

Final Project Report: Motorized “Hover Board”

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List of Nomenclature

Term	Definition
Momentary Switch	A form of push button that is only engaged when it is being pressed.
SPST	Single Pass Single Throw. The simplest switch type, “on or off”.
AWG	American Wire Gauge. A standardized wire gauge system used in North America.
RPM	Revolutions Per Minute. A measure of the frequency of rotation around a fixed axis per minute used to measure rotational speed of a mechanical component.
NiMH Battery	Nickel-Metal Hydride Battery. A type of rechargeable battery usually used for small electric vehicles.

Executive Summary

This document is the full report for the senior project of Cal Poly General Engineering student Gabriele Pregadio. This report includes all project steps necessary for the completion of the design. I was under the advisement of Professor Antonio Barata of the Cal Poly Music Department. At the beginning of the 2016 Spring quarter, Prof. Barata tasked me with building a concealed “hover craft” device which allowed the user to move without using their legs. The user would be a student performing as an angel in RSVP, a yearly student-produced performance. As the quarter went on, more information was revealed to me, including the angel’s clothing details and the fact that I would be performing as the angel in the performance. The device was constructed and tested during the few rehearsals prior to the performance. It was ultimately decided by the RSVP production crew that the device would not be used as it detracted from the angel’s performance and was deemed unnecessary as the angel was able to move eerily and seemingly floating as intended, solely by walking slowly and carefully thanks to the length of the costume.

1. Introduction

I was tasked by Prof. Antonio Barata of the Cal Poly Music Department to construct a device that would allow a person to move slowly and smoothly without performing walking movements with their legs and/or feet. The device was to be used in *MU 412 Sound Design: Composition and Production* course's student-produced performance at the end of the Spring 2016 term.

1.1 RSVP Background

At the conclusion of the Spring term, Cal Poly's Music Department sponsors a student-produced performance named RSVP under the supervision and direction of Prof. Barata. RSVP grew out of the Sound Design classes in Cal Poly's Music Department with the primary goals of generating a broad and engaging experience for student creators and a lasting impression on audiences. The first RSVP concert was held in 1993. Each concert blends acoustic performance with new and mixed media, theatre, and dance.

Spring 2016's RSVP production was a modern ballet based on Henry Wadsworth Longfellow's epic poem *Evangeline*, a story of separation from homeland and love. The production also encompasses the themes of the battle of good and evil, imperialist control, and the strength and strain of religious ardor. It is set in Israel and tells a story of a Jew (Evangeline) and a Muslim (Gabriel) falling in love shortly before being separated by imperialist powers. The production tells the story of Evangeline's lifelong search for Gabriel.

One of the production's main characters is Jibril, the great angel-herald. He moves eerily, almost floating, very slowly across the floor. His gestures are stayed, beautiful, elegant. He wears great angel wings and a loose, majestic costume. Three weeks into the course it was decided that I would perform as Jibril in the performance.

1.2 Problem Definition

Prof. Barata tasked me with designing a concealed device which would allow Jibril to move slowly and eerily across the floor. Due to the angel's long and wide costume, it would be possible to hide it from sight beneath the loose fabric.

The most important consideration for the device is balance. It is important that the performer will not fall off from the device. The impact of such a blunder during the performance would not only harm the scene in which the angel is present. The entire show's integrity would be compromised and harshly received by the audience, potentially as a comedic act, which would seriously damage the performance's reputation.

1.3 Objectives

The device's width and length could not exceed shoulder length as it could not be concealed beneath the costume otherwise. Its height from the ground could not be more than a few inches for the same reason. It was important for the user to have good balance while standing on the device.

The device was to move using motorized wheels and would be able to turn using swivel caster wheels. The batteries were to be mounted on the device underneath the device next to the wheels and off the ground, or otherwise concealed from the audience. The device was to be controlled via either remote control by another person or via switches by the user.

The device must allow the user to move forward and turn in both directions all while balancing. It is not necessary for it to go backwards. It must also be considerably quiet, as the audience is only a few feet away from the performers and loud motor noise would give away the "magic" of the angel's smooth and eerie movement.

2. Background

This section includes details on existing products which would allow for similar movements by Jibril.

The device that could most accurately perform the required movements is the Vecaro Hoverboard. It is a self balancing motorized two-wheeled balance scooter that uses innovative gyroscopic technology. With some modifications to prevent the costume from getting stuck under the wheels, the Hoverboard would likely accomplish the task successfully, but the price is out of the show's budget. The entry level model Glide 65 Vecaro Hoverboard is priced at \$599, and more powerful and precise versions reach the \$799 range.



Figure 1. Glide 65 Vecaro Hoverboard



Figure 2. Segway

Perhaps the most well-known similar product is the Segway, a popular personal transportation device. The Segway successfully moves a person without the use of their legs, but it would be appropriate for the purposes of the performance due to its bulky frame and the required use of hands for balance.

Heelys are shoes that have at least one wheel embedded in each sole, allowing the user to walk by shifting their weight to their heels and roll across the floor. It is a simple device which does not require a motor for movement, although it is necessary for the user to initially move their legs to spin the wheel. This movement broke the main requirement of the device and was therefore not considered for the design. However, it inspired a design concept which was ultimately not selected for implementation¹.



Figure 3. Heelys

¹ See section 3.1.1 Structure

3. Design Development

This section details the design process of the device, including conceptual designs, concept selection, and preliminary analysis.

3.1 Concept Generation

It was clear to me that the final product would involve motorized wheels and at least one surface for the user to stand and balance on. The device must also be powered by batteries due to power cables being aesthetically displeasing and a potential hazard for other performers on stage.

3.1.1 Structure

One design concept involved two separate motorized devices, one for each foot. This design was inspired by Heelys². Each device would be similar to a box, with the electrical components (battery, motor, wiring) inside. A wheel would be embedded on the underside of the pyramid-shaped “box”, and the user would rest their feet on the top, with the forefoot poking past the front of the device, resting on the floor while standing still. The devices would be separate, with each motor and battery having its own circuit (left and right feet independent of each other). Each device would be controlled via a momentary switch in the user’s hand, with wiring up each leg and arm, concealed by the costume.

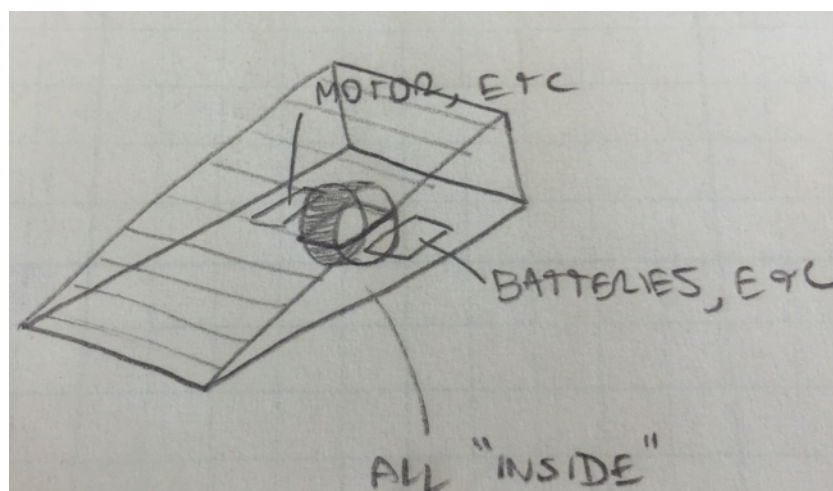


Figure 4. Pyramid-shaped “Box” design concept for each foot

² See section 2.1 Existing Products

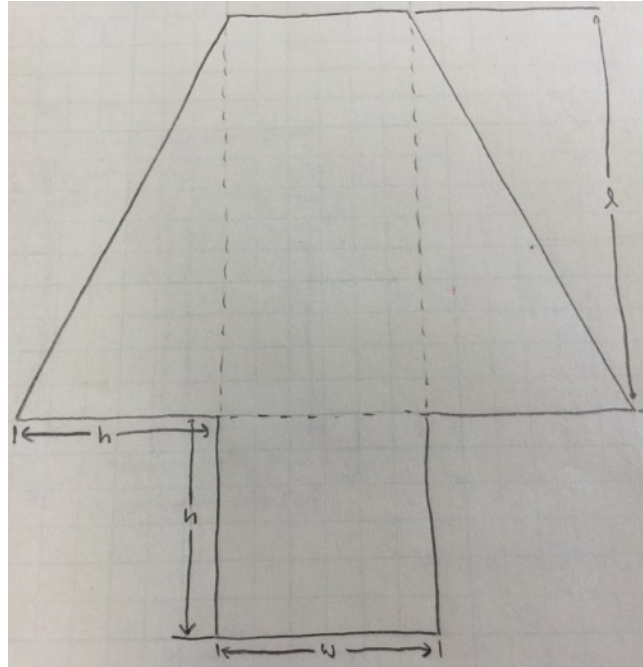


Figure 5. “Box” design cut-out

The primary advantage of this design is that it allowed the user to change directions easily and intuitively by lifting their heel (which is attached to the device) and pivoting with their forefoot. With practice, the user turn smoothly and be barely noticeable in the loose costume. Balancing issues may arise as the user would be The design would also allow the user to correct their posture easily and quickly in case they were losing balance simply by placing their forefoot down and turning the switches off. However, it was unclear whether there was enough room in the “box” to store the battery and motor. There was also a concern during movement when the forefoot is lifted from the ground, as the pressure exerted by the heel of the foot on the device could be too great to bear, and catastrophic failure may result.

A simpler design concept was also considered. The design incorporated all of the components into one structure, requiring the performer to stand on one platform with both feet. The platform would be attached to two motorized wheels on its underside and one caster wheel to allow for turns. All electrical components including wiring would be attached to the underside of the platform, next to the wheels.

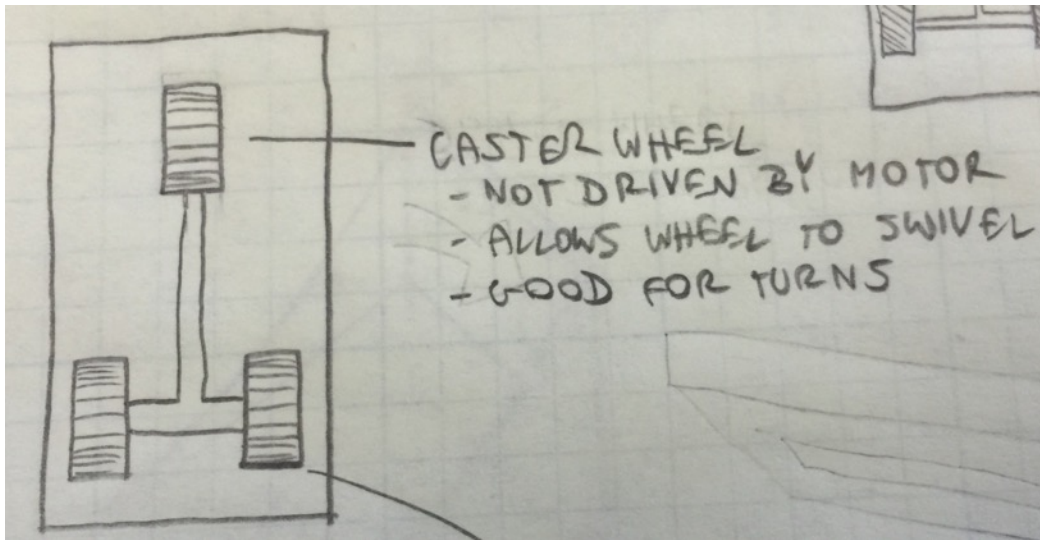


Figure 6. Early Platform design concept

3.1.2 Electrical

It was important to determine whether each motor would have its own circuit (and battery), or whether one circuit would include both motors and one or more batteries would power the motors.

With two separate circuits, each motor would require its own battery to run, allowing for the user to control each motor independently. This simplifies turning, as it would require the controller of the device to simply close one circuit and short the other. However, two batteries would be required as opposed to one. This further increases the weight of the device and the load supported by the wheels, as well as the total cost of the device.

Having one circuit for the device restricts it to one component, eliminating a previous structural concept³. Having one battery as opposed to two would reduce the total weight and cost of the device. The motors would be configured in parallel with each other in order to retain the voltage output of the battery. Controlling the device would also be more complicated, especially when turning.

³ See section 3.1.1 Structure, "Box" design concept

3.1.3 Control

The most straightforward and simple solution to control the device was via toggle switches. Controlling two separate circuits would involve two SPST switches, one for each circuit. Turning would involve turning one switch on while leaving the other off. The other option is having an assistant control the device remotely.

Switches controlled by the user would give them complete control of the device. The benefit of this is that it gives the performer a degree of freedom and correction in case they unintentionally move to a wrong location on the stage. The downside is that it gives the performer an additional thing to think about on top of their scripted gestures and locations based on lighting and timing of the music. This further complicates things for the user and divides their attention further, likely resulting in suboptimal theatrical performance.

A remote-controlled device would allow the performer to further focus their attention on the hand gestures. However, it would cause complications with balancing by the user. Giving control of the device to a different person means the performer may move unexpectedly, without having their feet set and body weight balanced appropriately for the transmitted movement. Another issue is that the assistant controlling the device would need a good view of the stage. It is important that the stage managers for the production are out of the audience's sight. Additionally, seeing the assistant remote controlling the device with a controller would "ruin the magic" of the angel's eery movement and detract from the show.

3.2 Selection

As previously stated, the most important aspect of the design is the balancing. The "Box" design concept would allow the user to correct their balancing issues, but it is desirable to eliminate those issues altogether. For this reason, the Platform design concept was chosen and altered by introducing a second swivel caster wheel for easier balancing. Both motors are to have their own circuits and powered by two separate batteries which would be attached to the underside of the platform.

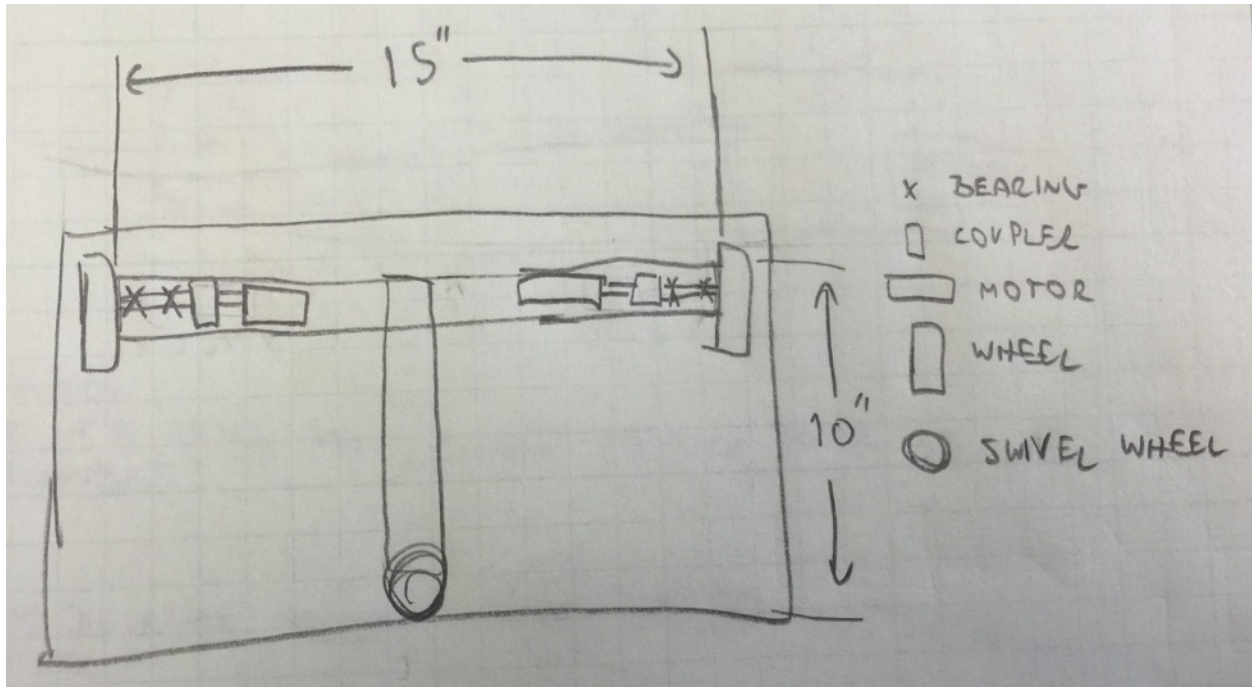


Figure 7. Original Platform design concept

Early in the design process, it was not clear whether the angel's hands were bare and used for theatrical gestures and motions. Therefore, the idea of controlling the device via switches in the angel's hands was acceptable. Later in the design process, it was revealed to me that the angel would in fact need to utilize its hands. This rendered the hand-controlled switch idea unacceptable and a separate way of controlling the device was required. The remote-controlled idea was also discarded as it would increase the cost of the device and it was decided that the benefits of giving full control to the user as opposed to an assistant outweighed the drawbacks. Two momentary SPST switches were selected to control each of the two motors.

A few weeks into the quarter, it was also decided that I would be the one performing as Jibril in the show. This further solidified the selection of the switches over the remote-control, as I would clearly be the one with the most control of the device seeing as I would build it.

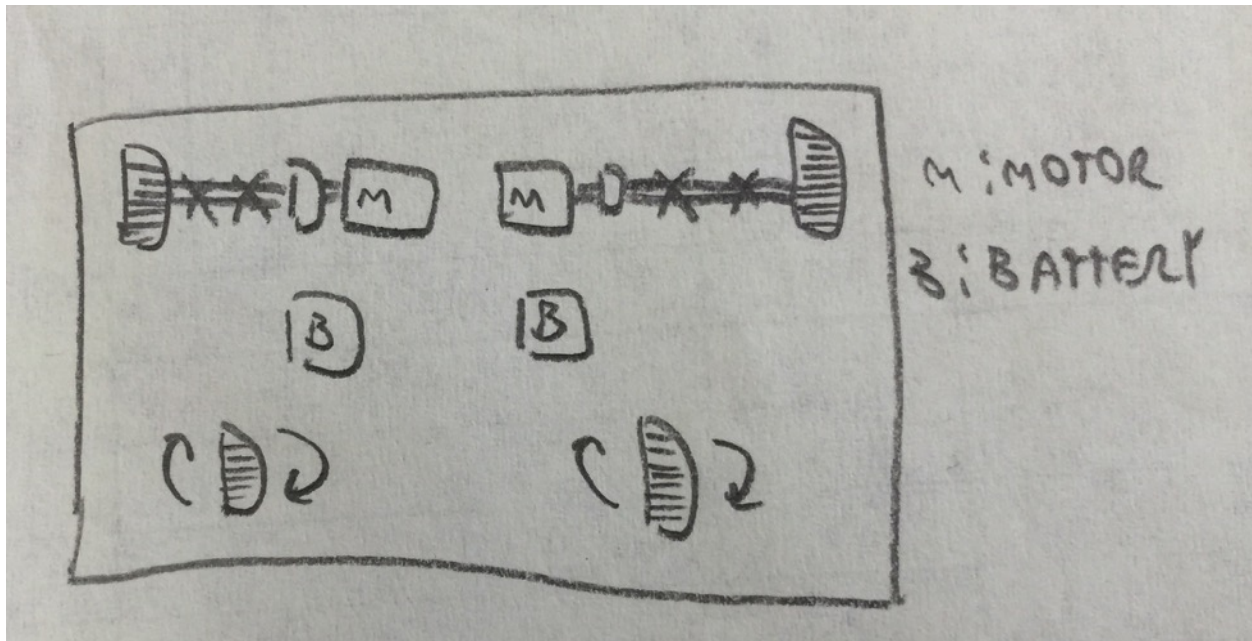


Figure 8. Modified Platform design concept. This is the underside of the device.

It was decided that in order to control the device in a concealed way, the switches will be placed on the platform itself and controlled with the toes. It is extremely important that the toe barely move in order to activate the corresponding switch and motor so that balance is not lost during control. The height of the exposed switch should not exceed half an inch.

4. Description of the Final Design

This section explains in detail the chosen design concept, including geometry, material and component selection, and cost analysis.

4.1 Design Details

This section describes each component's geometry and material selection. The design consists of a platform for the user to stand on with two switches near the toes to control movement. Attached to the underside of the platform are the batteries, motors, wheels, and all necessary wiring.

The selected parts are detailed in Table 1 below. Further explanations and reasoning is explained in the subsequent sections.

Table 1. Part Selection

Component	Selection
Platform	23/32"x15"x12" Plywood
Motors	437 RPM HD Precision Planetary Gear Motor
Motorized Wheels	4" Diameter Heavy Duty Wheel
Casters	3" Diameter Swivel Plate Caster
Batteries	3700 mAh 12V NiMH Battery Pack
Switches	Single-Pole Momentary Contact Push-Button Switch

The device components are broken down and detailed in three categories: platform, structural, and electrical.

4.1.1 Platform Details



Figure 9. 15"x12" Plywood Platform

Seeing as the device would use four wheels in total, it made sense for the platform to be rectangular. The chosen dimensions were 15"x12". The 15" width allowed for comfortable feet placement on the platform, with the user placing their heels together and pointing their feet slightly outward. The 12" length allowed for more room on the underside of the platform for electrical and other structural components.

As for the material, simple plywood was selected due to its high strength and resistance to cracking and bending. Its light weight was also a positive factor as it helped exert a lower load on the wheels. A 23/32" plywood height was selected.

4.1.2 Structural Details

The motor and motorized wheels were attached to the underside of the platform by connecting them with an aluminum channel. This channel ran alongside the width of the platform. It was connected to 90° brackets and attaching those to the underside of the plywood with wood screws.



Figure 9. Aluminum Channel

The total height of the device had to be considered. It should be kept as low as possible due to costume concerns. Increasing the height would make it more difficult to conceal the device using the angelic cloth costume. 4" diameter wheels were selected for the

motorized wheels. 3” diameter swivel casters were selected. The casters were directly attached to the underside of the platform by screwing the attached metal plate to the plywood.



Figure 10. 4” Diameter Motorized Wheel



Figure 11. 3” Diameter Swivel Caster

4.1.3 Electrical Details

Appropriate motor selection depended on the intended speed of the device and the load the motorized wheels would bear. An appropriate velocity for the angel would be walking speed. This speed was approximated to be 5 mph. RPM requirement with 4” diameter wheels was calculated as follows:

$$V = \frac{5 \text{ miles}}{\text{hr}} = \frac{5280 \text{ in}}{\text{min}}$$
$$RPM = \frac{5280 \text{ in}}{\text{min}} \cdot \frac{1 \text{ rotation}}{4\pi \text{ in}} = 420.17 \text{ RPM}$$

A 437 RPM brush motor was selected with a maximum torque of 305.5 oz-in at a rated voltage of 12 VDC.

The selected motor’s rated voltage was 12VDC, so a battery capable of producing 12V was required. The scenes in which Jibril appeared did not require him to move too often, so a 3700 mAh battery pack was selected as the motor did not have to run for too long. A NiMH type battery was deemed to be appropriate for the device seeing as the motor did

not require a high amp load. The battery is rechargeable with a universal smart charger, which was ideal seeing as the show was to be performed on two separate occasions. Two of these batteries were purchased, one for each motor.

As stated earlier, the switches' height had to be considered due to it being controlled by the toes. Small SPST momentary switcher were selected, mountable on half-inch holes which were to be drilled into the plywood platform. The switches were default off, momentary on in order for the user to press down with their toes in order to move forward. Two of these switches were purchased, one for each circuit.



Figure 12. Selected Switch

The electrical components were connected with 14 AWG wires taped on the underside of the platform. The wiring formed two circuits, one for each motor (left and right).

4.2 Cost Breakdown

This section presents the costs of the device. The data is outlined in Table 2 below.

Table 2. Actual costs for device

Part	Cost (\$)
Plywood Platform	29.98
Motors	79.98
Batteries	107.92
Other electrical components	22.50
Other structural components	133.95
Device Total	374.33

Refer to Appendix B: Vendors and Pricing for detailed cost breakdown.

5. Product Realization

This section outlines the manufacturing process and recommendations for future manufacturing of the design.

5.1 Construction

Once the plywood was acquired, the 15"x12" platform was created using a table saw. The edges were sanded in order to prevent wood splinters, as the device was to be picked up from its sides and moved during blackout scenes in the production. In order to find the best placement of the switches, I stood on the platform with my feet slightly pointed outwards. I marked the location of my big toes on the platform. A rotary tool was used to drill a half inch hole through the wood on the marked locations. The switches were then fitted through the holes, with the button poking out of the surface and the terminals on the underside of the platform. The switches were then attached to the platform with super glue.

The channel was attached by connecting it with three 90° brackets which were then screwed onto the underside of the platform on the opposite edge of the casters. The casters were attached to the device by screwing the attached metal plate onto the underside of the platform, half an inch from the edges.

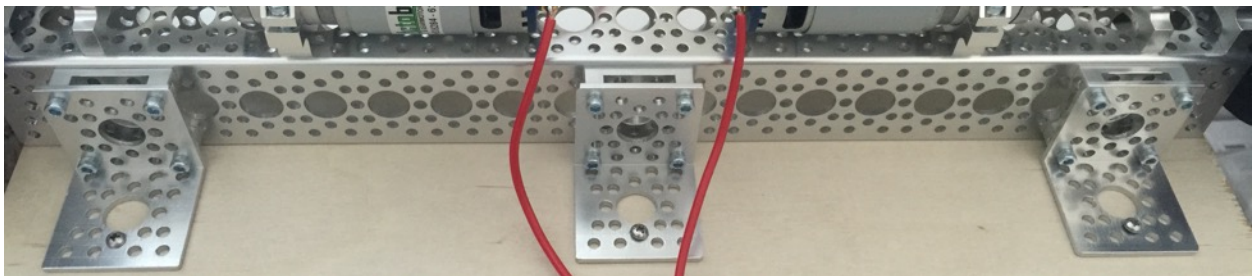


Figure 13. Channel Attachment with 90° Brackets

The motors were attached to the channel with clamping mounts, which were then screwed into the channel. The motor's shaft was connected to a 1/4" shaft with a coupler. The 1/4" shaft was attached to the channel with two pillow block bearings. The shaft was finally connected to the heavy duty wheel with a clamping hub. Figures 14 and 15 below help visualize this process.

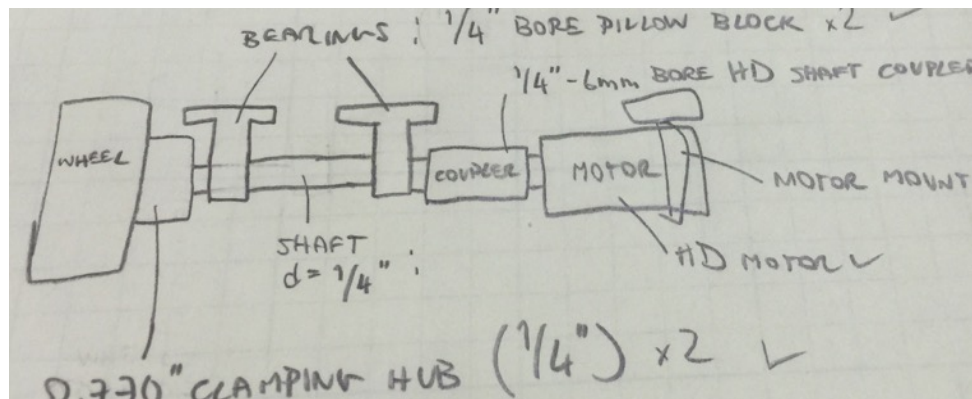


Figure 14. Channel Attachments (1)

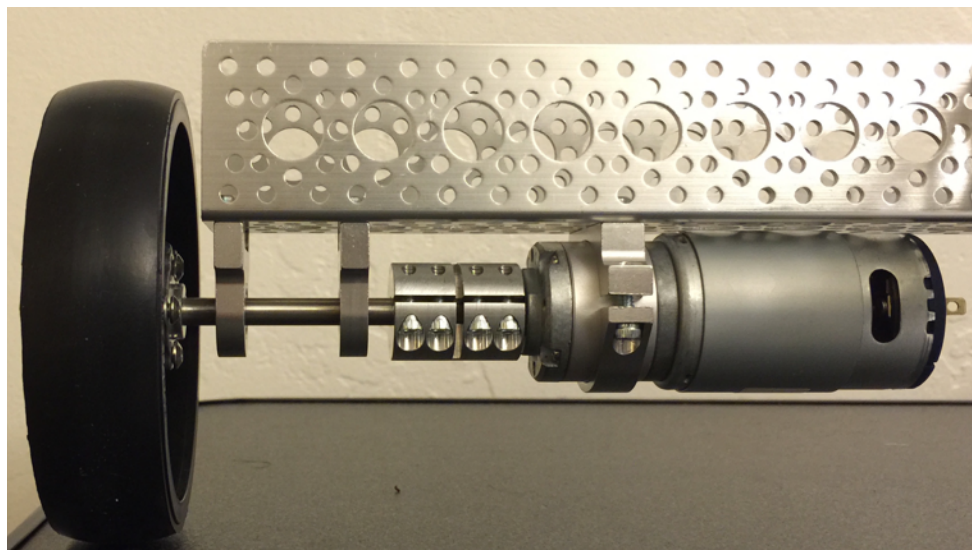


Figure 15. Channel Attachments (2)

The batteries were attached to the underside of the platform with duct tape. Wire was soldered onto the terminals of the motors and switches, and bullet connectors were used to connect it to the batteries. The wire was then taped onto the platform in order to prevent it from dragging along the floor and potentially getting stuck under a wheel. Figures 16 and 17 below help visualize the circuitry.

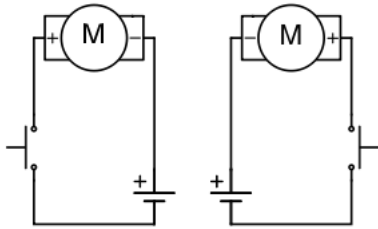


Figure 16. Circuit Schematic

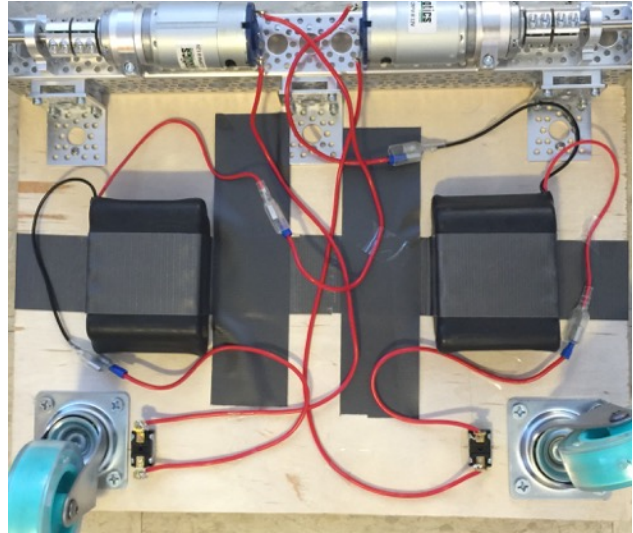


Figure 17. Underside of Device

Figures 18 and 19 on the following page show the completed device.



Figure 18. Top View

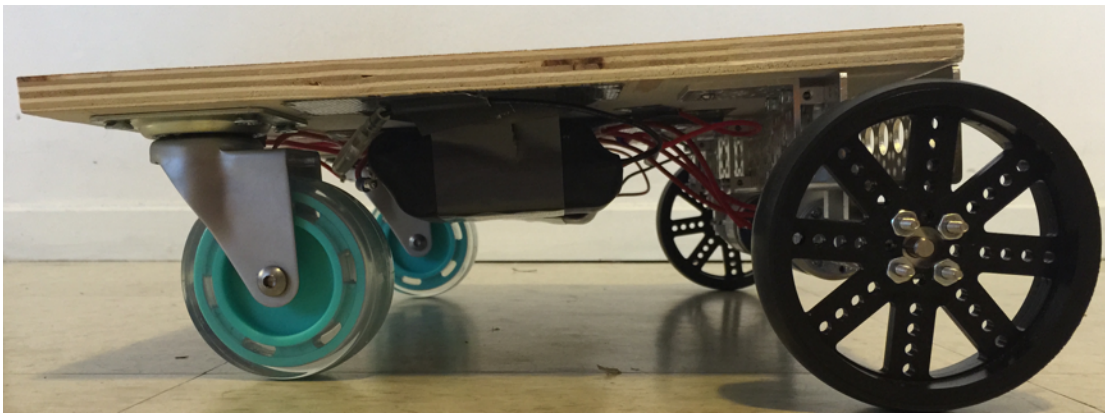


Figure 19. Side View

5.2 Recommendations for Future Manufacturing

The following section recommends design changes in order to improve the device.

5.2.1 Noise Reduction

The device was designed to be hidden from sight by covering it with the loose fabric of the angel's costume. This provided a small amount of noise reduction to the motors while the device is moving. In order to further suppress the sound of the operating motors, I recommend adding other means of sound insulation to the device.

5.2.2 Wheel Protection

During testing, the wheels collected any dust and small materials on the ground. This prevented the device from working to its full potential. The casters were more reluctant to swivel due to debris and random dust they collected. I suggest adding some way to easily brush off these inconveniences when not in use, or some way to prevent the dirt from becoming attached to the wheels.

5.2.3 Backwards Movement

It was not necessary for the purposes of the production for the device to move backwards. However, in the case that is desired, one could design more elaborate circuitry to make it happen. Using the remote-control idea⁴ would alleviate some pressure on the performer by giving them less things to think about while performing.

⁴ See section 3.1.3 Control

6. Design Verification

Following construction of the device, verification of the design was required to determine its performance and whether or not it met the requirements.

6.1 Costume Verification

It was necessary for the device to be concealed beneath the costume. I met with Kate Hepworth, who designed Jibril's costume. I showed her the device and informed her of the required length and width of the costume in order to conceal the device. Ms. Hepworth attached a slightly flexible metal ring to the end of the costume which was wide enough to cover the entire device. During testing of the device, it was found that the costume was too short. If the device would have made it through testing, I would have contacted Ms. Hepworth again to increase the length of the costume for it to fully conceal the device.

6.2 Testing Procedure

Testing occurred during the production's rehearsal days shortly preceding the first performance. The device was brought to rehearsal in the pavilion of the Cal Poly Performing Arts Center, where the performance was to take place.

I was to appear in five scenes in the show. The first introduced Jibril to the audience and required me to move in a circle two times around the stage before finally coming to the center. The second scene saw Jibril walking off to the side of the stage, then coming back to the center. The scene ended in a blackout, where I would pick up the device and place it in another location on stage where the third scene took place. I was not to move at all during this scene. The fourth scene saw me entering from the side and slowly make my way to the center. This scene also ended in a blackout, where I would pick up the device and quickly walk off stage. In the final scene, I would make my way slowly to the center of the stage and the show would end with me moving in a tight circle near the center.

The device performed worse than expected. With a little practice, I was able to move smoothly for a short while after the device had been inactive. However, the device started

to perform poorly after that period. The right motor would frequently stall, which left me immobile for the remainder of the scene. I was able to turn right by just using the left motor, which was not enough to move me to the necessary location. I noticed that the right motor would heat up quickly compared to the left motor. The device would work again after a period of inactivity to let it cool down, before once again stalling after continued use.

It was difficult for me to concentrate on both the movement of the device and my scripted gestures and spots based on musical cues. This led to decreased performance, which was noticeable by the stage managers and ultimately led to the decision that the device would not be used in the show.

The device was fairly quiet during movement, but it would have been noticeable to any attentive audience member sitting in the closest row to the stage. Jibril's movement was close to the edge of the stage, near some audience members on a few occasions.

7. Conclusions and Recommendations

This project was assigned to me by Prof. Antonio Barata of the Cal Poly Music Department. He wished for a device to smoothly and eerily allow one to move without using their legs. The device was to be used by myself performing as an angel in RSVP, a yearly student-produced production led and overseen by Dr. Barata.

The project began with exploring ideas for the design inspired by similar devices in the market. Ultimately, a rectangular platform with two motor-powered wheels and two casters was chosen. Parts were purchased and connected, and the device was built and tested.

During testing, it was found that the device did not perform as well as expected. A motor would frequently stall and cause me to become immobile or move in a jittery fashion, which was not desired. The project was eventually chosen to not be included in the show, and I would go on to successfully perform in the show without the need of a device. Recommendations for the product can be found in Section 5.2 Recommendations for Future Manufacturing.

8. Acknowledgements

I'd like to thank the following people for their support and encouragement throughout the quarter:

Dr. Antonio Barata of the Cal Poly Music Department for his leadership and support.

Dr. James Widmann of the Cal Poly General Engineering Department for his help and support.

Ms. Kate Hepworth for her cooperativeness and creation of Jibril's costume.

The entire 2016 RSVP crew.

Appendix A: Vendors and Pricing

Table 3. Vendors and Pricing

Part	Vendor	Amount	Cost (\$)
Plywood	Home Depot	1	29.98
437 RPM HD Precision Planetary Gear Motor	ServoCity	2	79.98
4" Heavy Duty Wheel	ServoCity	2	13.98
3 in. Teal Swivel Plate Caster	Home Depot	2	24.96
0.770" Clamping Hub	ServoCity	2	15.98
1/4" - 6mm Bore HD Shaft Coupler	ServoCity	2	25.98
32mm Clamping Motor Mount	ServoCity	2	13.98
1/4" Bore Pillow Block	ServoCity	4	23.96
1/4" Precision D-Shafting	ServoCity	2	4.38
15" Aluminum Channel	ServoCity	1	11.99
90° Single Angle Channel Bracket	ServoCity	3	4.77
90° Dual Side Mount D	ServoCity	3	20.97
3700 mAh 12V Battery Pack	Trail Tech	2	107.92
Single-Pole Momentary Contact Push-Button Switch	Home Depot	2	9.98
50' 14 Gauge Red Primary Remote Wire	Audiopipe	1	8.95
50pcs Premium Silver 14-16 Gauge Male-Female Solderless Crimp Bullet Plug Connectors	Genetic LA	1	3.57
Device Total			374.33