ECE PROMOTIONAL DISPLAY TECHNOLOGY

A Design Project Report

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Submitted by

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Abstract

Master of Engineering Program

School of Electrical and Computer Engineering

Cornell University

Design Project Report

Project Title: ECE Promotional Display Technology

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Abstract:

It can be difficult presenting the wide array of topics students learn about while studying electrical and computer engineering because of the extensive background knowledge needed to discuss most of these topics. Often when presenting to prospective students, there is only a short time to try to convey to them what kind of experience they can expect if they study electrical and computer engineering at Cornell, so a detailed technical discussion is often impossible. Ideally the work of the ECE department could be conveyed through physical demos that are attractive, interactive, and conceptually simple enough to understand at a high-level in a short time while still having enough technical depth to invite further discussion with interested students.

To address this need, our team has created an interactive promotional display project that can be easily used by the ECE department at a variety of events to spark interest in the field. The display is a fully realized, robust, and interactive project incorporating multiple aspects of electrical and computer engineering, similar to the type of projects many students complete in their classes but manufactured to a higher standard. We have created an autonomous mixing robot for creating sand-art as specified by the user. It has a custom manufactured wooden body as well as custom electronics that incorporate the popular Raspberry Pi single-board computer, which will be familiar to many prospective students that are already interested in hobbyist electronics. Due to our relative inexperience with mechanical synthesis we experienced difficulties designing and manufacturing the body and mechanical components of the robot, but we addressed this by creating a simpler scale model of the robot first to refine our mechanical

designs. We have also created custom printed circuit boards that can interact with the Raspberry Pi and a variety of sensors to control the robot.

Users will be able to enter their desired colors and order of sand through a touch-screen interface, and will then be able to watch as the mixer autonomously rotates to various containers of sand and dispenses them as necessary. Users can take the sand-art container with them as a small, low-cost souvenir. Importantly, the mixer must be extremely robust so that it will still be able to function reliably after transport and handling, and also quick and easy to set up. This project will ultimately help engage prospective students and others with the work of the ECE department at a variety of public events, improving understanding of the field and hopefully generating greater interest in electrical and computing engineering in future engineering students.

Executive Summary

Though we faced a variety of problems both electrical and mechanical, our team was ultimately successful in creating a robust, engaging demonstration project that produces sand art for users. Users can enter specifications for a piece of sand-art using a simple touch-screen interface, watch as it is autonomously created, and then take their newly created sand-art home with them as a souvenir. Users can also easily see inside the project through several access panels so they can gain a better understanding of its construction, which should help engage more technically knowledgeable users. Equally importantly, the faculty setting up and running the demo do not need any specialized knowledge or tools. The project can be transported in one piece, and simply needs to be filled with sand and plugged into a standard outlet to run.

Creating a project that was robust enough to survive extensive transport and user interaction proved to be one of the greatest challenges, as we had little previous experience with mechanical design and manufacturing. To address this issue, we designed a custom wooden body for the project which is secured using only angle brackets and screws. All mechanical and electrical components were firmly secured to the body, meaning that transport and handling of the device will not affect the functionality of the design. The components of the body can be easily manufactured from our existing design using a laser-cutter, so it is also easy to create any needed replacement parts for the project if there is any damage.

Another issue that commonly plagues student projects is the use of breadboards or hand-soldered protoboards. While easy to use when prototyping, circuits built using breadboards and protoboards are not particularly robust and can be easily broken if not handled very carefully. To eliminate this problem we designed custom circuit boards for all of the electrical components used in our design. Even with all of the electrical components secured by the circuit boards, the wiring between components still proved to be a possible failure point. We needed to ensure that wiring would not be disturbed being transport and prevent the possibility of users causing damage by connecting components improperly, and so we created wire harnesses with locking, polarized connectors to securely connect all components.

Creating a dispensing mechanism that could handle repeatedly dispensing sand accurately without jamming also proved to be a major challenge. Initial designs relied on rotating a cap between an open and closed position to start and stop dispensing sand, but sand would quickly jam the mechanism after dispensing only a few times. We ultimately moved to using a scoop and funnel with each dispenser that could be raised and lowered to control dispensing. This successfully prevented jams and can accurately place sand even in small containers.

Users also had to find the demonstration easy to use and engaging. We used a large touch-screen as our user interface because of the general familiarity with touch screen interfaces. The interface is simple, with only 2 buttons and a series of colorful sliders, allowing non-technical users to quickly grasp it. The use of a turntable to move the container to each dispenser adds an element of motion that helps to capture attention. Users can also take their sand art creation with them after the demonstration, which gives them a greater investment in the demonstration. All of these elements combined make this an especially engaging demonstration that will hopefully generate significant interest and enthusiasm among prospective students.

Introduction

Motivation

Cornell ECE faculty often go to events to discuss the ECE field with prospective students and the general public who may have limited knowledge of the field of ECE. In order to convey the diversity of the ECE discipline and engage with these prospective students ECE faculty like to bring student projects to these events and use them for demonstrations. These projects incorporate many different ECE specialties and can interest prospective students in further exploring the field of ECE. Unfortunately, these projects, while interesting, are not designed for long term use due to time and resource constraints imposed on the students creating them.

Our goal with our MEng project was to update an existing student project and make it more robust and maintainable so that faculty could bring our project to various events and run it without failure or in the case of failure, faculty could quickly and easily fix the project. We also aimed for the project to be aesthetically pleasing and interactive so as to pique students' interest and allow the ECE faculty presenting the project to engage them. The final goal when creating our project was to make sure it was easy to transport and set up as faculty will need to be able to carry it to the various events they attend and will need to be able to quickly prepare the project when they arrive.

The student project we chose to update was Zhengning Han, and Yannan Wu's cooking robot which had the user place a bowl on a turntable and specify a combination of spices. The robot would then move the bowl to dispensers and dispense the chosen spices. Figure 1 shows the cooking robot [1].

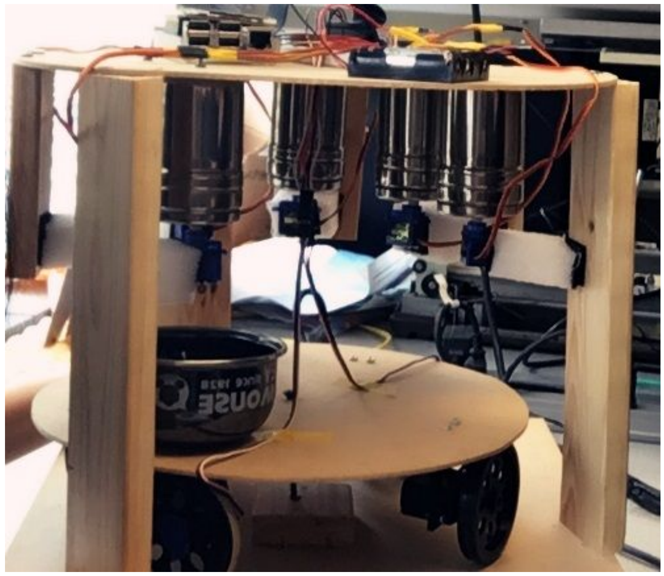


Figure 1: Cooking Robot

We decided to update this project as it had been popular at demonstrations given by ECE faculty. The design was also interesting to watch run as it had many moving parts. Additionally, the design offered an interactive component, allowing prospective students to choose what was dispensed, and with our updates, also allowed students to bring home what was dispensed as a souvenir.

Sand Art Novelty Dispenser (SAND)

The device we created to update the cooking robot is known as the Sand Art Novelty Dispenser (SAND). The SAND autonomously creates colorful sand art based on user specifications. An example of the type of sand art it creates can be seen in Figure 2.

Figure 2: Example Sand Art Created by SAND

The SAND has dispensers with five different colors of sand, and users can select which colors they want in their sand art, the ordering of the colors, and the amount of each color. The colors of sand available can be changed easily, but for all of our development we have used green, blue, red, yellow, and purple. Users create this specification using a simple touch-screen interface on the front of the SAND. When they are satisfied with their design, they can start the dispensing process. A small container for the sand is moved to each of the 5 dispensing locations in the appropriate order, and the specified amount of that color of sand is added to the container. After all of the specified colors have been added, the container returns to the front of the SAND, where it can be taken by the user. Users are then free to keep their sand art as a souvenir. The SAND can be seen in Figure 3 below.

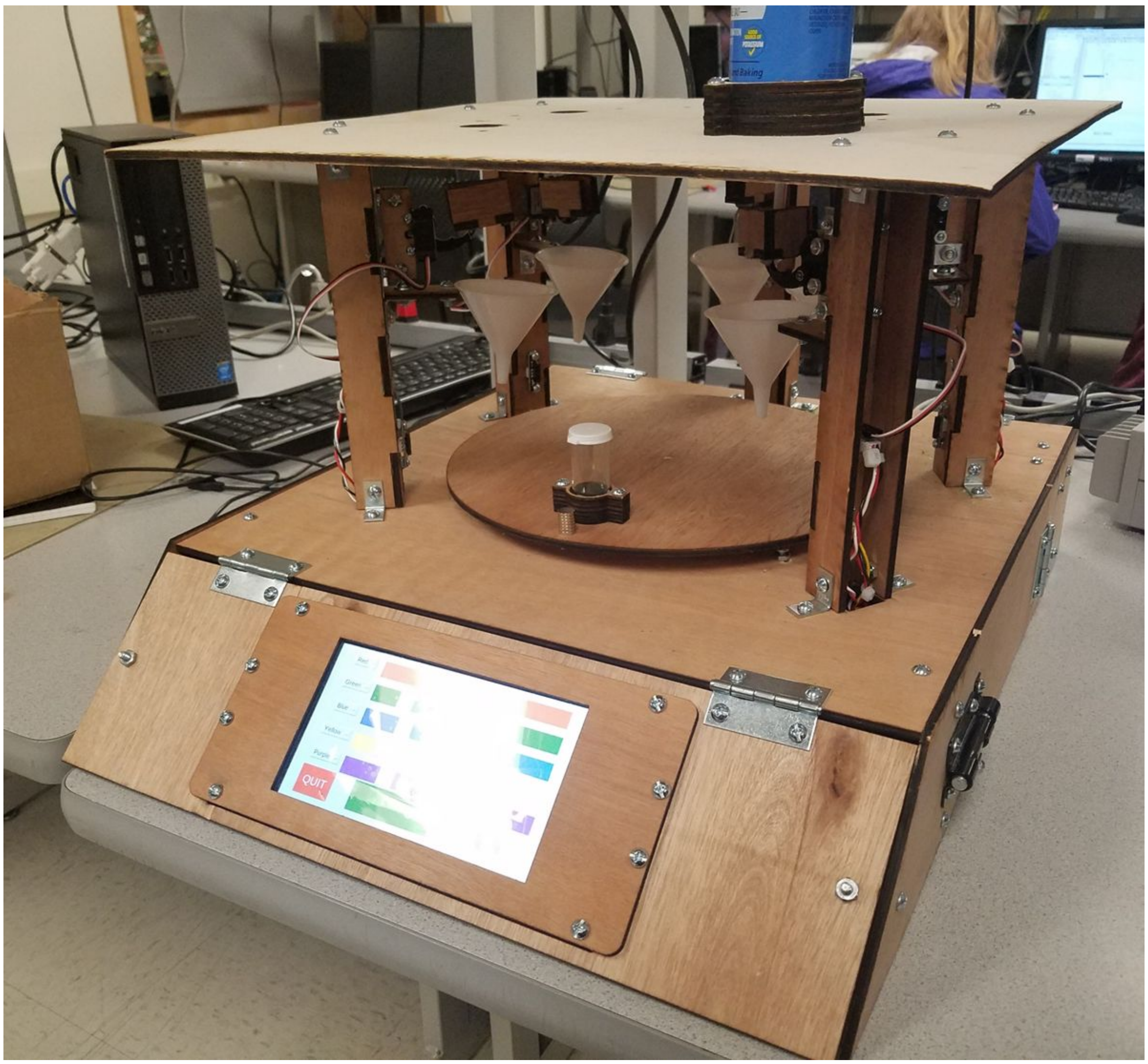


Figure 3: Sand Art Novelty Dispenser

This design was chosen because we believe both technical and non-technical users will find it engaging. The simple touch-screen interface should be familiar to most users due to the prevalence of touch screens in consumer electronics, so all types of users can creates sand art with ease. The entire dispensing process can be seen by users as they watch the turntable move and the sand flow from the dispensers, so it is easy for them to comprehend the high-level operation of the device without any specialized knowledge. For more technical users, access panels on the back, front, and sides allow them to take a closer look at the electrical components so that they can have a fuller concept of how the device operates. The combination of mechanical, electrical, and software components means that the demonstration will appeal to a wider audience and demonstrate the type of cross-disciplinary work commonly performed by electrical and computer engineers. The appeal of creating and keeping your own souvenir should also help to attract more attention to the demonstration. For all of these reasons, we decided that the SAND would be an ideal choice for a demonstration project that encourages prospective students to consider becoming electrical and computer engineers at Cornell.

Design

Mechanical Design and Synthesis

The mechanical design of the SAND was done by using Fusion 360 to create a 3D model of the frame. The model was used to laser cut pieces that could be used to build the design. Most of the design is connected with screws and nuts in order to allow for the design to be disassembled and reassembled easily so parts can be replaced. Other parts of the design were bought and used with little modification to simplify buying and inserting replacements if the parts break.

Scale Model

Before creating the final version of our design we began by creating a half sized scale model. We did this in order to test how different mechanisms would work. Implementing the small scale version used less wood than implementing the full version allowing us to save on resource usage as our design went through different iterations The small scale model was set up to dispense three different sand colors and had the screen and Raspberry Pi outside of the box with wire running to the different electronics. We would replace parts on the scale model as we refined our design and once we had the dispensing mechanism working satisfactorily we moved on to creating the full scale model and made the final refinements to it. Figure 4 shows a render of the scale model.

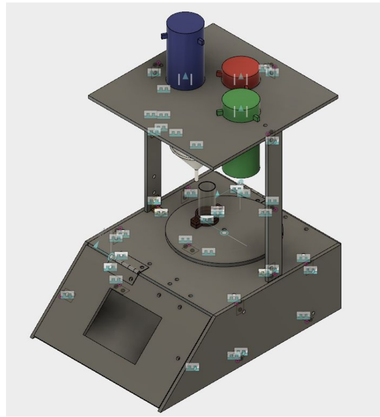


Figure 4: Scale Model of the SAND

We were able to test several dispenser mechanisms on the scale model until we found one that dispensed without jamming or spilling sand. We were also able to find out about mistakes on our model where parts appeared to fit correctly on the model, but did not on the physical version. We were also able to ensure that some of our initial ideas worked correctly before scaling up. We were able to make sure that our method of connecting parts together was secure enough and our maintenance panels could be opened without issues.

Frame

The frame of the SAND was designed as a 3D model and was then laser cut from pieces of plywood and assembled. A render of this model can be seen in Figure 5.

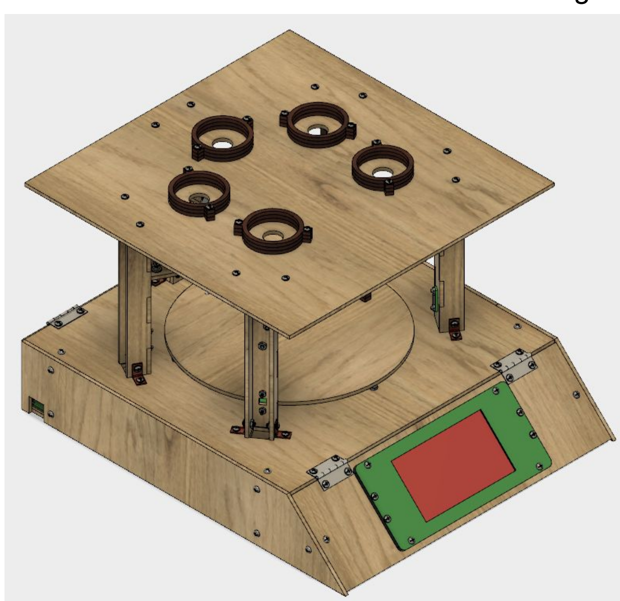


Figure 5: 3D Model of the SAND

The design is made up of seven plates. The bottom plate, two side plates, the back plate, the slope plate, and the turntable plate make up the box that houses most of the design's electronics. The bottom plate has the electronics attached to it to prevent them from sliding around inside. The slope plate holds the screen used for user interactions. One side plate contains a hole to allow running a power wire to the device and the other contains a latchable door that can be used to access the inside of the device for maintenance. The backplate can also be opened to allow for further access. The turntable plate holds the turntable, it's servo and the columns holding the dispensers. The top plate holds the shakers holding the sand. The design contains five columns which hold up the top plate and are used for mounting components for the dispensing mechanism. Details of how the design is assembled can be found in the instructions section of this paper.

The laser cut pieces of the design are attached together using angle brackets, hinges, screws, and nuts. We chose to do this instead of screwing directly into the wood or gluing as it allows for parts to be easily unscrewed and taken off if they are damaged. Designing in this manner made the system easy to maintain. If a single part of the system was damaged it could be unscrewed and taken off the system, a new part could be laser cut, and the new part could be screwed on. This meant that one failure in the design only required replacing a single part, and the rest of the design could be left intact.

Several parts of the frame such as the columns did require some gluing, but these parts were designed to interlock together to give a larger surface area and make gluing easier. Figure 6 shows how the column pieces of the design interconnect for easy assembly.

Figure 6: Column interconnection

Turntable

The turntable is laser cut out of plywood and is used to move a vial to the five dispensers. The turntable is attached to a servo which is screwed onto the turntable plate. The turntable also has a cup holder attached that the vial is placed in. Foam is glued into the cup holder in order to hold the vial securely while still allowing it to easily be removed.

Magnets are attached to the top of the turntable next to the cup holder and are used to trigger reed switches as the vial is moved so the software can determine vial's location. Magnets are also attached to the bottom of the turntable under the other magnets and are used to connect to anchor screws in the turntable plate. These anchor screws are positioned under dispensers so that when the magnet attaches to a screw the vial will be lined up with the corresponding dispenser. Figure 7 shows how the cupholder and magnets are attached to the turntable.

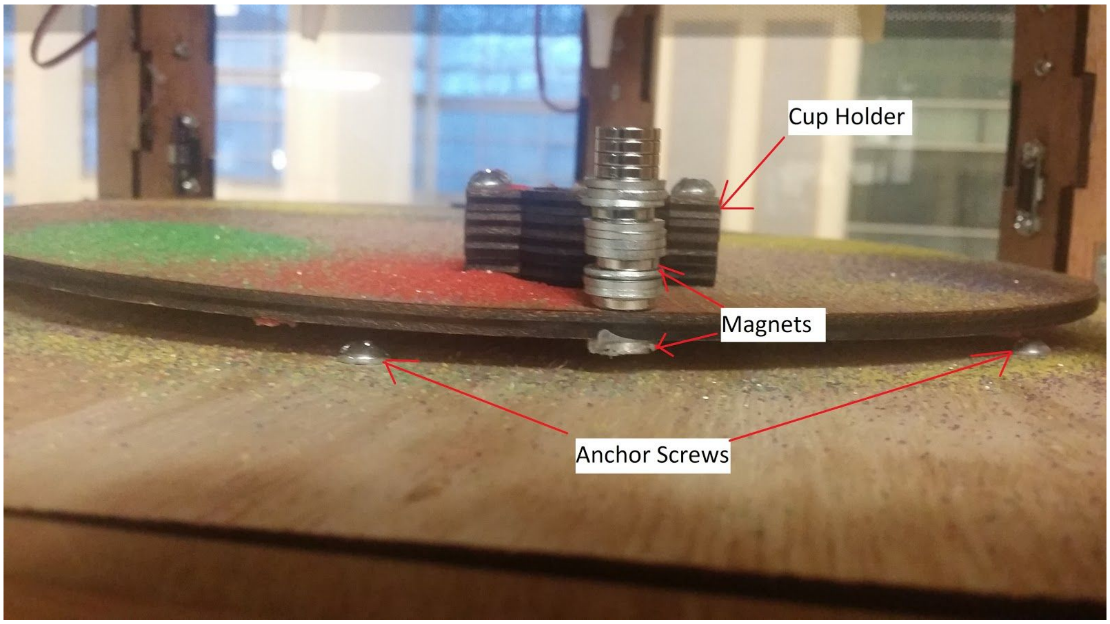


Figure 7: Turntable Attachments

Dispensing Mechanism

The dispensing mechanism's purpose is to drop sand into the vial from above in amounts specified by the user. The dispenser was required to cleanly drop the sand without spillage and needed to prevent sand from leaking even without power. We created several different iterations of the dispensing mechanism before arriving at the final version. The first versions of the mechanism used salt shakers to hold the sand and rotated the cap with a servo to open a hole to allow sand to flow out. Figure 8 shows the salt shaker cap.

Figure 8: Salt Shaker Cap

This design worked well at first but after several dispensing cycles sand would get caught under the cap and jam it in place preventing the servo from being able to rotate the cap open.

We avoided this jamming in the next iteration by drilling a hole in the bottom of the shaker and gluing a straw to the hole. We then used a servo to squeeze the straw closed to prevent sand from dispensing and open the straw to allow sand to flow. This mechanism prevented jamming, but allowed sand to leak out when the servo lost power as it would no longer hold the straw firmly closed.

The final version of the dispenser mechanism used the same straw and shaker setup but instead had the servo rotate a scoop up to cover the hole at the bottom of the straw or rotate the scoop down to open the hole and allow sand to flow out. The shakers holding the sand rested on top of the top plate inside holders that kept them in place. This helped aim the straws into the scoops. The holders also contained a small amount of foam that helped hold the shaker tightly in place while still allowing it to easily be removed. Figure 9 shows the final version of the dispensing mechanism.

Figure 9: Dispensing Mechanism from two angles

The initial version of the design used a sauce cup as the container for holding the sand as they are cheap, large enough to hold a few layers of sand, and can be capped. Later in the design cycle we switched to using small vials to hold the sand instead. The vials were made of a stronger plastic and had a tighter cap which reduced the risk of spilling sand after removal from the SAND. The vials were also taller and thinner so they required less sand per layer and could allow for larger layers of colors which made the resulting sand art more aesthetically pleasing. The vials had a smaller opening than the sauce containers so we used funnels to direct the sand into the smaller opening. The funnels also helped prevent spillage as they gave the dispenser scoop a large area to pour into.

The scoops were laser cut and glued together with interlocking pieces for easier gluing. We purchased a claw attachment for the servos from Sparkfun and glued the edge of the claw to the servo to allow it to rotate the scoop up and down [2]. When rotated up the scoop would block the flow of sand out of the straw and when rotated down the scoop would allow sand to flow into the funnel below which would direct the sand into the vial. Figure 10 shows the full dispensing mechanism.

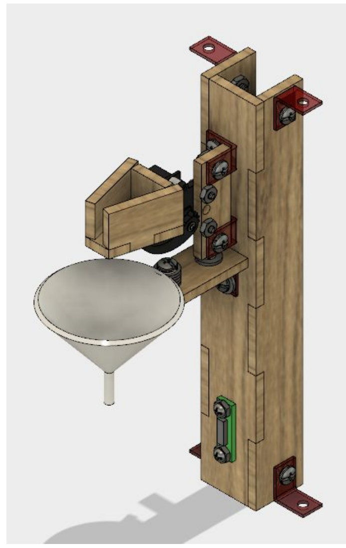


Figure 10: Dispenser Mechanism

Maintenance

When designing the mechanical parts of the SAND we tried to ensure maintenance would be easy. We ensured operators would have easy access to the inside of the SAND by allowing multiple panels to open and give access. The side panel had a latched door and the back and slope plate could be unscrewed to allow them to open as well. This access to the inside made running wires and unscrewing nuts simple in case parts needed to be added or removed, and prevented the need for taking the entire design apart to do so. We also created files that can be used to quickly laser cut new part if needed. These new parts can be swapped in without having to take the device completely apart. The salt shakers used for holding sand sit inside holders attached to the top plate and are held in securely with foam glued inside the holders. Figure 11 shows the shaker holders.

Figure 11: Shaker Holder

This setup allows for shakers to be removed during transport making the system easier to carry and preventing spills. The shakers still have the caps described earlier which allowed them to be open from the top. The caps can be closed to prevent spill or opened for filling. To fill the cap is rotated open and a funnel is placed inside. The shaker can then be refilled by pouring more sand into the funnel. Figure 12 shows the refilling mechanism.

Figure 12: Refill Mechanism

Electrical Design

Electrical Components Overview

There are five main electrical components in the SAND.

- The Raspberry Pi and Expansion Board handle the GUI, read the reed switches, and control all of the servos.
- The power distribution board takes in power from a power supply, provides overcurrent protection, regulates the voltage as needed, and distributes power to all of the other components.
- The reed carriers have reed switches which track the location of the turntable. The servo adapters connect the Raspberry Pi Expansion board to the servos.
- The screen displays the GUI and allows users to interact with the GUI by touching the display.

Each of the components is described in greater detail below. A block diagram showing the interconnections between these components can be seen in Figure 13 below.

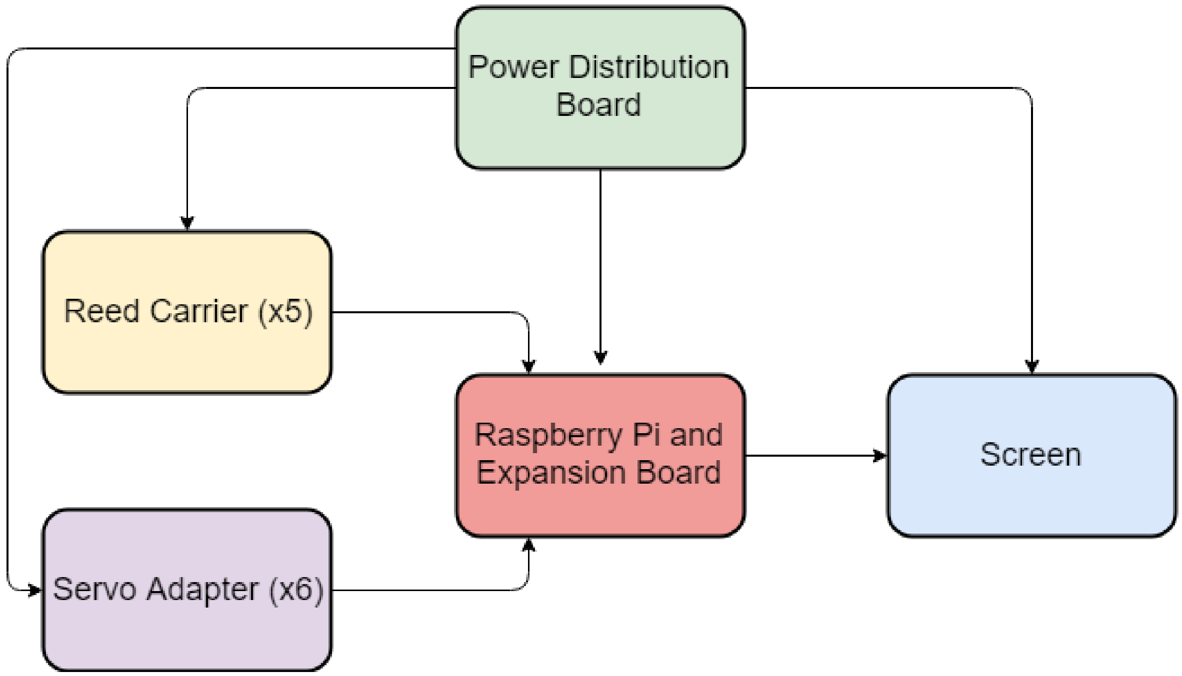


Figure 13: Electrical Components Block Diagram

Raspberry Pi and Expansion Board

The central electrical component controlling the operation of the SAND is a Raspberry Pi 3. All of the software runs on the Pi, and it controls the turntable, sensors, dispensers, and user interface. We used the Raspberry Pi instead of a simpler microcontroller because its large user-base and ability to run a full Linux operating system allowed development to proceed much more quickly. The Raspberry Pi is compatible with a huge range of existing peripherals, such as the touch-screen we used, and has extensive library support to allow easy integration with the majority of these peripherals. It also allowed us to use Python for development, which gave us access to a wide variety of well-documented libraries to further expand our capabilities and ease development. For example, the Tkinter library was used to develop the GUI, and allowed it to be significantly more complex and stable than it would have been if we had developed it from scratch or with a less feature-rich library. We used Raspbian Stretch as our operating system, though all of the software should be compatible with older versions of Raspbian as well.

The Raspberry Pi itself was not modified, but we found that the normal GPIO header on the Raspberry Pi did not allow for particular simple or robust wiring. To simplify attaching to the Pi, we created a custom expansion board that attaches to the Pi's GPIO header. This breaks out the needed GPIO connections to labeled headers that can attach to our wire harnesses. This allows other components to attach to the Raspberry Pi using mating, locking headers, leading to much securer connections. An image of the Pi with the expansion board attached can be seen in Figure 14. The schematic and board layout for the expansion board can also be seen in Figure 15 and Figure 16 below.

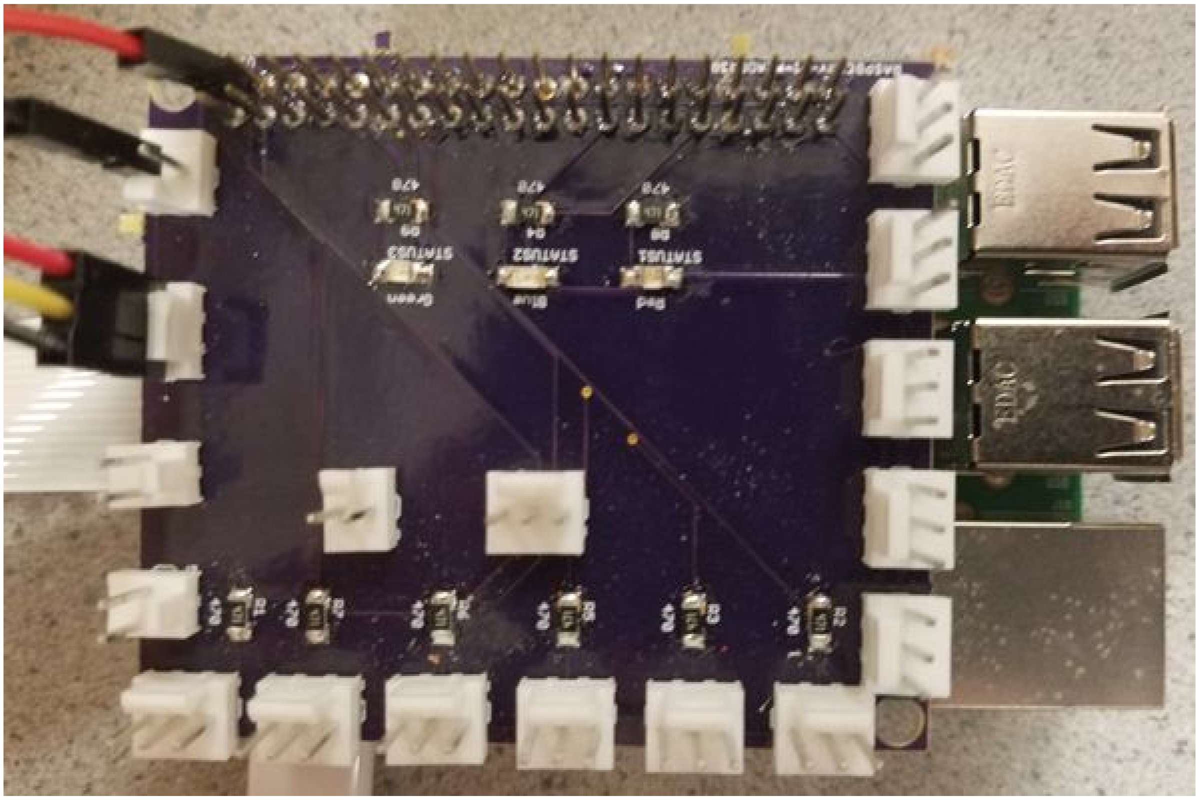


Figure 14: Raspberry Pi with Expansion Board

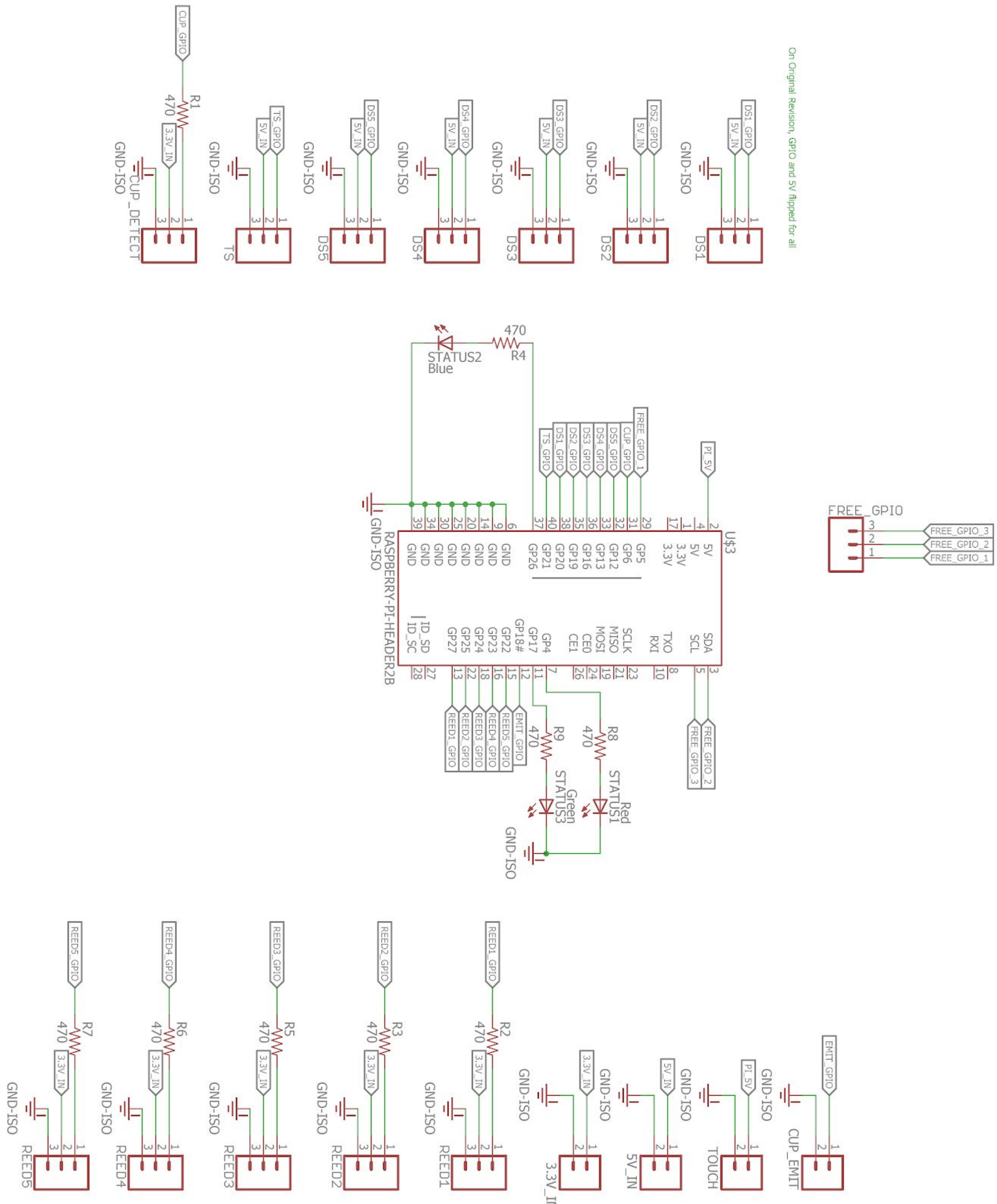


Figure 15: Expansion Board Schematic

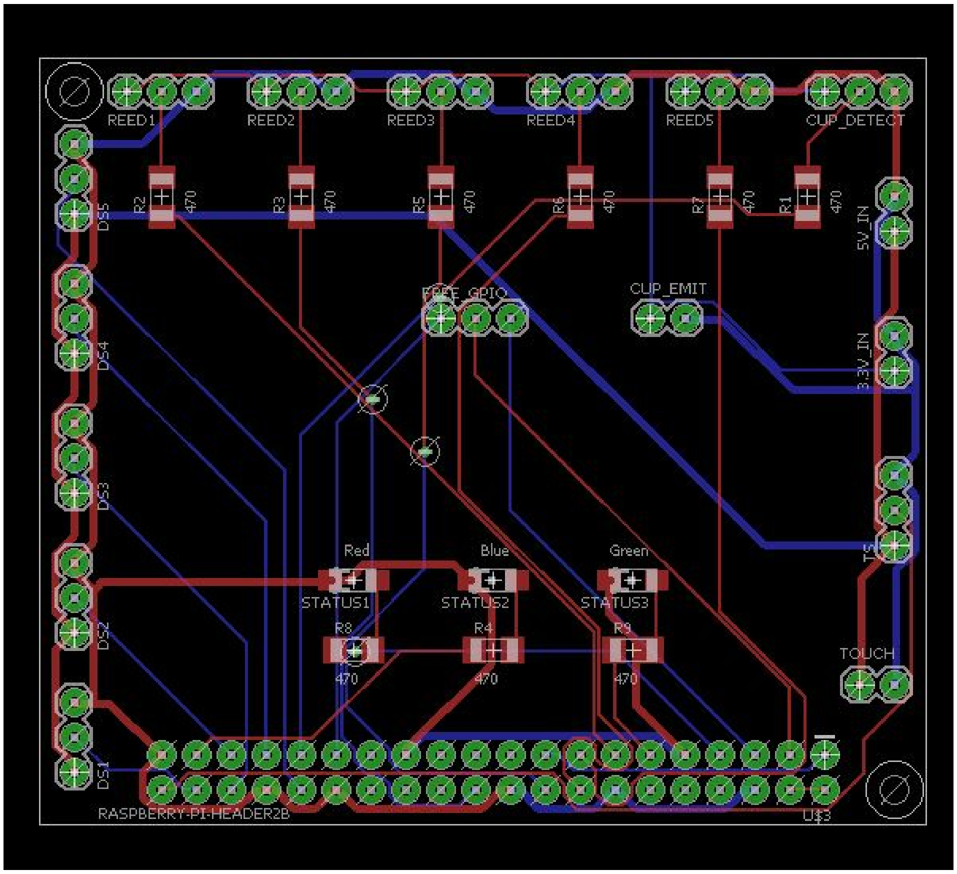


Figure 16: Expansion Board Layout

Reed Switches

The position of the turntable is tracked using five reed switches, with one attached to each column. Reed switches are switches that are controlled by the presence of a magnetic field. The reed switches we use are normally open, but in the presence of a magnetic field they close. Magnets were attached to the turntable in line with the container, so when a reed switch is closed that indicates that the container is near one of the dispensers. This is used to determine when the turntable has reached the current target dispenser. The output from each reed switch is read using a GPIO pin on the Raspberry Pi. We created a custom carrier board for each reed switch to include the needed supporting circuitry and to simplify attaching to the columns. The reed carrier board attached to a column can be seen in Figure 17, and the schematic and board layout for the carrier board can be seen in Figure 18 and Figure 19.

Figure 17: Reed Carrier Mounted to Column

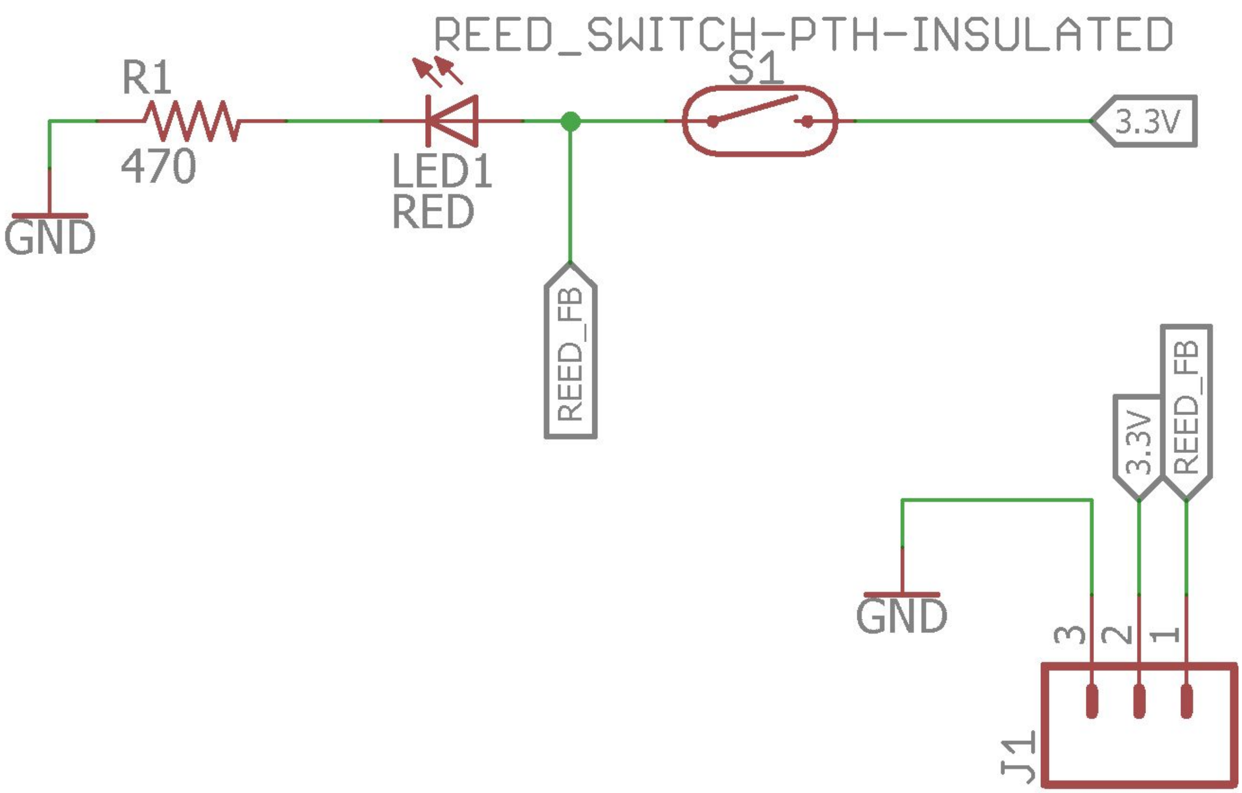


Figure 18: Reed Carrier Schematic

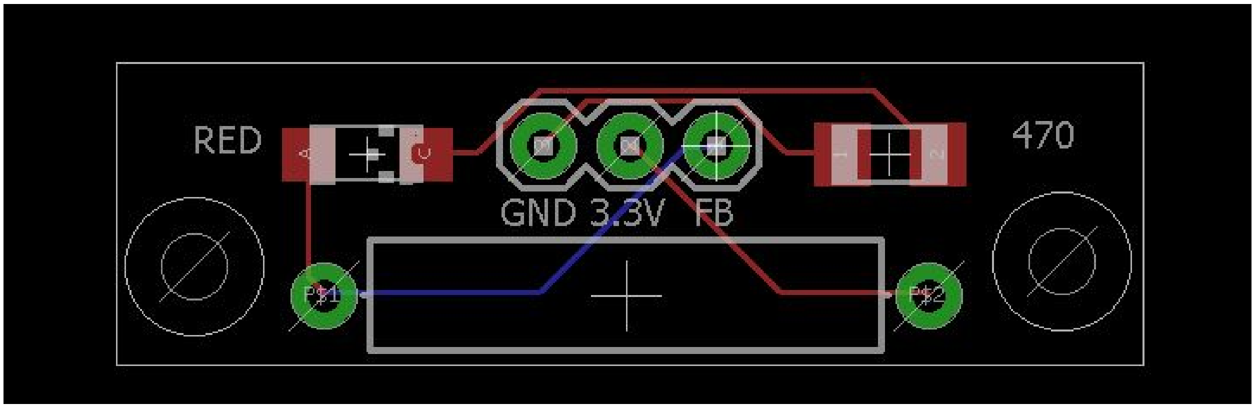


Figure 19: Reed Carrier Board Layout

Power Supply

Ensuring that the SAND is easy to power was an important part of our specification. Specialized power sources such as a benchtop power supply are not typically available outside of a lab, and using batteries is difficult because of the need to constantly monitor their charge level and the possibility of the battery dying partway through an event. Our goal was to make sure that the SAND could simply plug into any normal outlet and run. To this end, we created a power distribution board, where the output of a normal, wall power supply could be plugged in and then distributed to each component as needed. The power distribution board can be seen in Figure 20 below. The schematic and layout of the board can also be seen in Figure 21 and 22.

The board has a 3.5 mm barrel jack where a power supply can attach. We have used a 5V, 2A power supply for all testing. The 5V input from the power supply passes through a 3A fuse, to protect the components from damage if the current ever reaches dangerous levels. Two ripple capacitors then reduce any fluctuation in the output voltage, and this protected and smoothed 5V is then output through a USB-A socket. This is used to power the Raspberry Pi, by connecting it to the power distribution board using a USB cable with USB-A plug on one side and a USB-micro plug on the other end. This 5V source is also connected directly to the Raspberry Pi expansion board by a wire harness to provide power to all of the servos and the touch screen. In parallel with these connections, a MCP1702 voltage regulator reduces this 5V signal to 3.3V, which is then distributed to the Raspberry Pi expansion board using another wire harness to power the reed switches. A small LED on the board indicates when the board is powered.

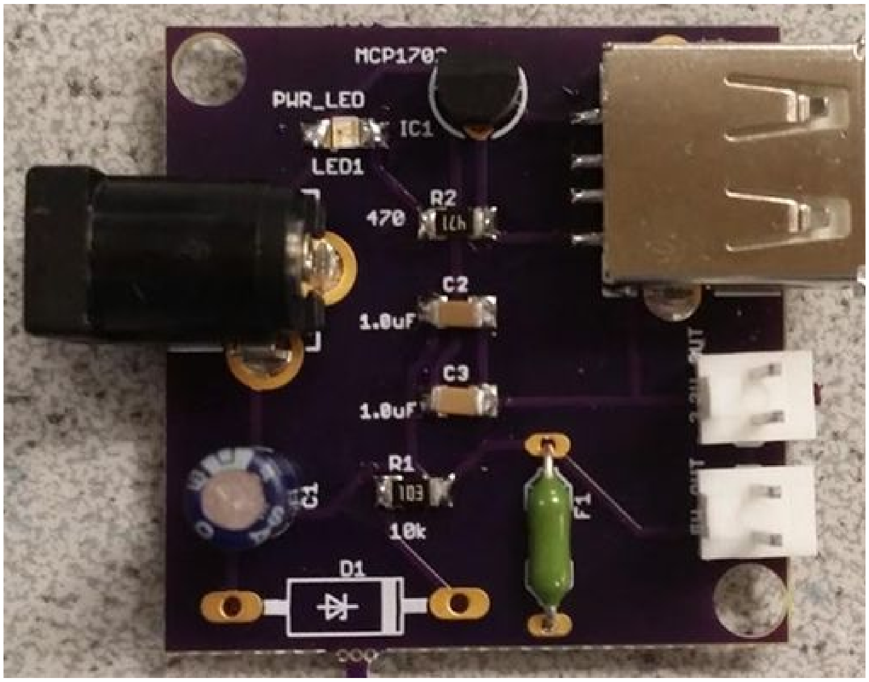


Figure 20: Power Distribution Board

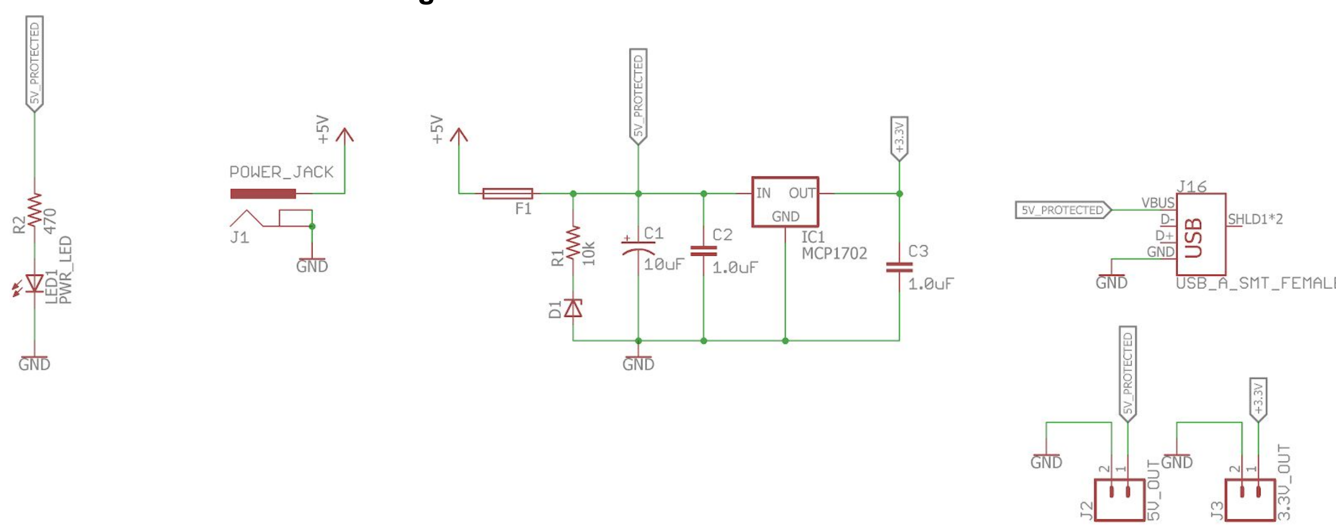


Figure 21: Power Distribution Board Schematic

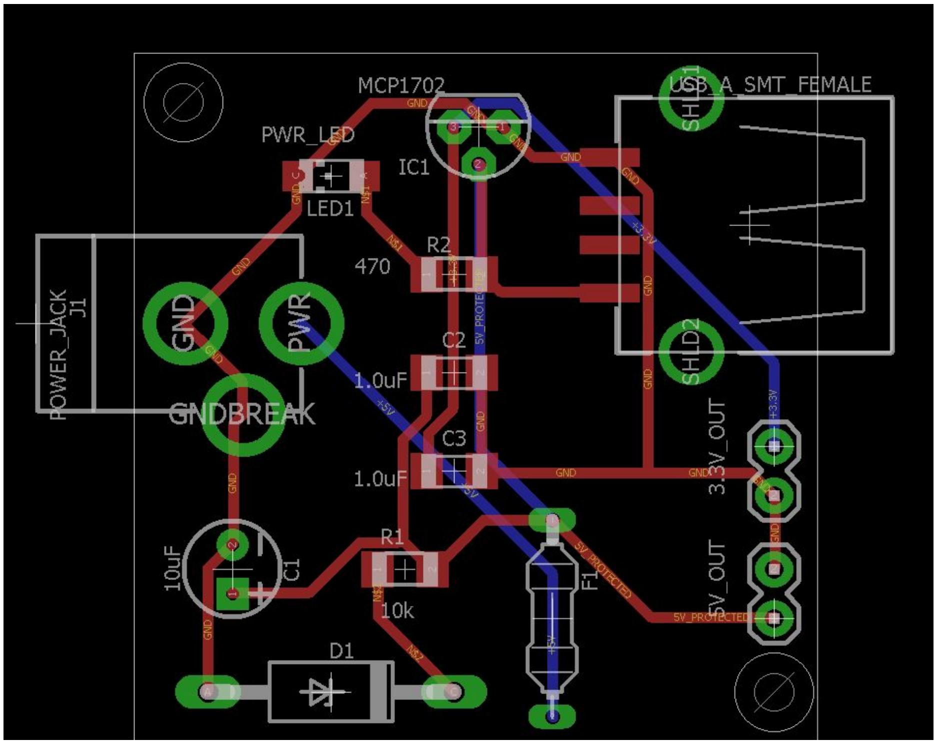


Figure 22: Power Distribution Board Layout

<u>Screen</u>

The touchscreen we used was the 7” Raspberry Pi Touch Display from the Raspberry Pi Foundation [3]. The front of the screen can be seen in Figure 23 below. This screen connects directly to the DSI port available on the Raspberry Pi, and simply displays whatever would normally be viewed when connecting a monitor to the Raspberry Pi. Taps on the screen are registered as mouse clicks allowing the user to interact directly with the GUI. The Raspberry Pi Touch Display is sold with an accompanying adapter board which powers the screen and allows it to connect to the DSI port on the Raspberry Pi. This adapter board can be seen in Figure 24. We did not need to make any modifications to the adapter board, we only needed to provide it 5V from the power distribution board.

Figure 23: Front of Raspberry Touch Display

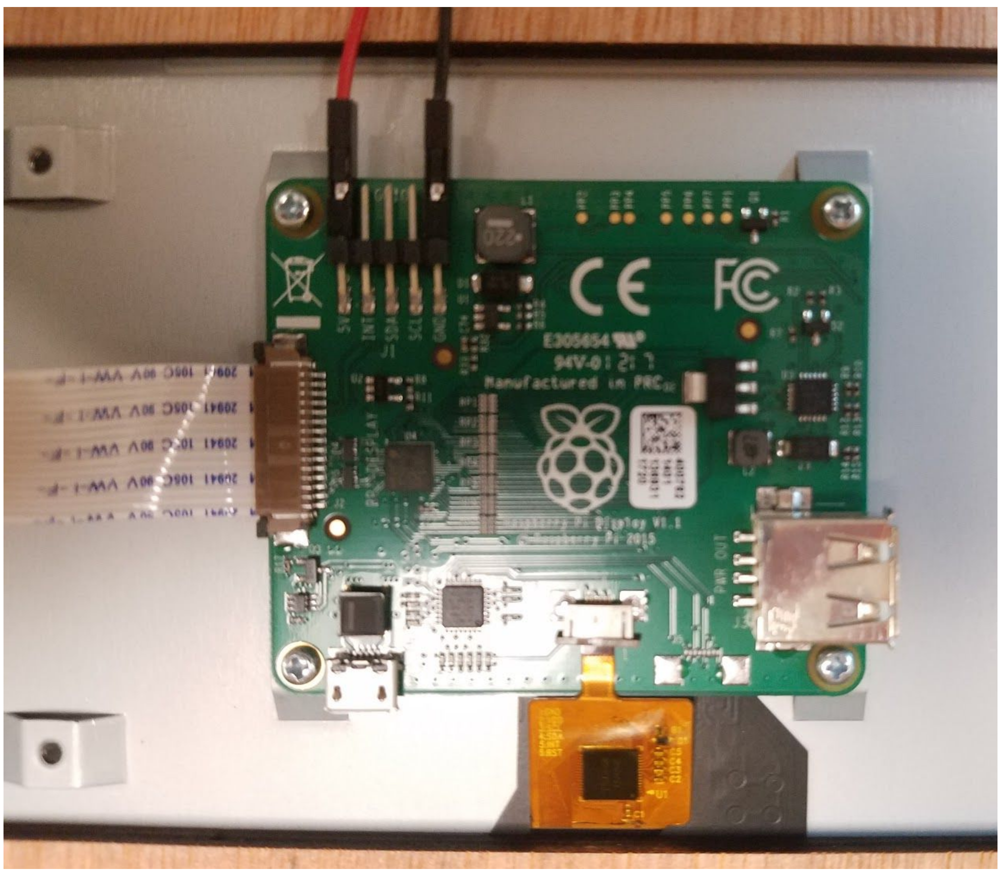


Figure 24: Touch Display Adapter Board

Servos and Adapters

We used two different servos in the design: A generic sub-micro positional servo and and SpringRC SM-4303R continuous rotation servo. Each of the five dispensers uses a sub-micro servo to control the position of the scoop. The larger SpringRC servo is used to rotate the turntable. Both servos can be seen in Figure 25 below.

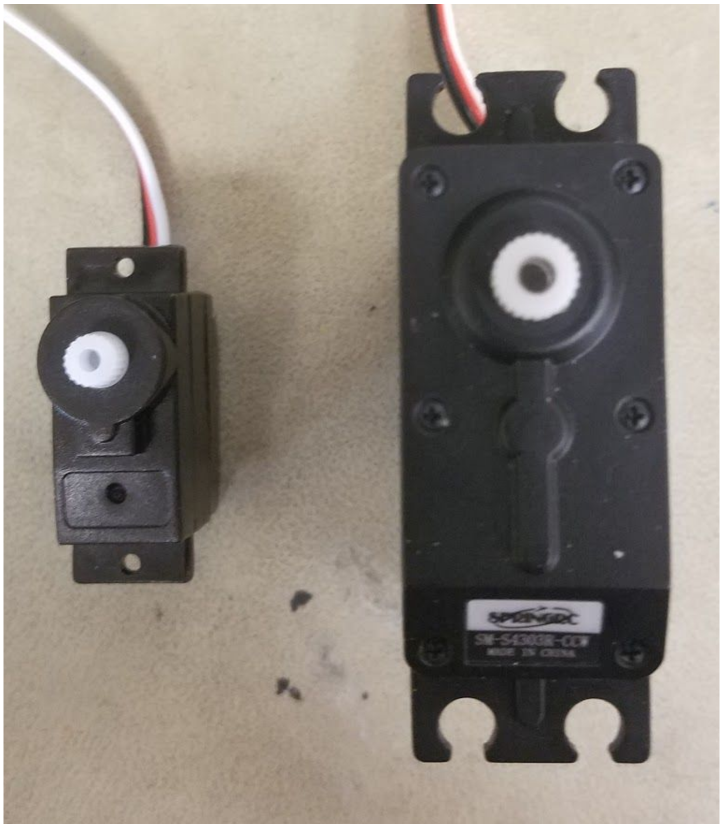


Figure 24: Sub-Micro Positional Servo (Left) and SpringRC Continuous Rotation Servo (Right)

Each servo is powered at 5V. The power distribution board provides a 5V source for the servos to the Raspberry Pi expansion board which the servos connect to through a custom-made servo adapter board. The cables from the servos are terminated with a small 3 pin header, but this header is not polarized or locking. These headers can easily be inserted upside-down and can come loose relatively easily compared to the Molex connectors we used on our wire harnesses and boards. We created a labeled adapter board that the servo cable can connect to that allows us to use a wire harness to connect the servos to the Raspberry Pi expansion board. The servo's cable connects to a labeled header on the adapter board, and then connects those signals to a Molex header that the wire harness can then connect to. An image of a servo adapter board attached to a column can be seen in Figure 26 below. The board layout for the servo adapter boards is shown in Figure 27.

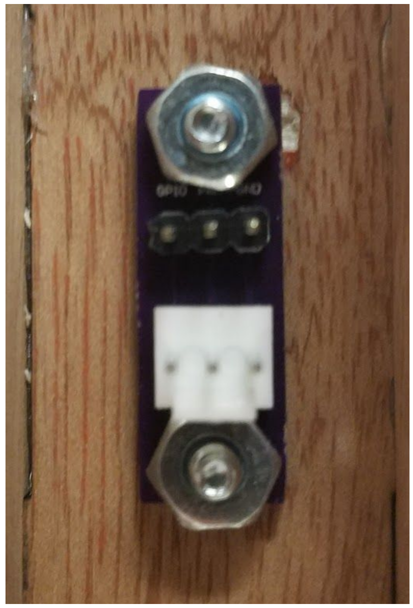


Figure 26: Servo Adapter Board Attached to Column

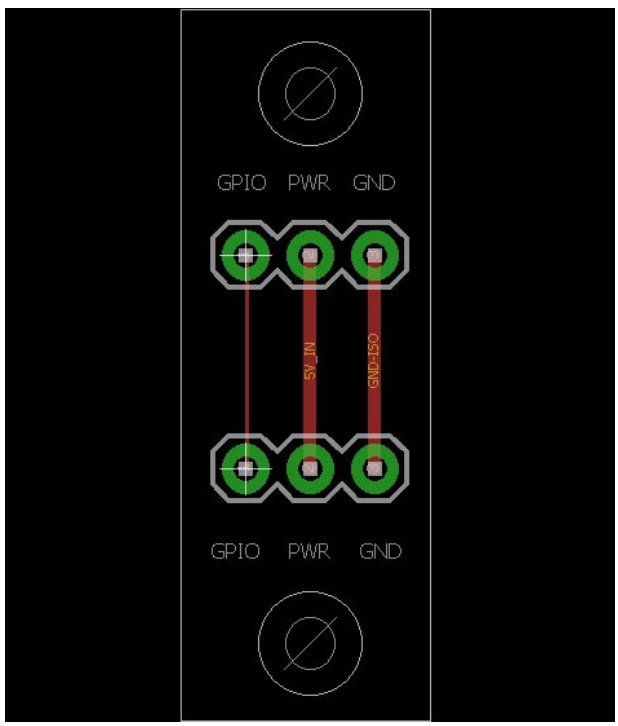


Figure 27: Servo Adapter Board Layout

Software Design

Software Overview

There are four main components to the software used on the SAND. The operator interface allows whoever is setting up a demonstration to configure which colors are being used and what order they have been placed into the shaker slots on the top plate. This makes it easy to change the colors that are being used based upon availability or the operator's preference. These colors and orderings are then stored in a text file referred to as the color database. When actually running a demonstration, there are two processes that run: the dispensing control process and the GUI process. The GUI process creates and renders the GUI, registering all slider interaction and button presses. It determines what colors should be available to use by reading from the color database. The dispensing control process is connected to the GUI process using socket 6000 within the Raspberry Pi. Communication over the socket is accomplished using the multiprocessing library [4]. The GUI process sends sand art specifications through the socket to the dispensing control process. The dispensing control process then handles rotating the turntable to the appropriate positions and dispensing the required amounts of sand. Python was used exclusively to create the software. A block diagram illustrating the interconnections between the different software components can be seen in Figure 28.

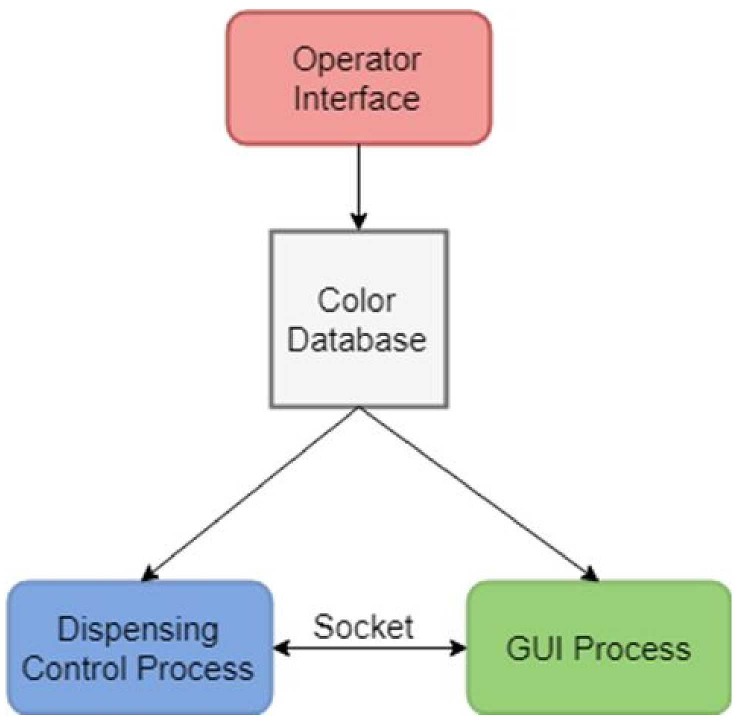


Figure 28: Software Interconnection Block Diagram

Operator Interface

The operator interface is quite minimal, since it is not meant to be used by the general public. When run, it simply creates a text prompt asking the user to enter the colors in use one at a time, in the order they have been arranged on the top plate. Only a limited number of possible colors are supported. The currently supported colors are: red, blue, green, purple, yellow, orange, white, black, and brown. If any other color is entered the operator interface will display what colors are supported and prompt the operator to enter a supported color. Once all five colors have been specified, the operator interface will update the color database and exit.

GUI Process

The GUI process relies on the Tkinter [5] library to create, render, and update the GUI. Tkinter allows for relatively easy development of rich GUIs, though we intentionally kept the GUI for the SAND simple so it would not be intimidating to users. The GUI has 5 slider bars that each represent one of the layers of sand that will be in the final piece of sand art. The bottom slider represents the bottom layer of sand, the second slider from the bottom will be the layer that is second from the bottom of the container, and so on. The SAND GUI can be seen in Figure 29.

Figure 29: SAND GUI

Within the GUI process, we created a Frame object, which creates an empty window which widgets can be placed in. A widget is an individual interactive components of the GUI in the terminology used by the Tkinter documentation. Examples of widgets are a button or a drop-down menu. We divided the frame into a grid to allow us to position widgets relative to each other. The quit and start button were both created and placed into the bottom row of the grid. Buttons can be linked to particular functions to run when they are pressed, so the quit button was linked to an existing global quit function in Tkinter and the start button was linked to the start_dispense function, which reads the color settings that the user had specified, concatenates them into a single string, and then sends this string over socket 6000 to the dispensing control process to specify the piece of sand art it should create. The drop down menus for color selection were created using the Tkinter OptionMenu widget, and they were linked to the colorAdjust function which changes the color of their corresponding slider each time a new color is selected. The sliders were created using the Tkinter Scale widget, and linked to the adjust function which tracks the total percentage specified by the user so far. The adjust function also prevents the user from increasing the fill percentage beyond 100% and handles adjusting the fill percentage display. The fill percentage is displayed in a blue box on the bottom right. This is actually accomplished using a button widget with no function linked to it to match the aesthetics of the other buttons in the bottom row of the GUI.

Dispensing Control Process

The dispensing control process controls the positioning of the turntable and the dispensers in order to create the specified sand art. It receives specifications from the GUI process by listening on socket 6000. Once it receives a specification, the dispensing process begins. The dispensing control process first parses the message, splitting it into five pairs of colors and corresponding fill percentages. These pairs are then stored in separate arrays to be referenced when dispensing each color. Based on the information from the color database, each color is mapped to a column, and each column is mapped to a specific reed switch input and dispenser servo. To facilitate this mapping, each column was assigned a number, starting from zero and ending with four. When facing the slope plate, column 0 is the first column that is clockwise from the containers starting position. The column numbers continue to increment moving clockwise from column 0, ending with column 4.

The fastest direction to rotate in is determined based on the current column the container is located at and the column with the color it needs next. The difference between the column numbers corresponds to the distance between two columns when moving clockwise, so this difference can be used to determine whether moving clockwise or counter-clockwise is more efficient. In most cases, if the difference is positive moving clockwise is faster, and if the difference is negative moving counter-clockwise is faster. The edge cases when the difference is between the columns is the maximum possible are anomalous though, as it is actually faster to go counter-clockwise from column 0 to column 4, so this case is handled separately.

After determining what direction is most efficient, the turntable begins to move at a set speed, continuously checking if the reed switch corresponding to the target column has been closed yet. Once that reed switch is closed, the turntable servo reduces its speed to allow the magnet on the bottom of the turntable to attach to the anchor point for the column. The dispenser for the target column then dispenses for an amount of time determined by the specified fill percentage.

This process then repeats for all of the specified layers. When all of the layers have been dispensed, the dispensing control process determines the most efficient direction for returning to the starting position, and turns the turntable to move the container back to the starting position. After completing a piece of sand art the dispensing control process then waits for another specification to be sent by the GUI process.

Results and Evaluation

Ease of Maintenance

We wanted to ensure that our model was easily maintainable so that the faculty demoing it could continue to use it long-term. We were able to test adding and removing parts from the model as we built it as we would replace parts when we updated them. Throughout the design of the SAND we we able to quickly assemble and disassemble the SAND without issue showing that fixing the SAND is straightforward. While working on the SAND we also needed to connect new electronics as we added parts. We found that we were able to easily connect the new electronics to the existing ones with our polarized connectors and we could access the inside of the SAND to wire the electronics together. We were also able to easily create new PCBs and lasercut new parts using the files we created as we designed the system so there were no issues replacing parts. We also ran many test of dispensing sand and had to refill the shakers as we tested. We found that it was quick and easy to put new sand into the shakers as they emptied meaning there are no problems with refilling the sand. Each shaker held 17 in^3 of sand and each vial held 1.2 in^3 of sand meaning refills do not need to occur often if sand colors are used mostly evenly.

Robustness

We tested the robustness of the SAND by running many dispensing tests to ensure that it would continue to function without issues. We ensured that the sand would never overfill the vial, and the vial would rotate to each station correctly no matter how many times we ran the device. We also tested that the device could be transported by carrying the device to different locations in a rough manner. We checked that parts did not come loose while we transported the device around. We checked screws and electronic connectors and both stayed securely in place.

Ease of Use

The mechanical parts of our design allowed for easy use as the cup holder on the turntable and the shaker holders on the top plate made it clear where the vial and shakers should be placed when operating the SAND. The SAND’s GUI used mostly visual controls instead of textual controls which made the device more intuitive to operate. The users can visually tell how much of each color will be dispensed by looking at how far they moved the percentage slider of each color. They can also see the order the colors will be dispensed in as the bars of color are in the same order that the sand will be stacked. After users choose their pattern, a large green start button makes it clear that pressing it will begin dispensing. The SAND makes it clear when dispensing has finished by returning the vial to its starting position which also make it easy for the user to remove as there are no columns in the way of the starting position.

Aesthetics

Our finished system was very aesthetically pleasing with cleanly laser cut parts that connected without gaps between pieces. The system had few visible wires and the wires that were visible were run through the columns in an organized manner. The sand art we produced had flat layers that visibly matched the chosen patterns. While working on the SAND many other students passing by were interested in learning what the device was and seeing it run. This proved that the device was interesting and aesthetically pleasing enough to attract Cornell students and will likely attract prospective students as well.

Conclusion

We were able to finish our project and meet all of our goals. The SAND was able to successfully dispense sand as specified by the user. We were able to make the SAND robust and modular so that faculty will be able to transport the device to events and repair it if it breaks. We also made the device aesthetically pleasing and interesting enough that prospective students will be interested in seeing the device and will likely discuss the field of ECE with the faculty performing demonstrations. The SAND is easy to use so operators and users can operate the device with minimal instructions. We believe the SAND will help bring many new students to the field of ECE.

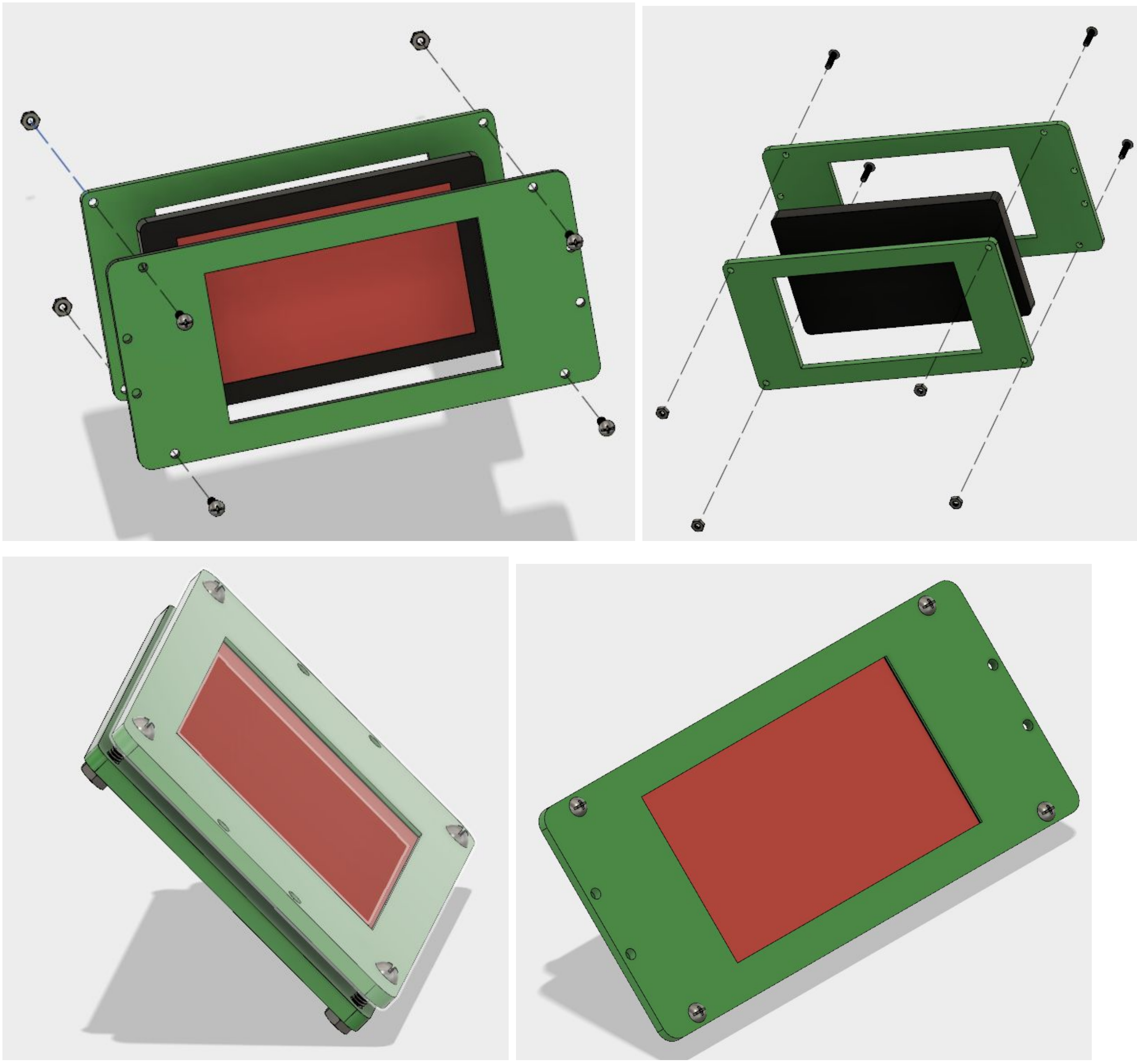
Instructions

Operator Instructions

Mechanical Assembly

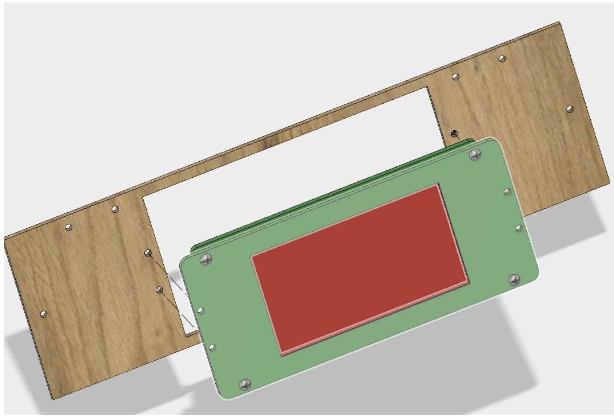
Screen

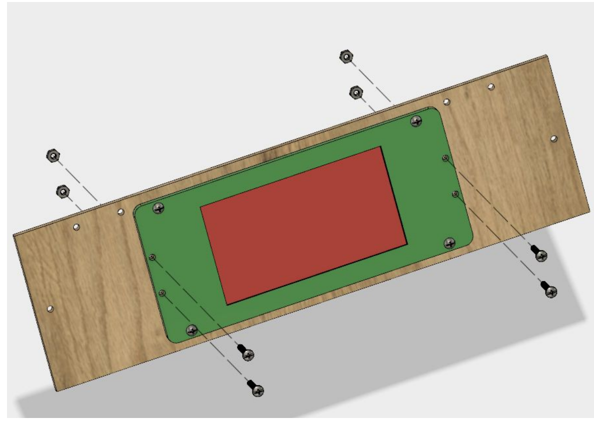
1. Position the screen between the two screen plates with the screen side facing toward the larger front screen plate
2. Use four ¾ in 10-24 screws in the uppermost and lowermost holes to connect the front and back plate together.

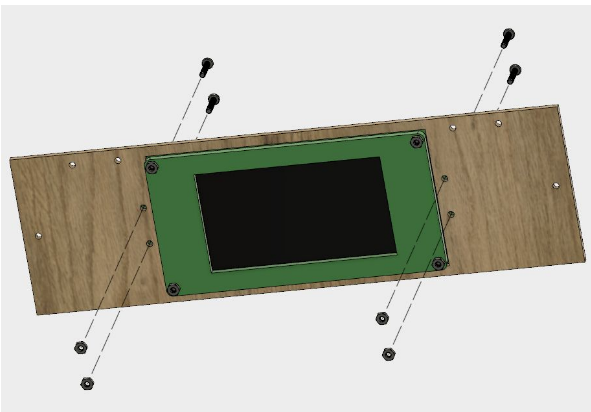


Slope Plate

1. Use four 1 in 10-24 screws in the outer screen front plate holes to connect the screen assembly to the slope plate.

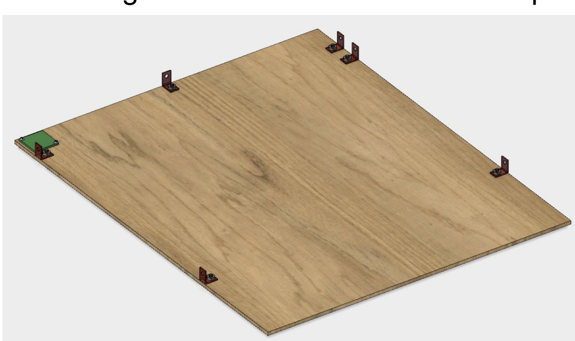






Box

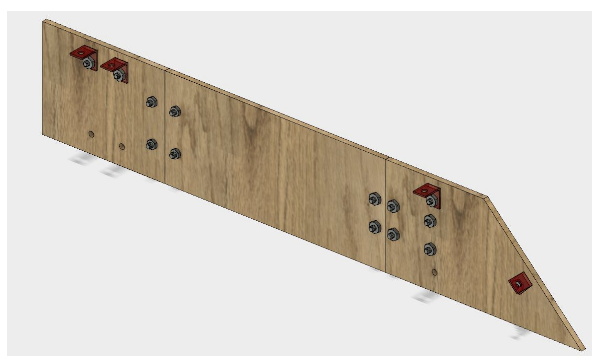
1. Attach power board to corner of bottom plate using two ½ in 6-32 screws.
2. Attach angle brackets to all other bottom plate holes using ½ in 10-24 screws.



3. Attach angle brackets to the side plate with a hole using ½ in 10-24 screws.

4. Attach the side plate to the bottom plate using ½ in 10-24 screws.

5. Attach angle brackets to the latch side plate using ½ in 10-24 screws.
6. Assemble the latch side plate using the hinge and latch pieces using ½ in 10-24 screws..

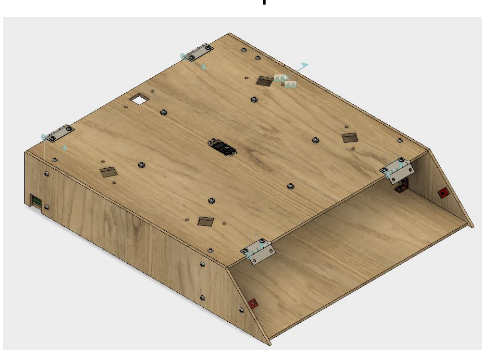



7. Attach the latch side plate to the bottom plate.

8. Attach angle brackets to the side edges of turntable plate using ½ in 10-24 screws.
9. Attach four hinges to the front and back edges of the turntable plate using ½ in 10-24 screws.
10. Attach six ½ in 10-24 screws to inner holes of turntable plate with an additional nut in between the turntable plate and the top of the screw.
11. Attach the turntable servo to the turntable plate using four ½ in 6-32 in screws. The wings of the servo should be below the turntable plate.

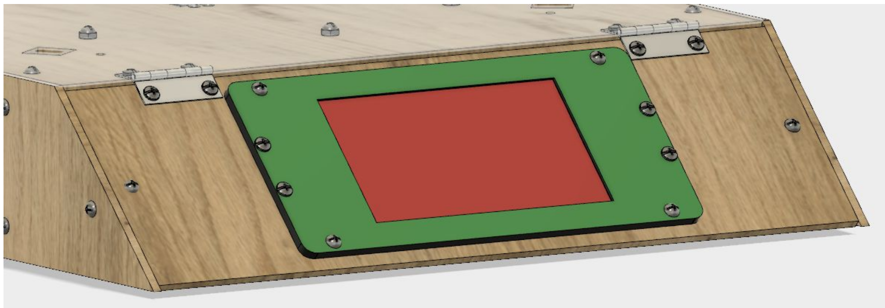
 

12. Attach the turntable plate to the two side plates using ½ in 10-24 screws.

13. Attach the slope plate to the turntable plate using the two hinges on the front using ½ in 10-24 screws. The screws on the sides of the slope plate can be attached using ½ in 10-24 screws to secure the plate in place. Alternatively, these screws can be left off to

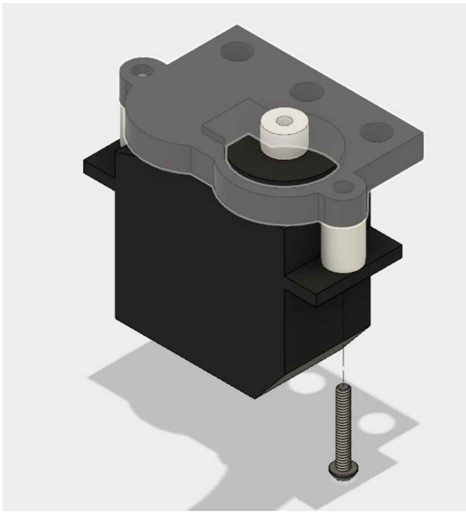
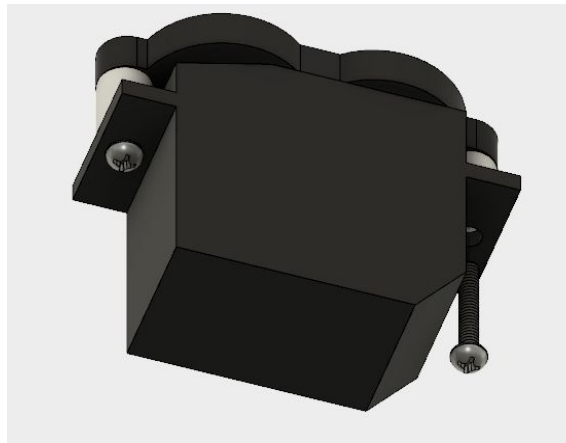
allow the slope plate to be used as an access hatch.



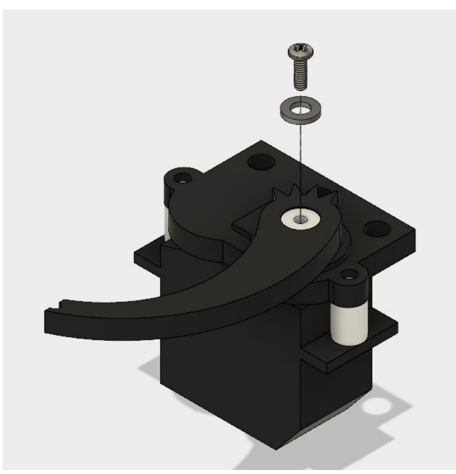
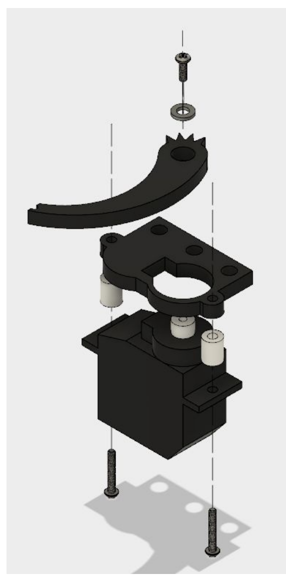
14. Attach the back plate to the turntable plate using the two hinges on the back using ½ in 10-24 screws. The screw on the bottom can be attached using a ½ in 10-24 screw to secure the plate in place. Alternatively, this screw can be left off to allow the back plate to be used as an access hatch.

Servo Claw

1. Attach the plate to the top of the servo. Place the standoff between the servo and the plate. Screw the screw into the bottom of the standoff

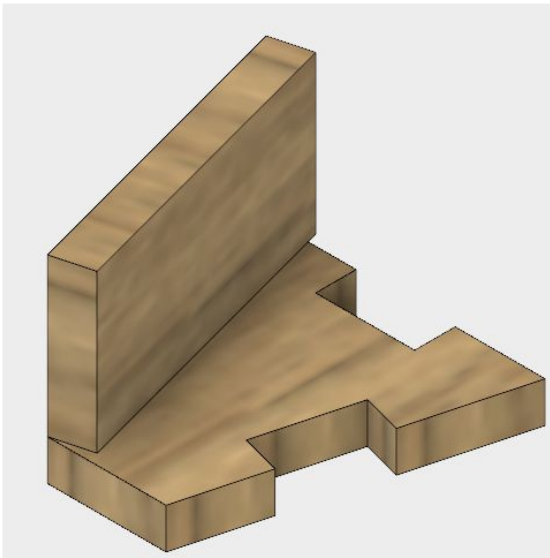
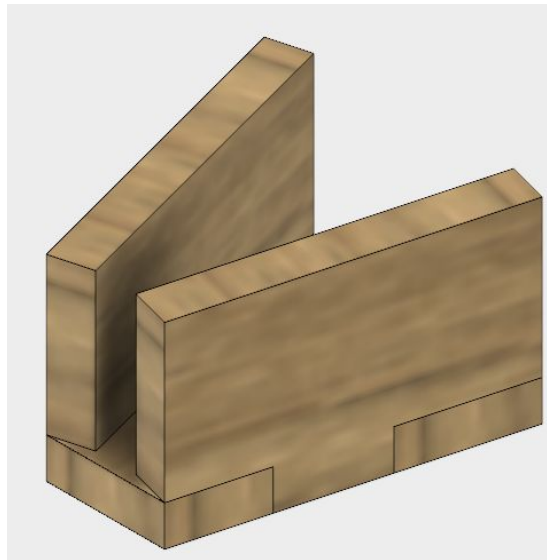
 

2. Attach the claw to the top of the servo with the screw and washer.

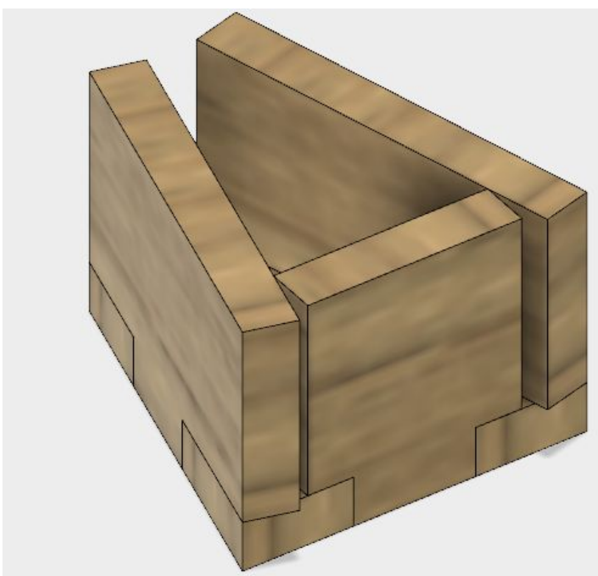
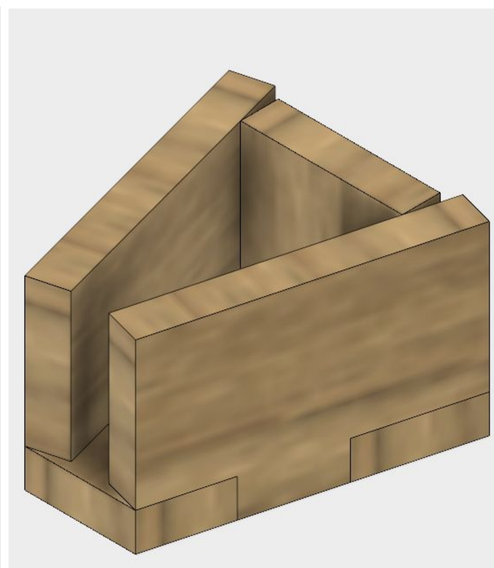
 

Scoop

1. Glue the two side of the scoop to the base piece.

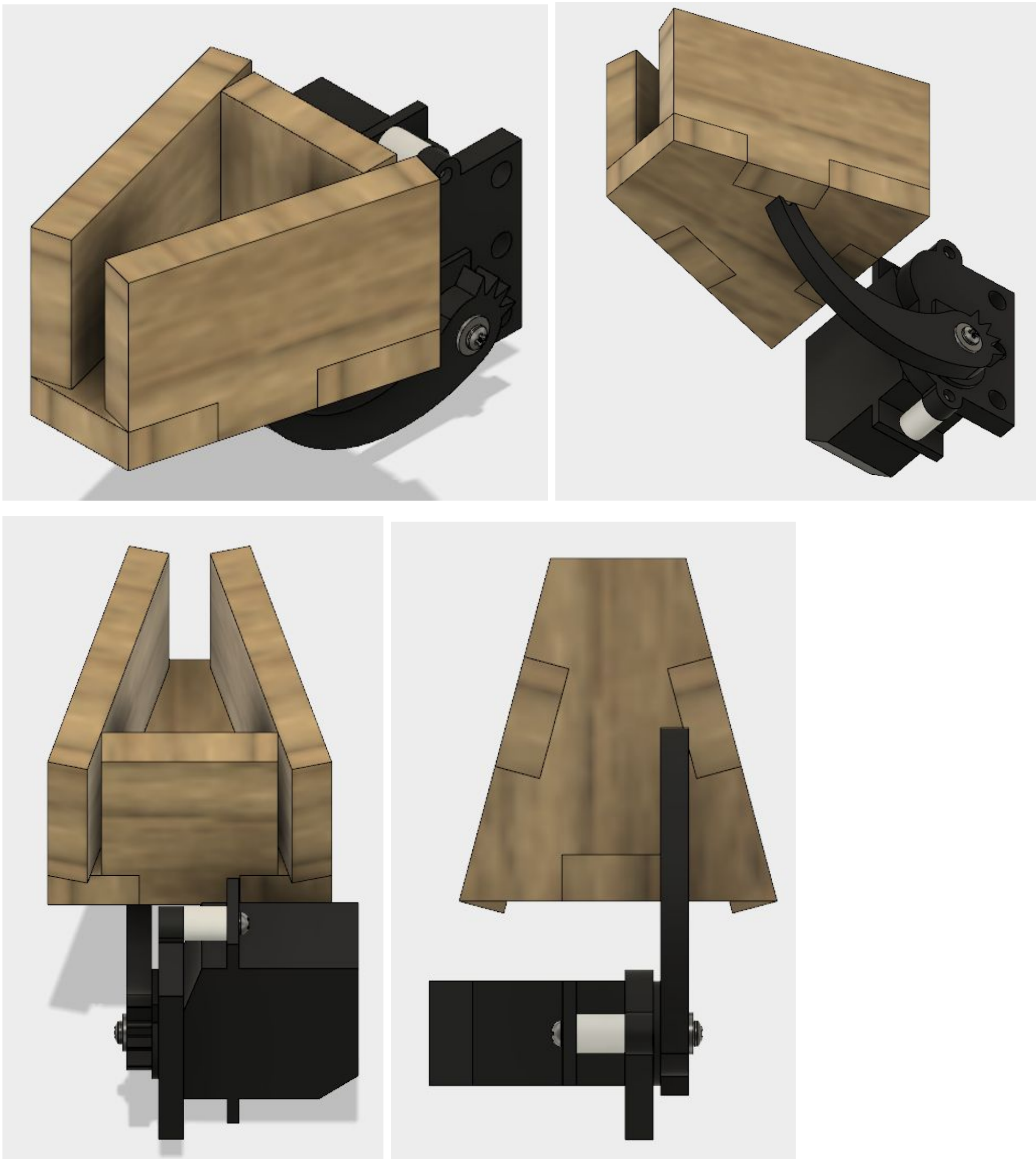



2. Glue the back of the scoop to the base piece.

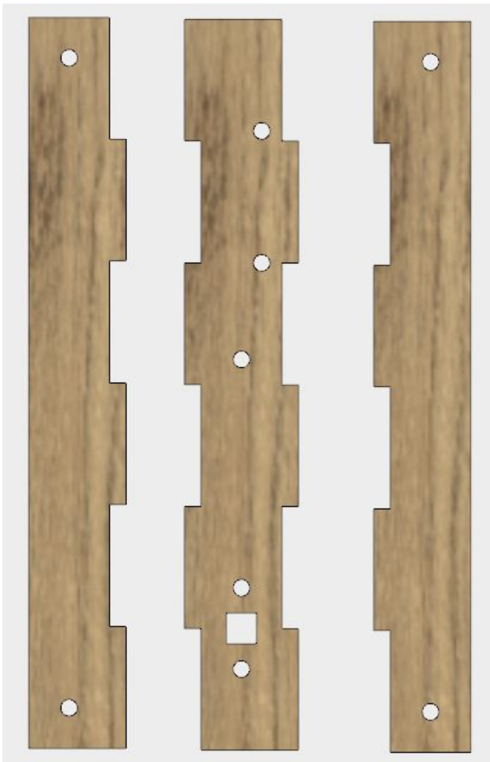
Scoop Claw Assembly

1. Glue the edge of the claw to the bottom of the scoop. This step may require later adjustment to ensure the straws of the shakers line up with the scoop.

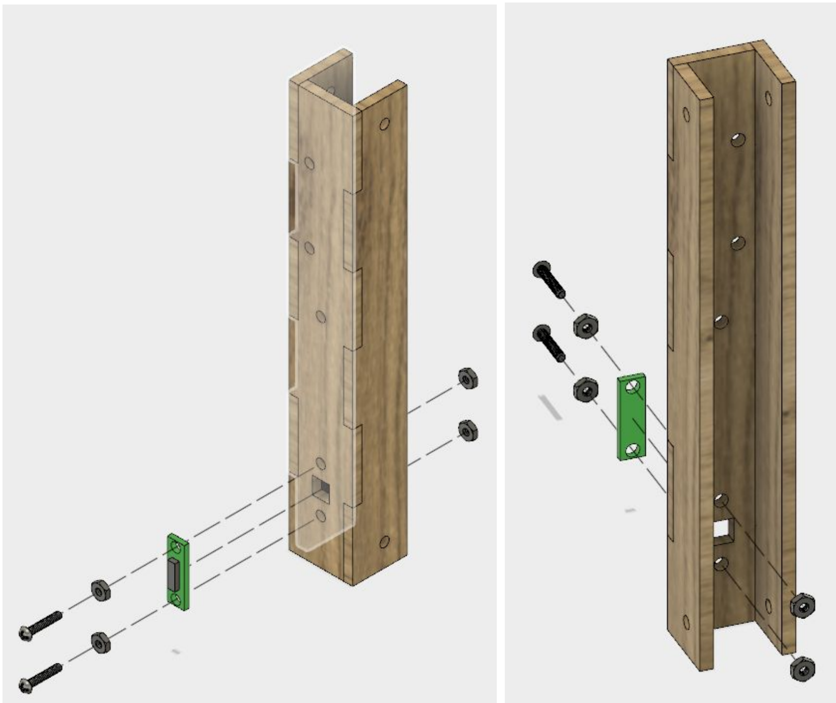


Column

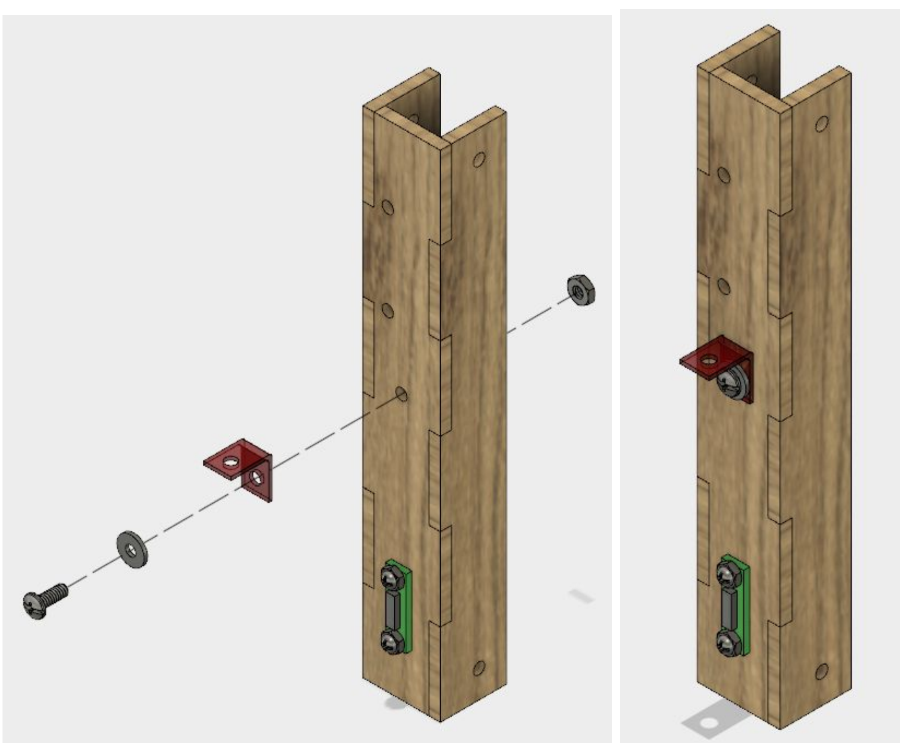
1. Glue the two side of the column to the center piece.



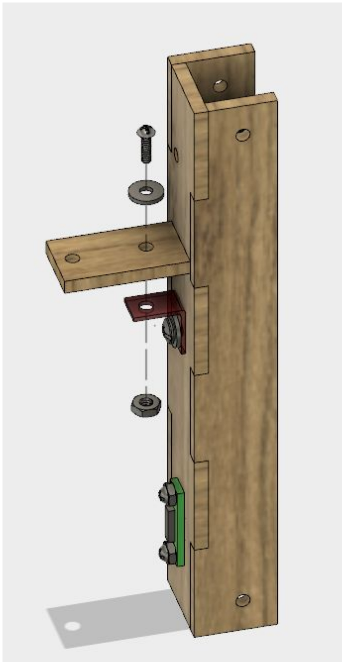

2. Attach the reed switch board to the of the center piece using two ½ in 6-32 screws.



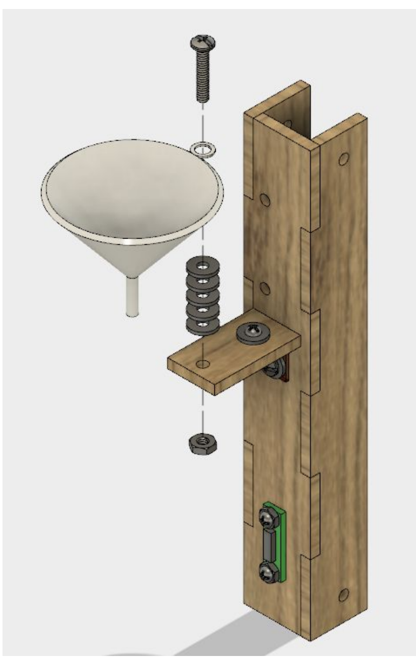
3. Attach the center angle bracket to the column using a ½ in 10-24 screw and a washer.



4. Attach the funnel holder to the angle bracket using a ½ in 10-24 screw and a washer.



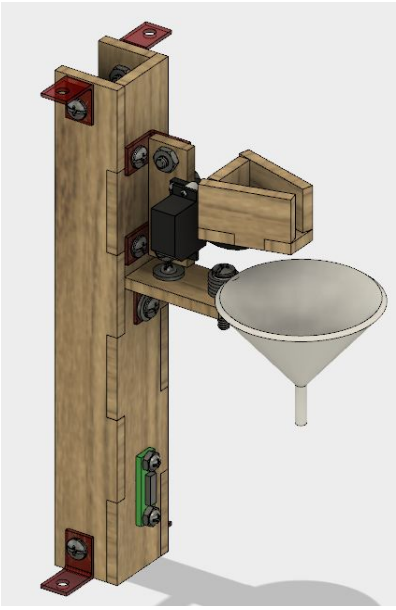
5. Attach the funnel to the funnel holder piece using a ½ in 10-24 screw and five washers.



6. Attach two angle brackets and the servo holder using ½ in 10-24 screws.

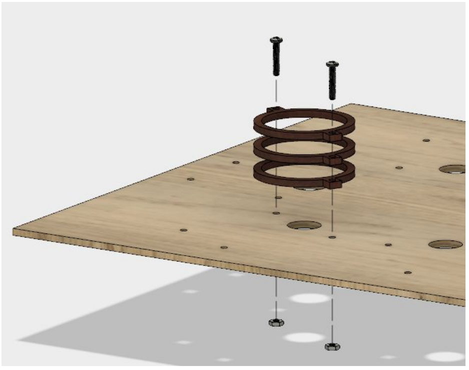
7. Attach the servo scoop assembly using two ½ in 6-32 screws.

8. Attach four angle brackets to the side holes of the column using ½ in 10-24 screws.




Top Plate Assembly

1. Attach three cup holders to each of the five positions using 1 in 10-24 screws.

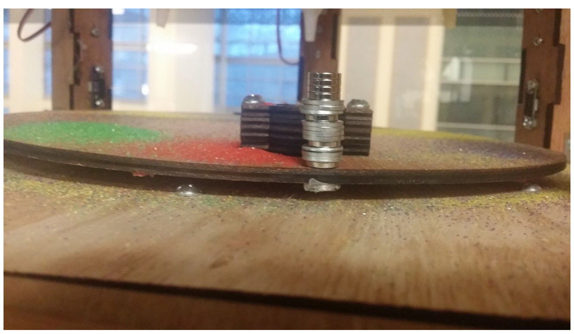


2. Glue a small amount of foam to the edge of the top shaker holder in each position. Use enough foam to hold a shaker in securely.

Turntable

1. Attach three cupholders to the turntable using a 1 in 10-24 screw.


2. Glue a small amount of foam to the edge of the top cup holder. Use enough foam to hold a vial in securely.
3. Glue a single magnet to the bottom of the turntable next to the cupholder. Attach several magnets to the top of the turntable on the top of the other magnet.

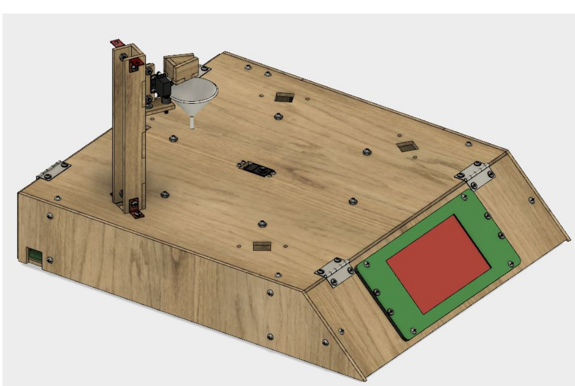


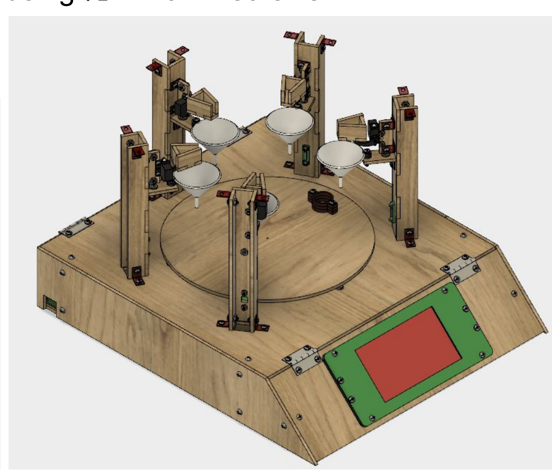

4. Glue the servo horn to the bottom of the turntable so the hole of the horn lines up with the center hole of the turntable.

Final Assembly

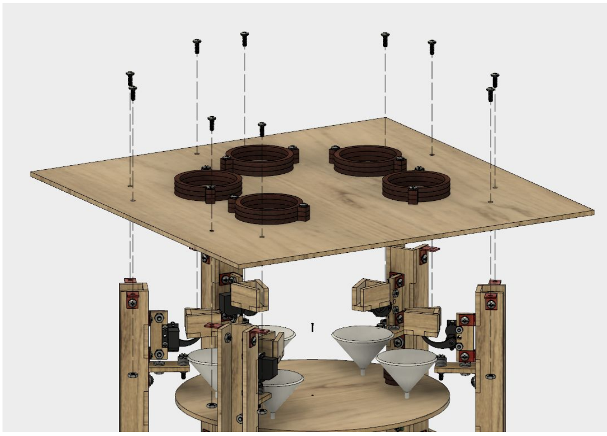
1. Attach the servo to the box assembly with the servo screw.

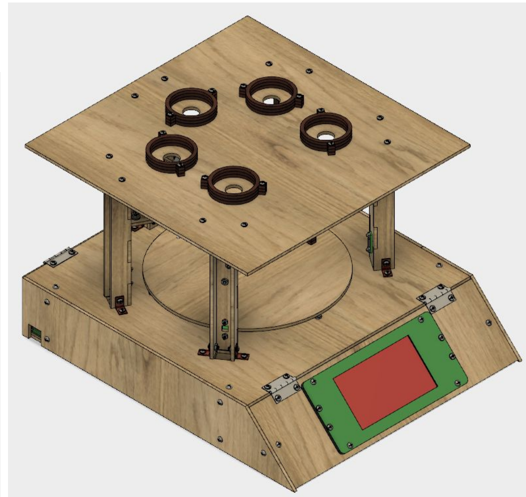
2. Attach the five columns to the turntable plate using ½ in 10-24 screws.





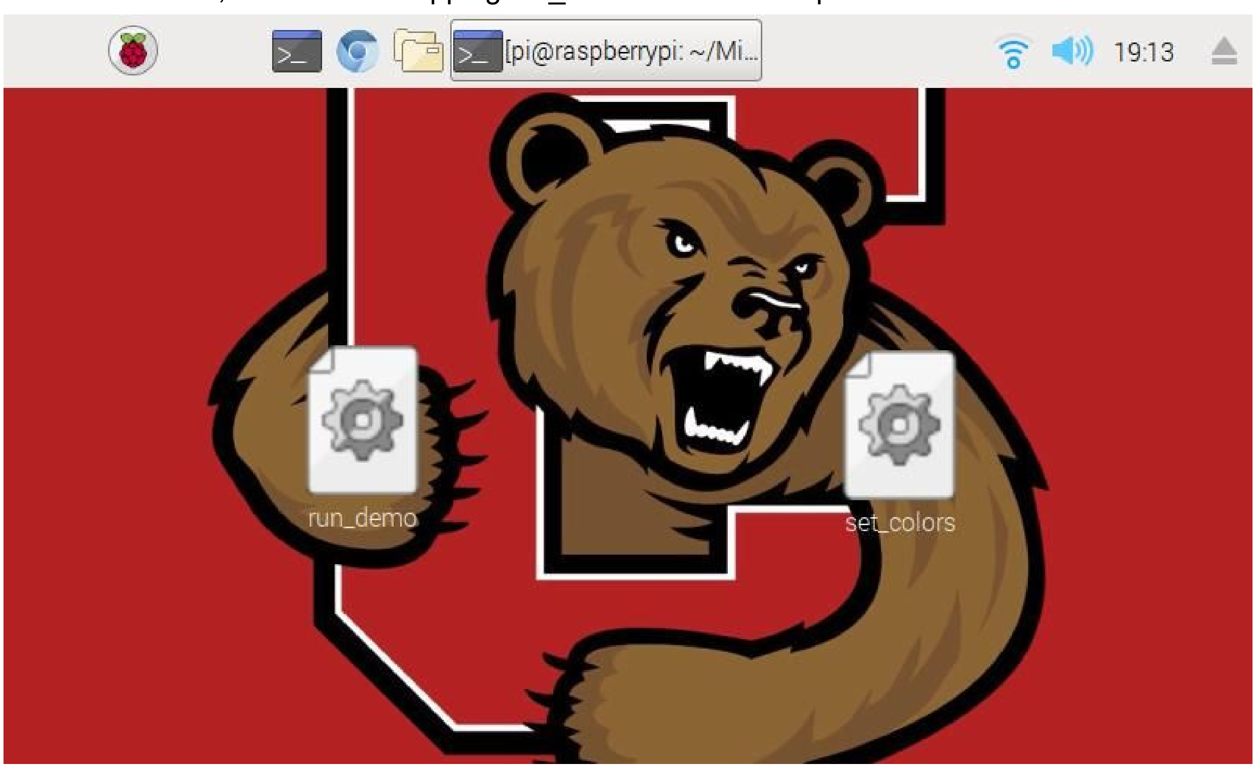
3. Attach the top plate to the columns using ½ in 10-24 screws.





Operator Instructions

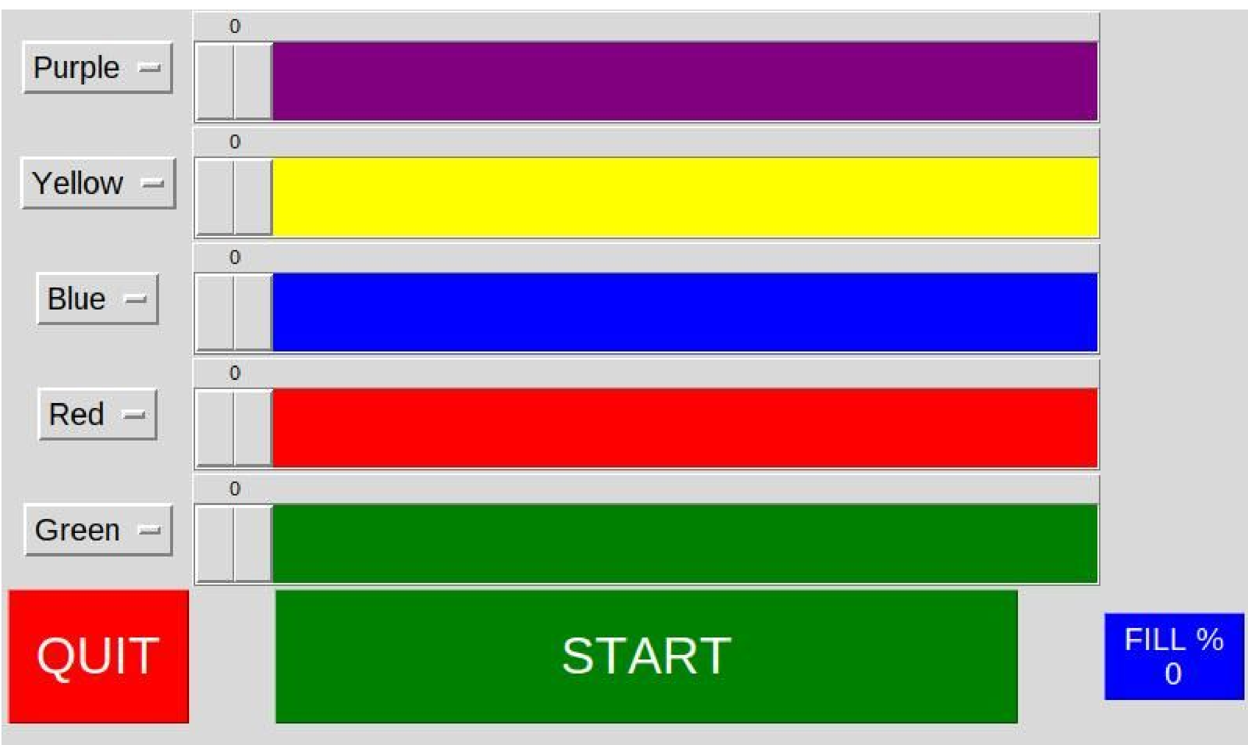
1. Ensure all shakers are placed appropriately and filled with sand
2. Insert the barrel jack plug of the power supply into the socket on the back of the left side pane, then plug the power supply into the outlet. This should power on the SAND.
3. Wait approximately 1 minute for the Raspberry Pi to boot up. When the sand has booted up, the screen should appear as below. There are two icons on the desktop, one labeled run_demo and the other labeled set_colors. Double tapping on run_demo will start the the demo, while double tapping set_colors will run the operator interface



4. To begin a demo, double tap run_demo. A prompt will ask you if you wish to execute run_demo. Select “Execute”. After a few seconds, the GUI should appear on the screen.

User Instructions

1. Insert an empty container into the container holder on the turntable.
2. The screen should display the GUI, as seen below. Each of the slider bars corresponds to a layer of sand that will be added to the sand art. The bottom bar will be the bottom layer of sand, and the top bar will be the top layer of sand.
3. Select which color you would like each layer to be by tapping on the text boxes to the left of each slider bar. A drop down menu with a choice of colors should appear. Tap on the color of your choice.
4. Move each slider to set the percentage of the container you would like each layer to occupy. The total fill percentage of the container is indicated in the blue box in the lower right hand corner of the screen. It is not necessary to fill the container to 100%, but to begin dispensing you must specify at least a 10% fill. Filling more than 100% is not possible, once the total fill percentage reaches 100%, none of the sliders will be able to increased further.
5. Once you are satisfied with your sand art design, tap the large green “Start” button on the bottom of the screen once to begin dispensing.



Work Contribution

Douglas Katz

I began the project by brainstorming potential project ideas with Fred before deciding on creating a sand art dispenser. We then worked together to plan out the different subsystems we'd need to create and a timetable for creating them. I came up with the idea to dispense sand by rotating the cap on a salt shaker. I then began work on creating a half scale 3D to use for planning our physical design. We planned to make all parts modular and planned to laser cut all our parts so I created the design with this in mind. I created each individual piece of the model as a 2D sketch so we could laser cut the pieces from wood or acrylic. I also made sure that the design could be assembled using angle brackets, screws, and nuts. After I finished modeling the design I used the model to create files for laser cutting the design and then Fred and I laser cut all the pieces out of wood at Cornell's RPL. Fred and I assembled our design and I wrote code for controlling our servos so we could implement and test our turntable and dispenser mechanisms. I proposed the original dispensing mechanism of rotating the cap on a salt shaker and Fred and I implemented and tested the design. We tried several ways of doing this, but found that this method of dispensing was too prone to jamming. We brainstormed new dispensing mechanisms and iterated on them together until we arrived at our final dispenser design. As we worked on the dispenser we began work on other parts of the design such as the GUI and I refined the model as necessary. Once the dispensing mechanism was complete I moved onto creating the full scale 3D model. Fred and I worked together to refine our dispensing mechanism and I edited the model to match our changes. Once we completed our design I worked on creating assembly instructions so that operators would be able to disassemble or reassemble the system to add or remove parts. I then wrote mechanical sections of this report while Fred wrote the electrical and software sections.

Fred Kummer

I started by discussing potential promotional display projects we could create with Doug. We settled on a short list of projects we were interested in and brought them to our advisors to discuss, and we settled on creating a sand art dispenser. Then we began planning out our approach to the project. We created a timetable and sketched out some rough block diagrams for how we envisioned the mechanical, electrical, and software components of the design. While Doug began experimenting with creating CAD models and laser-cutting, I designed the first version of the expansion board, power distribution board, and reed carrier boards. We ordered the boards and the needed components and then I set to building them. We also began testing dispenser mechanisms at this time. We tried a variety of mechanisms, but we had the most initial success by attaching a servo to the cap of a shaker and rotating it between an open and closed position, so we decided to move forward with that design. While I tested the electronics and created new revisions of the boards, Doug was designing and manufacturing a scale model of the frame to test our design. Once the scale model was created, I mounted the reed switches and created code that integrated reading them and controlling the turntable and dispenser servos. We also began designing the GUI. Though we started with both of us working on it, I eventually wound up creating the majority of the GUI code. We tested our dispenser design, and found that after several rounds of dispensing it would quickly jam. We then shifted our focus to trying out alternate dispenser designs. We went through several dispenser iterations over the course of a month or two, and finally arrived at our final design. We both tested a variety of different designs before combining elements from several of them to reach a design we were happy with. We then moved onto the full-scale model. Doug took the lead on creating the CAD drawings for the full-scale model while I improved the GUI and dispensing code and ordered new revisions of the boards. We then both constructed the full-scale model and mounted the electronics. I created the wire harnesses to connect the electronics and continued to improve the GUI. I also added the routing algorithm to allow the turntable to find the most efficient route to its dispenser. Then, most of our time was spent on testing and calibrating the dispensing to ensure that the proper percentages were dispensed. We collaborated on writing the report, I focused more on the electrical and software portions of the report while Doug focused on the mechanical portions.

References

[1] Cooking Robot: https://courses.cit.cornell.edu/ece5990/ECE5725_Spring2017_Projects/Final%20Report/index.html

[2] Micro Gripper Kit A: https://www.sparkfun.com/products/13176

[3] 7” Touchscreen: https://www.raspberrypi.org/products/raspberry-pi-touch-display/

[4] Multiprocessing: https://docs.python.org/2/library/multiprocessing.html

[5] Tkinter: https://wiki.python.org/moin/TkInter

Appendix

Link to GitHub repository containing all code used for this project.