Team No. 515: Music Machine

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***Abstract*— Engineering can be complex and difficult to understand, but music is a universal language that can reach all audiences. The music machine is a public relations project with the purpose of attracting and entertaining an audience. The device plays and displays fun elements such as colorful lights, whimsical moving parts, motion triggered actions, and musical instruments which will play and move in time with our song. The various entertaining elements also represent the main branches of engineering. For example, the light towers which look like buildings represent civil engineering, while the lights themselves represent electrical engineering.**

Historic machines were an inspiration for many parts of this project. For example, calliopes were loud machines used by circuses to draw crowds, just like we want our device to draw crowds. To keep the crowd engaged, our machine will play well-known music. Specifically, our machine will play excerpts from the FAMU and FSU alma maters. This machine is also designed to inspire young people to take part in science, technology, engineering, and math career paths. Another source of inspiration for our music machine included music boxes, which have also delighted people for ages. We are using the core of a music box, the music roll, to play notes on an electronic keyboard. Our machine will also have new electric versions of some classic percussion elements, such as drums and cymbals. Marbles and other moving parts will play these instruments while also providing fun visuals. The electronic instruments also keep the option to use the sounds of instruments which are hard to move. All in all, with the variety of music and visuals, our machine aims to engage audiences from all walks of life and showcase the fun side of engineering.

Introduction

The objective of this project is to create a portable device which utilizes musical and visual elements to engage an audience for the purpose of representing the FAMU-FSU College of Engineering to the public. The music machine is intended as a public relations tool to foster community relations, recruit potential funding sources, and inspire future engineers.

The key goals for this project will be to select and use a recognizable. It will also be important to choose instruments that will not mask the chosen song. Since the device will be displayed to the public, it must be robust enough to survive transport between locations. It must also be small enough to fit through standard interior doors and light enough that one person can maneuver it.

Inspiring Devices

Calliope: A loud musical machine combining various instruments that was used to attract people to fairs and carnivals. Originally utilizing train whistles, the volume was meant to be loud and unchangeable in order to attract people from miles in any direction.

Orchestrion: Large machines designed to play instruments autonomously, orchestrions held various instruments which were necessary to play entire symphonies from one box without human interaction aside from starting the machine.

Music Box: A simple mechanical machine involving a music roll and metal tines which would hit indentations on the music roll (normally metal) and reverberate, producing a song.

Wintergatan's Marble Machine: A large mechanical machine that plays music through different materials being hit with marbles in order to make sounds that resemble instruments. The user spins a crank which allows the machine to let the marbles travel to their designated areas depending on what sounds are meant to be played. In order to control which sounds the machine makes, there are levers that can be pulled to activate the type of instrumental sound that is needed for the machine to create. The levers are controlled by the user. The only instrument that is fully played by the user is the guitar that is attached to the machine.

Targets

Every category is broken down into needs which are both specified by the customer and interpreted by the team. Each need is broken down into targets in order to explain what will be measured. The targets that are most important to the customer, as shown below in Table 3, are the number of songs to be played (at least 1), audio volume and range (40-110 dB and 5 m2), corded/battery power source (12V), volume and weight of the objects, and the force required to move the machine. The customer has specified that they would like for the machine to play at least one song and to be used in a variety of settings, making battery power very important. We will use no larger than a 12 V battery to power the entire machine because this is a common affordable battery size.

To ensure this criterion is met, the device will be designed with this limit in mind and tested with a multi-meter. The audio volume and range will be measured using a decibel meter, which will be used at different distances in order to detect the range at which the machine can be heard clearly. In order to detect if the song is recognizable, multiple people will be selected to listen to the machine play while not knowing what song they will be listening to. The power source will be measured using a voltmeter. The volume, weight, and force required to move the machine are also important and must be such that the device is portable and can be brought to different locations. We have concluded that our volume will be no larger than 2.5 m3 and the weight will be no more than 22 kg. Some of this volume is based on the smallest dimensions of a standard interior door, 1.98m by 0.81m. (DoorMore, n.d.) This is simple to test, as it only requires a measuring tape or a door. The weight is small enough that it can be measured using a standard bathroom scale. The force necessary to start moving the machine should also be less than 220 N. (Canadian Centre for Occupational Health and Safety, n.d.) This force was determined from the Canadian Center for Occupation Health and Safety's recommendations for hand pushed carts. To measure the force required, we will use a spring scale.

The units on the right side of the table shows exactly how each target will be physically measured. Each need will be measured by the respective unit of their targets, i.e. audio will be measured using units compatible with audio volume from either an electronic device or a physical component which creates a sound, while the machine's power source will be measured using voltage. Some of the targets and their metrics address multiple functions not stated here; for example, the power target will also fulfill the electronic lights display and, as a result, will aid in displaying visual elements.

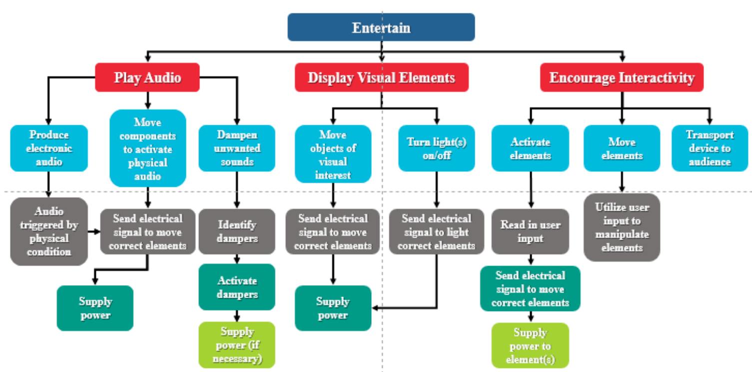
The mission-critical targets include the audible production of one song, the power supplying the entire machine, and the portability of the machine, including dimensions and weight, so that it may be used as a successful public relations project. To validate the design, the machine will be tested in multiple environments which will vary in terms of power options, acoustics, audience, and ease of access. This will generate an understanding of possible design improvements as well as ultimately deciding the level of success of the music machine. Resources needed to test the machine include locations differing in acoustics and ease of access, audiences of varying backgrounds, and the aforementioned testing mechanisms for portability and power.

Critical Targets and Metrics

Category	Need	Target	Number
Audio	Move physical components to produce audio	Audible volume	40-110 dB (Virosteak, n.d.)
		Audible range	5m^2 (Stierwalt, 2017)
	Recognizable song	Number of songs	1 song
Power source	Supply power	Corded/ battery	12 V
Portability	Size	Volume	2.5 m^3
		Weight	22 kg
		Max length/ width	1.98mX 0.61m
	Ease to move	Force required to start motion	220 N (Canadian Centre for Occupational Health and Safety, n.d.)

Functional Decomposition

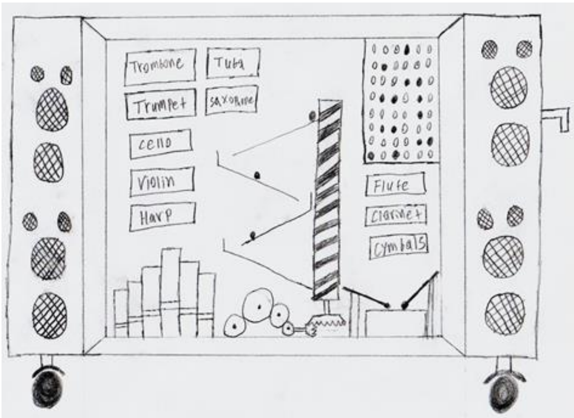
The functional decomposition represents the processes necessary for the music machine. Arrows show the flow moving between functions and sub functions and progresses through the outcomes of the music machine. The three main functions of the music machine are playing audio, displaying visual elements, and encouraging interactivity. Using the functional relation matrix, the sub-functions were compared to each main function to determine which sub-functions overlapped. From this, we determined that providing power and signal is an element intrinsic to all of the main functions, so it will be a key focus in our later designs. Furthermore, interactivity often relates to both audio and visual elements. Though the exact degree will vary based on our design choices, it is important that the interactivity be considered at every phase.



Concept Generation and Selection

Pictured below are the top three designs chosen from a list of nine generated concepts. Following the design description is a detailed explanation of how these designs were chosen to be the best, in terms of the defined targets, and how the team used Pugh Charts and the Analytical Hierarchy Process to determine the best design from those generated.

Concept 6.



As shown above, concept 6 is an easily transportable music device. The machine has four pneumatic casters. Two of the casters are rigid while the remaining two casters are swivel casters to allow the device to be turned. The pneumatic tires will ensure optimum transportability because of the wide range of surfaces these tires can handle. This device features a soundproof enclosure which dampens all the noise produced inside the box. The basic concept behind this device is that the device could feature very complex instruments that would be difficult to produce the correct notes autonomously. The device would give the appearance of playing these instruments but the sounds being produced would not escape the box. Instead, there would be hidden speakers on each side of the device that would play the sounds electronically. This device could feature many different instruments such as a trombone, trumpet, tuba, saxophone, cello, violin, harp, flute, clarinet, cymbals, pipe organ, drum, etc.. In the middle of the device there is a series of ramps that a marble will fall down then feed back into the marble elevator that will carry the marble back to the top to repeat the process. The marble elevator is driven by a bevel gear that is driven by the gear set connected to a motor. On the top right side of the machine, there will also be a panel of LED lights that change based on the notes that are played by the electronic accompaniment, in order to help intrigue the audience.

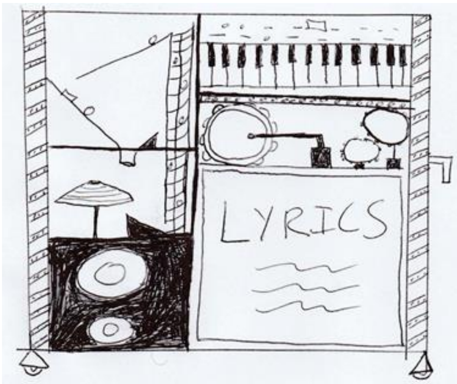
Concept 8.

Entitled "Engineering the Music", this design features various departments of the FAMU-FSU College of Engineering in many of the musical elements, both electronic and mechanical components. The audience is encouraged to interact with the machine by pressing the button that says "Press Me", which will start a sequence of machines and electronic signals that play the music. A microprocessor will use a pulley to pull the first ball of Newton's Cradle, while simultaneously pulling open a small lever that kept marbles from rolling down a curved marble ramp. The ramp will have LEDs and programmed sound effects that will be triggered when the marbles pass over the sensors. Once at the bottom, the marbles are loaded into a marble elevator which will pass the marbles back onto the marble slide, (the lever will be closed by now to keep the marbles from continuously rolling down the marble slide).

Additionally, the marbles will be carried up to the top of the elevator where the remainder will be deposited onto another slide. This one leads out to two paths, one where the marbles will fall onto cymbals and another where the marbles will fall onto a drum. The lever controlling whether or not the marbles will be let onto a path, and which path they will travel, can be pre-programmed to match the song on the music roll. In the bottom right corner, various mallets shaped like tools will be programmed by a microprocessor or the music roll to strike the appropriate key on the keyboard or xylophone when appropriate. Just behind this contraption is a building-like structure made of LEDs which can also be programmed to light up in patterns, to match the music, or to create designs that look like falling shapes or patterns. There is a light in the top corner of the machine which provides an internal spotlight to draw audiences and emphasize the movement and design of the machine.

Various components were designed to feature or exhibit the main characteristics of the various departments of engineering. Environmental engineering can be seen in the marble elevator, designed to look like a tree. Mechanical engineering is featured in the mallets shaped as various tools as well as the gears that will be needed throughout the design. Civil and industrial departments are recognized in the LED cubes which represent buildings or systems. Chemical and biomedical engineering is depicted in the carefully crafted Newton's Cradle, which features various molecules as the hanging marbles. "Engineering the Music" is designed to draw attention to the FAMU-FSU College of Engineering and all of its departments in a way that people from all backgrounds can relate to and appreciate.

Concept 9.



Marble elevator leads marbles onto a sensor pad which allows the speaker to play a certain tune. After sensor pad the marble is dropped onto an electronic drum pad that can be programmed to play anything when hit. The marbles are then brought back to the top by the marble elevator. The speaker below is used to play the sounds made by the marble hitting the sensor and electric drum pad as well as any other tunes of which is decided it should play.

The upper left consists of an electric keyboard with strip of lights going across the bottom. The keyboard can also be configured to play any song that is prerecorded on it. Underneath the piano are more drum pads that are hit by a drum stick that is on a motor that rotates quickly and with enough force to hit the drum pads and create a sound. The drum pads on the right are on a motor that makes them go either up or down so the drum stick can hit the correct one for whatever song is being played. Underneath the drum pads is a screen with the lyrics of whatever song is playing so that the crowd may sing along to the song that is being played by the machine. On each corner of the machine are strips of lights going up the columns that shine to the beat of the music for a better visual effect.

This machine combines physical components with electrical components as well as interactivity with whomever may be using it. Because these components are played electronically, they can be programmed to play many different songs. Since this involves electric drum pads, that means there is still a physical aspect to the machine because the drum pads must be hit in order to work. Also, there is a lever on the side of the machine which can be used to charge the battery. There will be a plug as well in order to connect the battery directly to an outlet.

Following the concept generation phase there was a total of nine developed concepts. These nine concepts needed to be cut down to a single concept. In order to do this without introducing bias from each of the group members, and to ensure that the customer needs and engineering characteristics were taken into consideration, several concept generation tools were used. Through the concept selection process, a house of quality, Pugh charts, and an analytical hierarchy process (AHP) were employed to narrow down the concepts.

Pugh Charts

The purpose of a Pugh chart is to determine which concept of the final design will be rated the most successful in achieving the key purposes of the project. This is done by comparing each design to a datum. Initially, a similar device which is already out on the market is chosen. For our purpose, we used a calliope for the first comparison, since it was a musical device used to draw crowds and create a spectacle, as shown in table 5. After the first iteration we wanted to eliminate 1/3 of our concepts. So concepts 3, 5, and 7 were eliminated since they had the fewest positives and, in the case of concepts 5 and 7, more negatives than the other designs. We then proceeded with concept 6 as the datum since it had the same number of positives, but it had one more negative than the remaining concepts.

Pugh Chart Iteration One

		Concepts								
Selection Criteria	Calliope	1	2	3	4	5	6	7	8	9
Number of songs	Datum	S	S	S	S	S	+	S	S	S
Audible Volume		-	-	+	+	-	-	-	+	+
Volume		+	+	+	+	+	+	+	+	+
Max Power		+	+	+	+	+	+	+	+	+
Number of Electronic Instruments		+	+	+	+	+	+	+	+	+
Weight		+	+	+	-	+	+	+	+	+
Number of Moving Elements		+	+	-	+	-	+	+	-	+
Customizability of Lights		+	+	+	+	-	-	-	+	+
Cost		+	+	+	+	+	+	+	+	-
# of Plus		7	7	6	7	5	7	6	7	7
# of Minus		1	1	1	1	3	2	2	1	1

After the second iteration, (not pictured here), concept 9 was somewhat tied with concept 8, with 4 areas where it was better, but 4 areas where it was worse. The other two concepts were worse than concept 8 by a large margin, especially concept 1, which only had 1 area where it surpassed concept 8. At the same time concept 6 performed worse than concept 8 in five areas, which was the most out of any of the remaining concepts. Because of this after the final iteration of the Pugh chart it was decided that concepts 8 and 9 were the best two concepts when compared to the original nine. The three best concepts from this Pugh chart were taken on to the Analytical Hierarchy Process, described in the following section.

Pugh Chart Iteration Three

		Concepts		
Selection Criteria	8	1	6	9
Number of songs	Datum	-	+	+
Audible Volume		S	+	+
Volume		-	-	+
Max Power		-	-	-
Number of Electronic Instruments		+	-	+
Weight		-	-	-
Number of Moving Elements		S	-	-
Customizability of Lights		S	S	-
# of Plus		1	2	4
# of Minus		4	5	4

Analytical Hierarchy Process (AHP)

An important part of the Analytic Hierarchy Process is ensuring that ratings are objective and unbiased. This method allows any bias that may occur unintentionally or on purpose to be observed through calculations, allowing the members of the project to decide if the ratings are accurate or leaning in favor of one specific idea through favoritism. The first comparison required is comparing the key engineering characteristics to each other to determine their final weights.

Normalized criteria comparison matrix

Normalized Criteria Comparison Matrix [NormC]				
	Concept 6	Concept 8	Concept 9	Concept Weights {W}
Concept 6	0.111	0.130	0.077	0.106
Concept 8	0.556	0.652	0.692	0.633
Concept 9	0.333	0.217	0.231	0.260
Sum	1.000	1.000	1.000	1.000

Through comparing these, it was determined that cost was the most important, and therefore most heavily weighted, criteria to consider. The number of electronic instruments was calculated as the next most important criteria, followed by the number of moving elements, the number of songs, and the weight, as can be seen in Table 10 under the column marked Criteria Weights. The consistency ratio for this matrix was 0.076, the math for which can be seen in the appendix, so this ranking is indeed mathematically fair. It is interesting to note that these rankings do not necessarily correspond with those established by the House of Quality above.

Once the criteria were weighted, it was then necessary to evaluate each of the concepts which made it through the Pugh matrices in accordance with the weighted criteria. This process can be exemplified by the table below, for the "cost" characteristic.

Final Analytical Hierarchy Process Chart

Concept 6	0.179
Concept 8	0.476
Concept 9	0.345

Final Rating Matrix			
	Concept 6	Concept 8	Concept 9
Cost	0.106	0.633	0.260
Number of	0.467	0.067	0.467
Number of	0.140	0.286	0.574
Weight	0.143	0.714	0.143
Number of	0.211	0.686	0.102

Criteria Weights {W}
0.354
0.119
0.299
0.060
0.167

As shown in Table 10, the top block depicts the various final calculations led to a weighted total which determined that Concept 8 was the "best" design in terms of achieving the best in the most important criteria. Concept 9 was a close second in being successful in achieving the criteria, and Concept 6 was last. The second table shows the normalized rankings for each of the concepts listed and the criteria the rankings pertain to. Basically, the sum of each row will be one in order to ensure each concept is ranked on one scale; this makes comparing them over different criteria much easier. The last column of the second table gives the final weights of each criteria.

Final Decision

Using the pairwise comparison, house of quality, Pugh charts, and the analytical hierarchy process (AHP) it was determined that Concept 8 was the best concept out of the eight other concepts generated. As shown in the Pugh Charts Concept 8 performed better than the Calliope and all other eight concepts. Through the use of the analytical hierarchy process it was clear that the best concept for this project was Concept 8. Concept 8 outperformed Concept 6 and Concept 9 when compared to the criterion that was determined to have the most significance.

Manufacturing and Testing

Cart

A cart was constructed to house all the subsystems and their components that make up the overall system. It was made out of cypress and oak wood. The dimensions allow for it to fit through a standard interior door to in order for the music machine to be portable. The cart was also placed on four two-inch swivel casters to allow the device to be moved easily. After testing the portability, it was determined that the two-inch casters should be replaced with larger casters to ensure the cart does not bottom out on uneven surfaces. The resulting cart is a 25.5" x 61.5" x 64" box with storage space under the display.

Music Wheel

A 26.95” PVC pipe with a 9” outer diameter is used as a music wheel, with holes drilled and wooden dowels used to represent the notes needed to play the music composition on the keyboard. The holes were spaced horizontally according to the spacing on the keys of the keyboard, and the vertical spacing was determined from how fast the shortest notes in the composition needed to be in order for the music to still be recognizable, or accurate. The equation used to determine the final spacing is shown below. Once the holes were drilled and the dowels placed, the music wheel was mounted and set next to the mounted keyboard while the motor was used to test the spacing and final sound checks were conducted to ensure peg spacing was adequate to recreate the desired sound.

Mallets

The mallets are constructed from flagpoles with ball ends. The ends are covered with Model Magic in shapes of either hammers to represent mechanical engineering, or molecules to represent bio and chemical engineering. The molded ends serve a dual purpose: they dampen the loud impact of the mallets on the keyboard and serve as a visual connection to the various branches of engineering that the device is supposed to represent. The mallets are attached to the shaft upon which they rotate via 3D printed attachments in colors that correspond to the piano keys they touch. These were tested in conjunction with the music wheel spacing described above to ensure the mallets successfully fell in time to be hit by the next peg of the music roll.

Marble Subsystem

Pieces were designed and added to the marble elevator (described below) in order to stabilize the subsystems connecting to the marble elevator, mainly the marble pathways and the marble tubes that feed back into the bottom of the marble elevator.

Elevator

The elevator subsystem is 3D printed from PLA filament. The rotating cam shaft at the bottom of the elevator is powered by a small DC motor, which is controlled by the Arduino Uno and Raspberry Pi via an H-bridge motor driver. This system also serves as a support for the wire tree. To test this system, several 3/8th inch metal balls were placed in the hopper and the motor was turned on via battery power. After the first marble elevator prototype was printed and assembled, various adjustments were noted and the design was revised; some adjustments to the original design includes making the elevator itself longer to compliment the tree and sanding down specific parts that were printed roughly in order to improve the friction during movements. The next version was the final version; the system successfully brought marbles to the top as long as the branch at the top was not applying undue pressure.

Ramp and Gate

The ramp is made of clear plastic, superglued together to create a three-branch system which can distribute marbles to the two cymbals and the return funnel. The gate is actuated with a small servo, controlled by the Arduino Uno and Raspberry Pi. During testing, the first version of the gate was clumsy and undependable, it would get caught on the tree and the marble paths. After redesigning it a new version of the gate was printed and connected to the servo. This was programmed to rotate the opening in the gate to uncover one path at a given time, and after running the program with predefined ranges the new version of the gate was deemed to be a success.

Funnel and Return

The funnel, disguised as a house to represent civil engineering, is 3D printed from PLA filament. The return mechanism is also 3D printed, and feeds into a clear tube which fits into another 3D printed part, feeding into the hopper of the marble elevator. This will provide a continuous stream of input marbles to the marble elevator and ensure the machine has access to ammunition when a cymbal sound is needed. The funnel successfully returned all the marbles funneled through it even when bounced off the cymbals.

$$Space\ per\ note = \frac{\pi * External\ diameter}{Number\ of\ Notes}$$

Audio Synchronization

The Raspberry Pi, using the Sonic Pi software, will be the core of the audio synchronization system. The Pi will coordinate with the Arduino Uno to control the motor for the music wheel, motor for the marble elevator, and gate for the marble ramp. Sonic Pi will allow the keyboard to sound more like a traditional piano. When the Arduino allows a marble to pass through the gate for the electronic symbol, Sonic Pi will send a signal to the keyboard in order to make the sound that a symbol would make.

Conclusion

The final product is a 25.5” x 61.5” x 64” music machine which plays a compilation of the FAMU and FSU alma maters while featuring various departments of engineering in an engaging and entertaining show. Two LED light towers represent electrical and computer engineering, a tall copper wire tree stands for environmental engineering, the marble elevator represents the factories which industrial engineers often improve, the house funnel showcases civil engineering, and the hammer and molecule shaped mallets express mechanical and bio/environmental engineering, respectively. The final product represents both universities affiliated with the College of Engineering through their alma maters, while calling attention to the various disciplines and skills of engineering students. The result of this project is to raise awareness of the College of Engineering, and to potentially attract more students and support in an engaging, commemorative show which audiences of all backgrounds can appreciate.

Acknowledgements

The members of Team 515 would like to personally thank Dean Murray Gibson & Mrs. Faye Gibson for allowing us to take part in this project. We would also like to thank our instructors at the C.O.E. for providing the guidance and instruction to be where we are today.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The manufacturing and testing of this device was funded by Dean Murray Gibson and Mrs. Faye Gibson at the FAMU-FSU College of Engineering.

Peer review

None applicable at the time of this publishing.

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