Suite. The image below is a snapshot of a G4 note getting analyzed using the Fast Fourier Transform (FFT). All notes were analyzed in a similar manner.

WavePad Sound Editor software allowed testing audio files to be accessible. The FFT feature takes in the audio file, and transforms a decibel versus time wave to amplitude versus frequency waveform - seen in Figure C5. The visual output came in handy, when it came to having a visual representation of a note. This association between music and visual aid are two fundamental points in the project.

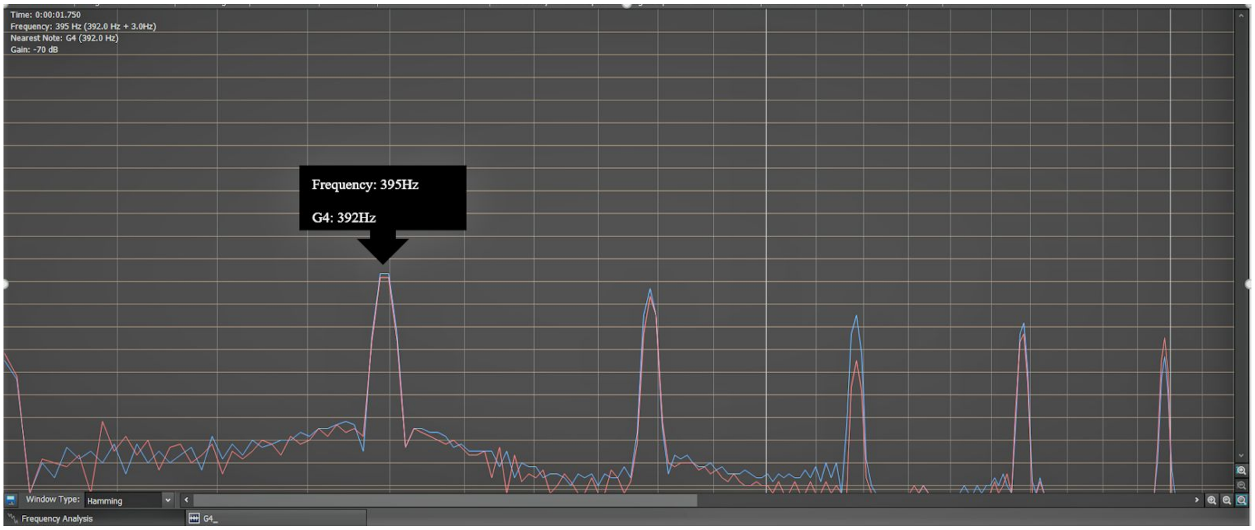



Fig. C5. WavePad G4 Note Gain vs Frequency Waveform [16]

Testing results concluded from importing audio files are in Table B-II in Appendix B2. They reveal the ideal frequency of the note, the measured value, and the frequency range per note set in the Color Frequency Table.

**Appendix D. Mechanical Aspects**

For the Mechanical aspects, we will go over the building process of our prototype. First we purchased 6 8x8 acrylic panels, each panel is approximately .080 inches in thickness. In Fig.D1, shows what a single panel looks like.

Fig. D1. Single Acrylic panel [71]

One of the panels has to be cut shorter, so that there is enough room for the cables to pass through. Fig. D2, shows an example of the back panel.

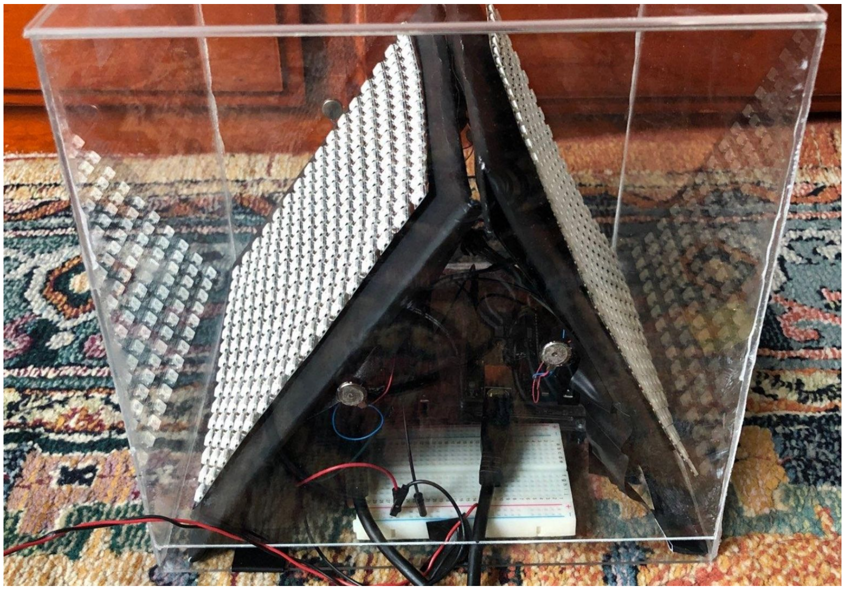


Fig. D2. Shorter back panel [72]

We decided that, in order to give the user an immersive experience, the LED panels, would be at an angle. In order to support the LED panels at an angle, we decided to fit 2 6x6 cardboard panels, which are covered in black poster paper. A hole was also placed in the center of the cardboard panel so that we could run some cables through. You can see an example of the panels at an angle in the previous Figure. D2.

In order to put the panels together, we used Gorilla super glue. We placed each panel at a 90 degree from each other. Make sure not to close the cube, without installing the electrical components together (Vibrational Motors, LED panel, arduino uno and breadboard).

## Appendix E. Vendor Contacts

**Music Prof. Chavez** luis.chavez@csus.edu - Phone: (916) 278-6558

- Aided with studies of the Musical element mainly in the Fall 2019 semester
- Recommended the book "Keywords in Sounds" by David Novak and Matt Sakakeeny

**Professor. Burnside** scott.burnside@csus.edu

- Aided with opinion and knowledge regarding use of accelerometer
- Also advised our group with how to get correct FFT data from the vibration motors
- RVR 5062 Mon & Wed | 5:15pm - 5:45

## Appendix F. Resumes

# Alexis Lozano

### Objective

Pursuing a full-time position that will incorporate my Computer Engineering courses to develop with a company in creating the next generation of world class technology and solutions.

### Education

Bachelor of Science Computer Engineering — **Expected**: May 2020
California State University, Sacramento — **CSUS GPA:** 3.5
**Honors:** Dean's Honor List, Fall 2017 – Fall 2019

### Relevant Courses

- Advance Logic Design
- Object Oriented Prog. With C++
- Data Structure +Algorithm Analysis in Java
- Intro System Programing – Unix
- Operating Systems
- Computer Interfacing
- Network Analysis
- Computer Network & Internet
- Database Management Systems
- Computer Hardware Design
- Digital Integrated Design CMOS/VLSI
- Signals & Systems

### Technical Skills

**Scripting/Programming Languages:**

- 4 years of C / C++ Programming
- 2 years of Assembly Programming
- Python
- Java

**Software Applications:**

- MATLAB, Visual Studios, Jet Brains (IntelliJ, CLion), Microsoft Office Suite (Word, PowerPoint, Excel), Vivado

**Platforms/Environments:**

- Windows, Unix, Linux, Mac OS

**Hardware Description Languages:**

- Verilog, VHDL using an FPGA

**Hardware Test Equipment:**

- Oscilloscope, Digital Voltmeter, Analog Discovery

### Technical Projects

- Capstone Project (in progress): A multi-sensory device that uses visual aids and a haptic feedback system for an encompassing experience with music. The design optimizes the use of microcontrollers, LEDs, and vibration motors.
- Created a Two-Way Traffic light System and pedestrian crosswalk. Built with a group of 4 students using C language and a Propeller Board.

### Work Experience

Designer Shoe Warehouse (DSW) — October 2016 – March 2018, October 2013 – November 2015

- Garnered reward sign ups every shift, signing up at least 85% of customers who made a purchase.
- Cross-trained and managed more than 10 associates in order to improve productivity.
- Improved customer satisfaction with skilled resolutions of conflicts, issues, and concerns.
- Consulted with customers to evaluate their needs and determine the best options to upsell products.
- Managed preparation of store floor plans for new shipment, therefore stayed up to date on latest trends.

### Volunteer Work/ Activities

- Tau Beta Pi – National Engineering Honor Society. CSU Sacramento — Fall 2018 – Present
  - Leadership Officer: Webmaster — Spring 2019
- Mathematics Engineering Science Achievement (MESA) (MEP) CSU Sacramento, — Fall 2017 – Present
- Society of Women Engineers (SWE) CSU Sacramento — Fall 2018 – Present
- MESA, Cosumnes River College — 2013 – 2015

# Alexander Tan

**OBJECTIVE**

Looking for a full-time position that utilizes my knowledge of computer engineering. Also open to any internships that will give helpful experience to make me a better engineer.

**EDUCATION**

Bachelor of Science, Computer Engineering — Expected Spring 2020
California State University, Sacramento — G.P.A. 3.35

Relevant Course work:
CPE 166 - Advanced Logic Design introduction to VHDL/Verilog testing FPGA
CPE 151 - Cmos and Vlsi taught about cmos construction rules and SPICE software,
CPE 159 - Operating System Pragmatics (currently taking) teaches OS function and using C to create a barebone operating system
CPE 186 - Experience with microcontrollers and how to access their registers for desired functions

**KNOWLEDGE AND SKILLS**

- C, Verilog, VHDL, SPICE, Java, x86 assembly, Python, JavaScript
- Design of microcomputer system, Synthesize designs such as state machines on FPGAs, Hardware architecture and memory layout
- Great at communication, to focus on the most important tasks
- Friendly and Understands customer service
- Experience with page scanner

**PROJECT or LAB EXPERIENCE**

Sight of Touch — August 2019-Present
Senior Design, involves haptic feedback and visual to utilize different sense with experiencing music.

Multiple Device Semester Project — August 2018 – December 2018
Moisture sensor powered by solar panel. Controlled using STM32 board and raspberry pi.

**PROFESSIONAL or WORK EXPERIENCE**

Sacrament State Library, Library Student Assistant, Sacrament California
March 2017-present

- Help librarians pull, scan, or send requested books for either patrons or other CSU
- Receive, process, and deliver mail to the internal offices of the library
- Fill out computer forms needed to process books

# Carmela Flores

## OBJECTIVE

To obtain a position in either software or hardware development to further enhance programming and verification/validation skills.

## EDUCATION

Bachelor of Science, Computer Engineering — **Expected:** May 2020
California State University, Sacramento — **GPA:** 3.78
**Honors:** Dean's Honor List, Fall 2016 – Spring 2019

## TECHNICAL SKILLS

| | |
|---|---|
| **Scripting/Programming Languages:** | Java, Python, C, HTML, XML |
| **Hardware Description Languages:** | Verilog, VHDL |
| **Engineering Tools:** | Cadence |
| **Platforms/Environments:** | Windows, Mac OS Sierra, UNIX |
| **Software Applications:** | Microsoft Office Suite (Word, PowerPoint, Excel), Google Drive |

## SKILLS AND QUALIFICATIONS

**Leadership:**

- Managed Society of Women Engineers (SWE) club accounts and Section funds for the fiscal year 2018 – 2019.
- Administered SWE club monthly meetings to present information about volunteer/professional opportunities to active members and a broad audience.

**Communication:**

- Collaborated with SWE President to manage club costs for future SWE officers.
- Reported financial standing of SWE club section to Sacramento State's Business Office and officer board to ensure that money is appropriately distributed for events that promote professionalism and outreach.

## EXPERIENCE

**ASIC Verification Engineering Intern,** Aruba, Hewlett Packard Enterprise Company — May 2019 – August 2019

- Assisted the ASIC development team on next generation products and networking chips.
- Adapted a Graphical User Interface (GUI) tool to create network topologies that will output its corresponding model network files to reduce time consumption of having to hand generate topologies.

**Scholar Mentor**, Square Root Academy, Sacramento, CA — January 2018 – October 2019

- Mentored and assisted Scholars of the Academy by promoting innovative thinking and creativity.
- Instructed weekly class sessions in various Sacramento schools to help expose students (aka Scholars) to the fundamentals of STEM through hands on project based learning experiences.

## PROJECTS

**Capstone Senior Design Project,** Team member, programmer, designer — Fall 2019 – Spring 2020

- Building a multi-sensory device that incorporates visual aid and haptic feedback to enhance an individual's musical experience.
- Programmed in Arduino Uno and Processing Software to elicit synchronization of features.

**Multifunctional Car,** Team member, programmer, designer — Summer 2018

- Built a 4-step motor car consisting of various features that utilizes Arduino IDE and Parallax Propeller Software.
- Designated to use a potentiometer to control music volume, turn on/off a servo, and to print temperature, distance, volume measurements to an LCD Screen.

## AFFILIATIONS

**Philanthropy Chair, Member** — Fall 2018 - Present
Tau Beta Pi Engineering Honors Society, California State University, Sacramento

**Treasurer, Member** — Fall 2018 – Spring 2019
Society of Women Engineers, California State University, Sacramento

# Christian Anaya

## Objective

- Inspired electrical and electronics engineer student seeking and entry-level position to begin my career in a high-level professional environment.

## Education

- Bachelor of Science, Electrical Engineering — Expected Spring 2020
  California State University, Sacramento — GPA 3.0

## Relevant Courses

- Information Theory
- Power System Analysis
- Power Electronics Controlled Drives
- Digital and Wireless Communication
- Network Analysis

## Technical skills

**Software applications:** MATLAB (Simulink), Visual Studios, Microsoft Office (Word, PowerPoint, Excel)
**Hardware test equipment:** Oscilloscope, Digital Voltmeter, Power Source, Digital Multimeter
**Platforms/Environments:** Windows, Mac OS
**Engineering Tools:** Cadence, PSPICE
**Hardware Description Languages:** Verilog, VHDL using FPGA

## Technical Projects

Sight of Touch — August 2019-Present
Senior Design involves haptic feedback and visual aid to utilize different sense with experienced music.

Boe Bot — January 2019 – May 2019
Computer controlled autonomous mobile robot which can find a predetermined destination.

## Professional Work Experience

**SAP CLERK** — JUN2011 - CURRENT

Supported day to day operations of tomato processing facility by monitoring finished good production and managing inventory and shipments using SAP Materials Management module.