Smart Walker

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by

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ABSTRACT

The smart walker project was established in an effort to address a demand in the elderly community for mobility assistance. Aging individuals gradually lose strength and their ability to walk long distances but that does not mean that they have to lose their dignity and independence. In order to combat this loss of mobility and independence, we have come up with an innovative, hybrid, solution that converts a typical 4-wheeled walker into a short-term motorized wheelchair. This solution allows the user to remain independent, while giving their loved ones and caretakers' peace of mind.

This text explores our research and other designs that led us to why we created a conversion kit. The text also details a number of the customer and engineering requirements used to come arrive the walker design and prototype that was eventually completed. This paper also explains the materials and manufacturing process used in the production of the prototype, as well as any relevant and necessary testing. This paper is a proof of concept for our design and general guideline for next steps in the improvement of the design.

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PROBLEM DEFINITION AND RESEARCH

PROBLEM DEFINITION AND BACKGROUND:

The number of people 65 or older in the United States was 46.2 million in 2014 according to the U.S. Department of Health and Human Services (1). By the year 2060 there is estimated to be 98 million. This being the case giving older people the opportunity to live in their own homes longer will not only help the already struggling health care system, and families trying to make ends meet, but also help them remain more independent and happier.

One way to help elderly stay in their own homes longer is to help them with their mobility. A walker is a common tool that is used to help with getting around. We propose to improve upon the current wheeled walker design to make it more functional for the end user. Many users get tired or their joints get too sore to continue walking and need to sit down. Many walker designs allow for this but then require an aid to push the user to the desired location or for the user to stay in that place until they desire or can get back up.

RESEARCH, TECHNOLOGY AND EXISTING PRODUCTS:

Professionals within the Maple Knoll Retirement Community prompted the Smart House collaborative engineers with an idea for a wheeled walker that was also capable of becoming a motorized wheelchair. After meeting with Dr. Kumar, an advisor with the Smart House team, and his associates we began to research current walkers (wheeled and non-wheeled) designs as well as wheelchair designs on the market to get a better understanding of available products. Our research was then focused on wheeled walkers which turned up the following designs:

- Simple two-wheeled walkers for stability only
- Three-wheeled walkers used for easy maneuverability of tight indoor spaces
- Four-wheeled walkers without a seat
- Four-wheeled walkers with a seat

Each type of walker had its pros and cons but our focus was the four-wheeled walker with a seat. This walker would provide the best transition to a motorized wheelchair and fit the best into the original scope provided by the Smart House team.

This focused decision led us to extensive patent research. We researched all types of walkers, wheelchairs and motorized walker designs. Basic designs have the ability for the walker to convert from a walker to a wheelchair, or for the customer to sit and rest. Extensive patent research produced two motorized walker designs that appear to be bulky, cumbersome and rigid (2) (3). Based on this research we believe that we can design and produce, a walker that can allow the user to keep more mobility and freedom than the current designs allow.

After much deliberation among ourselves and our advisor we have decided that producing a kit to modify a customer’s current walker would be a more feasible product. This will allow us to prove our concept cheaper and get more customer feedback before potentially designing an entire walker. Our design will create a conversion kit for current wheeled walkers with a seat to transform them to have motorized capabilities so that the user may travel a distance/time while sitting to regain strength and energy. This design will need to remain lightweight, collapsible and user friendly. Further patent and product research has been unsuccessful in producing any sort of conversion kit similar to our design idea.

CUSTOMER SURVEY:

Our conversion kit will be useful for anyone that currently has a 4-wheeled walker and anyone that would potentially buy one. This customer base could include:

- Elderly currently using a 4-wheeled walker
- Scooter or power wheelchair users
- Rehabilitation patients

To obtain optimal feedback from our customers we conducted two informal interview with Maple Knoll Village residents and staff. Our first meeting consisted of six females, the director of residential services, and the director of corporate communications. Our questions were also distributed to other residence and staff to obtain further feedback. Based on this information we identified the below customer features:

- Height adjustment
- Sitting function
- Storage-removable
- Backrest
- Way to keep it folded up
- Improved brakes
- Comfortable handles
- Ability to move while sitting
- Improved shock absorption
- Better brakes

Our second meeting consisted of scooter or motorized wheelchair users; four females, four males, the director of residential services, and the director of corporate communications. Our questions for this group were similar to that of the first. Based on this group’s feedback we identified the below customer features:

- Light Weight
- Storage
- Easy to collapse
- Smooth ride/ feeling

- Disassemble easily
- Easy to control steering
- Good brakes
- Carry things without getting squished when collapsed
- Safety

ENGINEERING CHARACTERISTICS AND PRODUCT OBJECTIVES

ENGINEERING CHARACTERISTICS

Utilizing Quality Function Development (QFD) we translated the "voice of the customer" into a house of quality (HOQ). The HOQ was then used to narrow down those characteristics for design purposes. The top five characteristics that we will aim to adhere to in our design are:

Table 1: Engineering Characteristics Based off HOQ

Engineering Characteristics Based on HOQ	Weight
Weight	4.48
Collapsible	3.23
Braking	2.27
Battery/ distance capable of travel	2.22
Removable Motors	2.06

PRODUCT OBJECTIVES

Proceeding with the above characteristics in mind we began to decide what should be included in this design and what our goal was. The following list encompasses the scope of our design:

- Create a product that is light weight
- Create a product that is collapsible
- Improved braking
- Small battery that can be used to run the product for 30 minutes to 1 hour
- Easy to remove motors
- Tracking capability to measure how long the user walks/ rides product
- GPS tracker for missing or lost users

DESIGN ANALYSIS

The Maple Knoll Community donated a used, 4-wheeled walker with a seat to our project and it is pictured in its original form in Figure 1, below. This walker has an aluminum frame with 4 caster wheels, of adjustable height, has a seat, and is collapsible. Our design would include a basic kit to upgrade this design to a motorized option. That kit would include the generic elements shown in Figure 2 and will comprise of the wheel mounted motors, joystick, software, batteries, and all necessary attachments. The software and batteries will be contained inside the grey project box, also displayed in Figure 2: Basic Kit Contents. The walker upgrade will look like Figure 3 (the arrows indicating kit contents).

Figure 1: Original Walker before modification

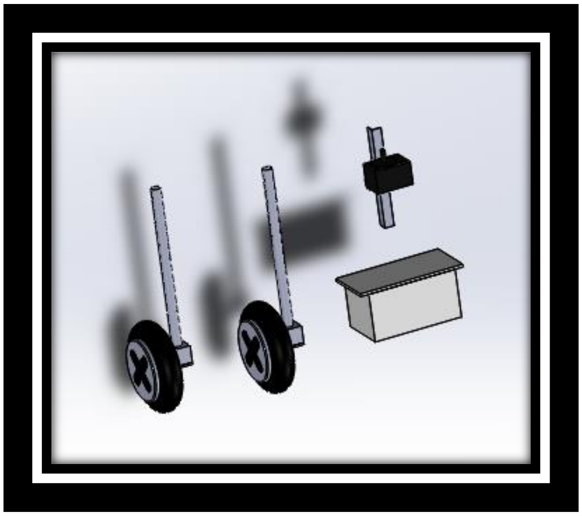

Figure 2: Basic Kit Contents

Figure 3: Final Walker Design

Mechanical Component Design

Wheel Mounts

After establishing our plans to create a walker conversion kit, it was determined we would need a mechanism to attach our motors to the walker. Early in the design stage, we discussed multiple angles of approach for the wheel/motor mounts. The design needed to meet three main requirements:

1. It needed to immobilize the motor axle
2. It needed to attach the wheel to the walker
3. It had to be small, lightweight, and strong

Ultimately we settled on the design in Figure 4, below:

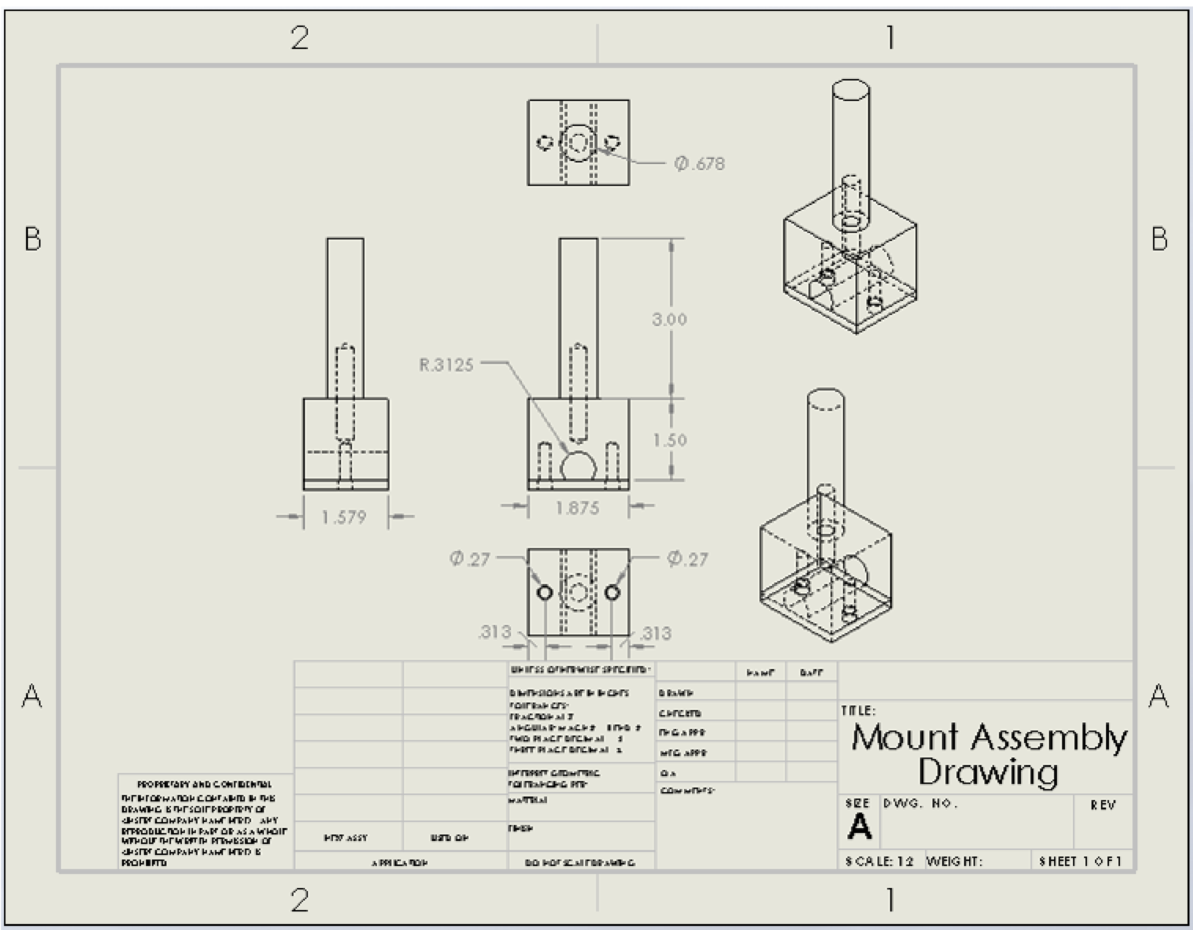

Figure 4: Mount Assembly Drawing

Wheel Mounts: FEA Analysis

An FEA was performed for the wheel mount design to determine if the design could withstand the maximum possible load applied to it. The FEA was ran for a 250 lbf, which is our maximum allowable weight rating for the walker. The FEA was tested at a 30.5° angle based off of the angle at which the walker leg would meet and rest on the mount. The Yield Strength of Aluminum 6061-T6 was determined to be 275 MPa. The Safety Factor of the design was 5.5. The maximum Stress was 57 MPa and found at the base of the shaft, as shown in Figure 5. The maximum Strain was .0535 MPa and also found at the base of the shaft, as shown in Figure 6. Maximum displacement was found at the top of the shaft and was .1422 nm, as shown in Figure 7. These values were found to be well within the yield strength of the aluminum and elastic bending range. There will be no permanent deformation and therefore be well suited for this application.

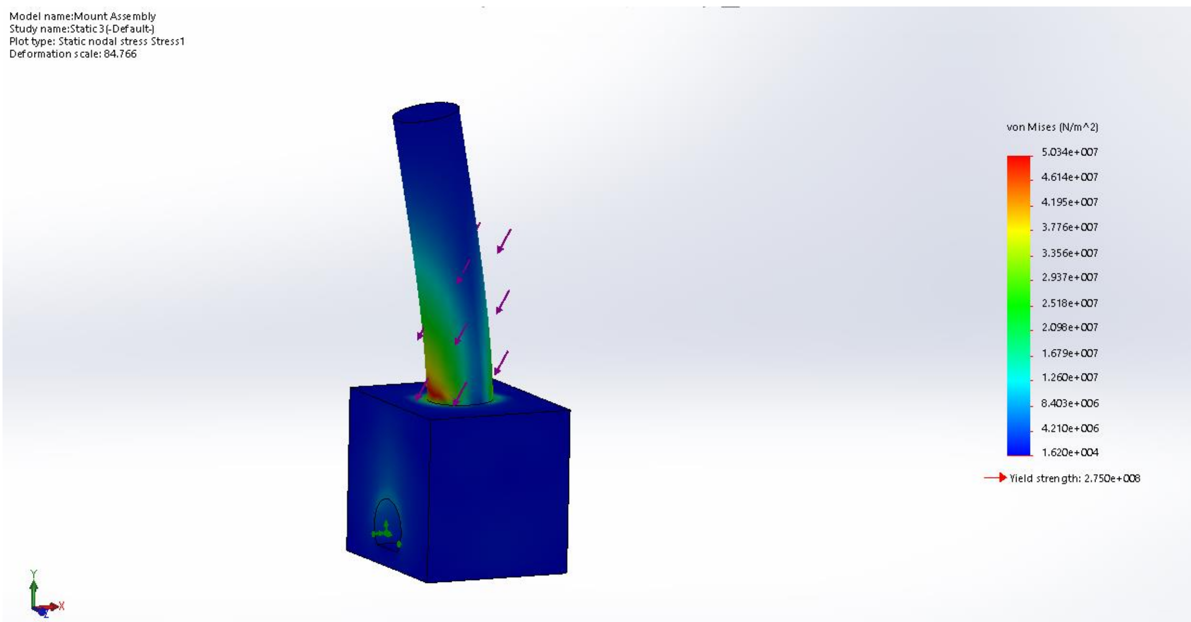

Figure 5: FEA Stress Analysis

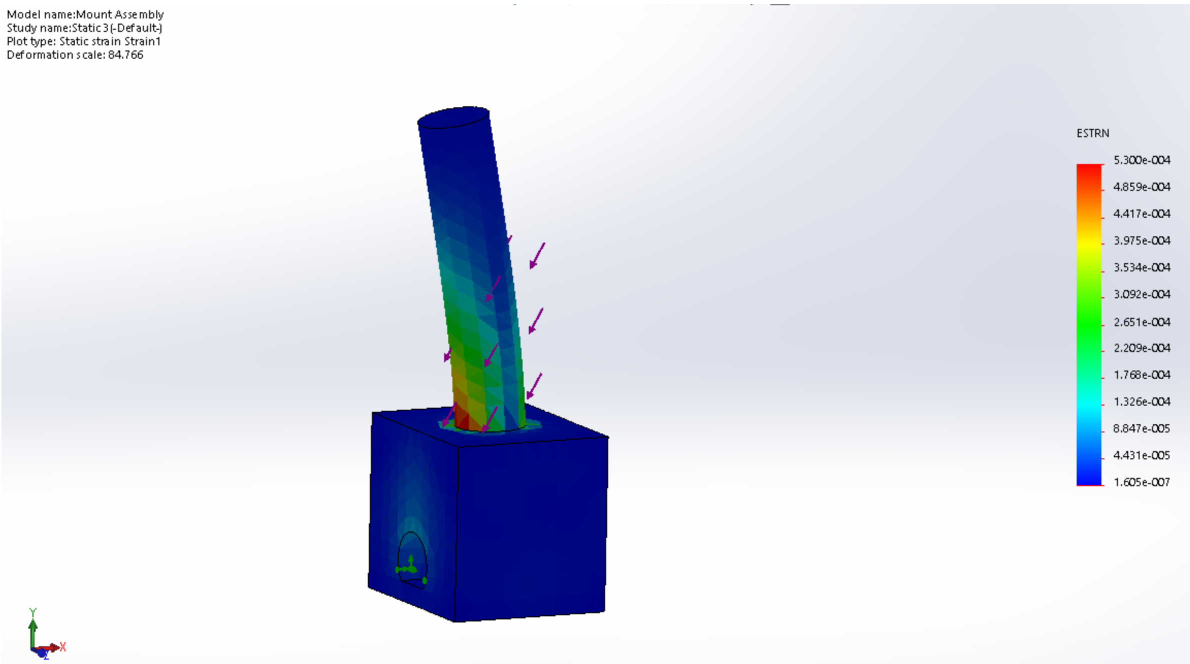

Figure 6: FEA Strain Analysis

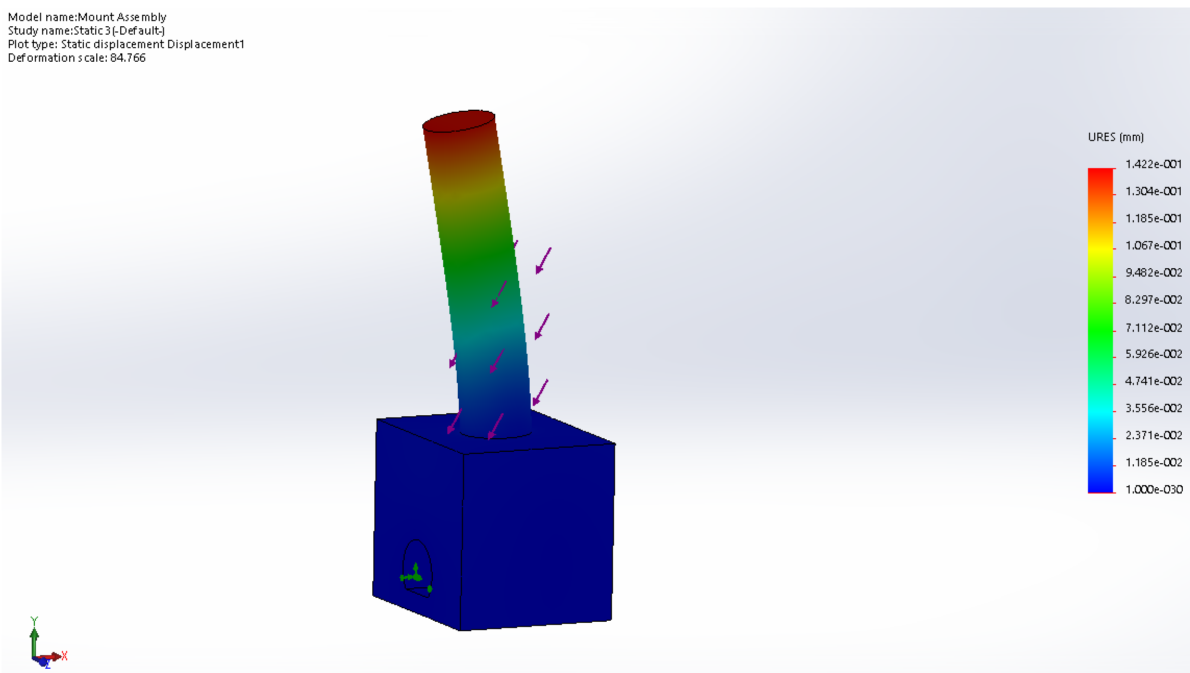

Figure 7: FEA Displacement Analysis

BRAKES

After our initial assessment of the walker, it was determined that the original braking system was flawed. The original system utilized a hand-squeeze system that actuated a smooth steel bar used to apply pressure and create friction, thus stopping the wheels. The friction was often not enough to provide the necessary stopping power. Another issue found with the brakes was that the locking screw used to hold pressure in the brake line frequently came loose and needed readjustment. ‘

For our new design we wanted to keep it as simple and as close to the original braking system as possible. We did this for two reasons. First we wanted to keep the cost of the new system as low as possible and second we wanted to maintain a user friendly system without an entirely new learning curve for the customer. The new design would be a simple modification of the old system to add more friction and make sure the locking screw remained in place.

In order to ensure that the locking screw remained in place, we added Loctite adhesive to the threads. The next step was to create more friction. To supply the friction we needed to the rubber tire treads, we decided to add rubber bike brakes. We designed an L-shaped fixture to ensure the proper height and location and then attached the rubber bike brakes. (See Figure 18 & Figure 19 on page 20 for more on Brakes)

Footrest Mount

After discussing it with our adviser it was decided that buying a footrest would be a better option than designing our own. The desired footrest would be light weight, small, capable of moving out of the way and could be easily attached. Such a design was found in the footrest used on the Roscoe Transport Rollator with Padded Seat (4), as shown in Figure 8.

Figure 8: Roscoe Transport Rollator with Padded-Seat-Burgundy

Unfortunately, replacement footrests where not able to be sourced. This caused more research into a footrest that would meet the needs presented above. The Excel Translator Transport Chair / Rollator, shown in Figure 9 (5), had a footrest design that could swing to the side allowing them to be out of the way of the user while they were walking. They were also able to be purchased as replacement parts.

Figure 9: Excel Translator Transport Chair / Rollator

Inopportunely the footrests where sent to New York City by mistake of the company they were bought from. This led to an extended lead time receiving the merchandise 3 days behind schedule. Upon arrival, it was noticed that the attaching mechanism was not what was expected and mounts needed to be designed that where easy to install and would restrict movement in the X and Z coordinates, while allowing rotation on the Y axis so they could swing to the side out of the way. Sketches in Figure 10 below were concept ideas of a mount that could be attached easily but that could be manufactured quickly.

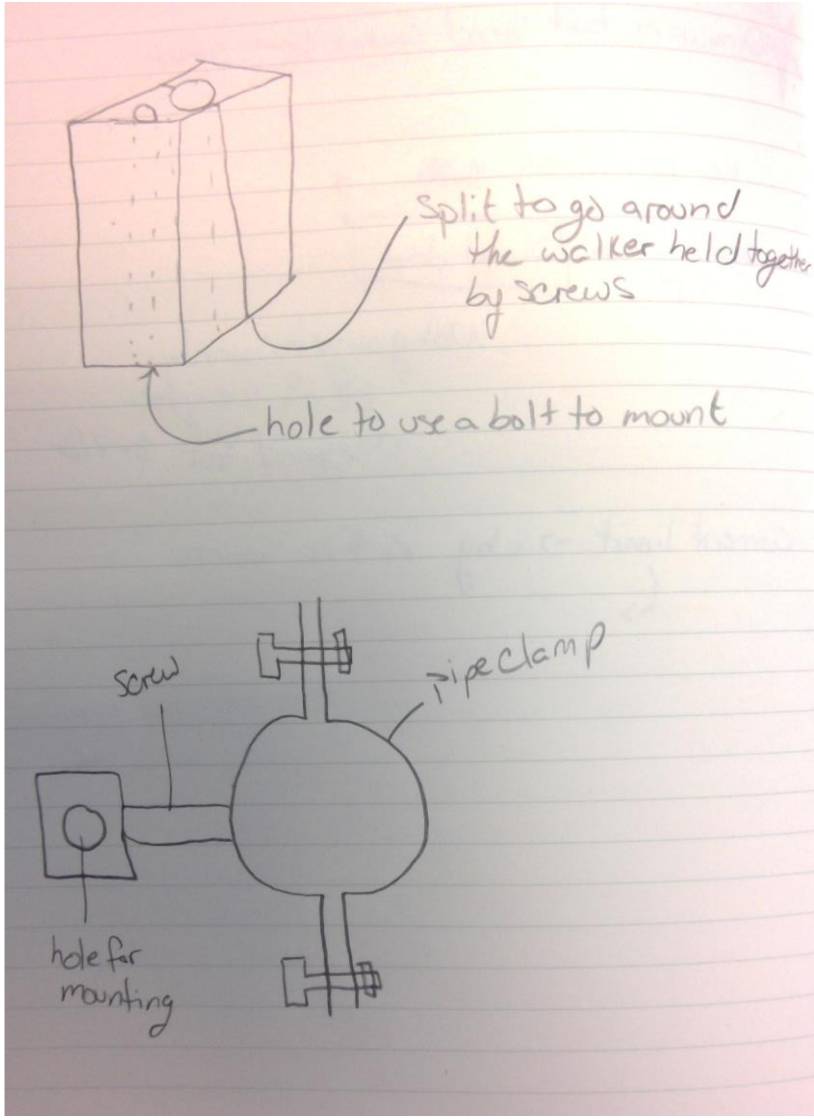

Figure 10: Footrest Mount Sketch Ideas

The second idea shown in the Footrest Mount Sketch Ideas was chosen to be used because it could more quickly be produced. This was important because there was only one day to manufacture a solution. After discussing the idea with Brian Yockey, a fellow student with considerable manufacturing and design knowledge, and Nick Plataniotis an adjunct professor on UC's Victory Parkway Campus, a design for a simple metal block with a bolt hole running vertically to hold the footrest and another hole running horizontally to attach the block to the pipe clamp was produced. A sketch of the mount is shown in Figure 11.

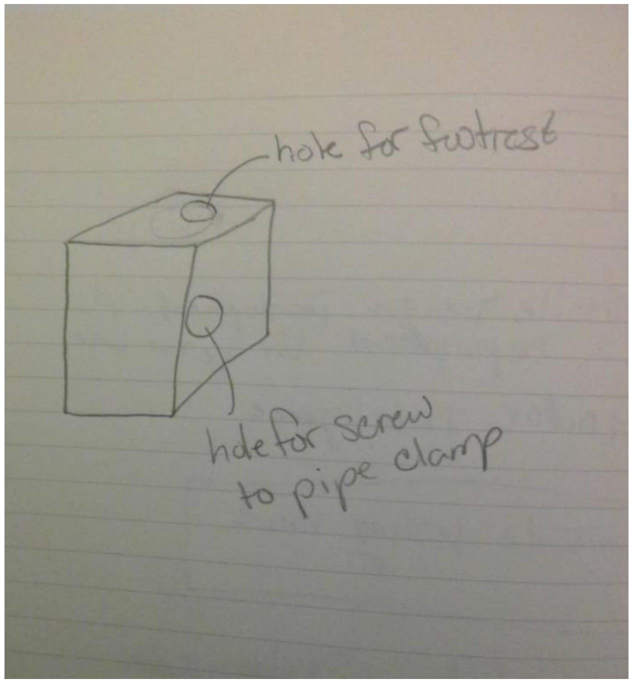

Figure 11: Footrest Mount Design Sketch

ELECTRICAL COMPONENT SELECTION

WHEEL AND MOTOR

The original idea for this Smart Walker design came from watching a YouTube video of a self-balancing hoverboard that had been converted into a seated, four-wheeled cart. If these hoverboards could handle a cart then, surely the motorized wheels powering the hoverboards, could power a four-wheeled walker.

The research process began by determining whether it was possible to purchase the individual motorized wheels and how much they might cost. This proved to be quite easy. The difficult part was determining the specifications of these motors. Would they hold up to the job required of them?

According to our research, the type of motors we would be using are considered brushless direct current (BLDC) motors, mounted in various sized wheels. These wheels came in 6.5 inch, 8 inch, and 10 inch diameters. Torque calculations were performed for the motor specifications and each diameter and can be found in Table 2.

Table 2: Torque Calculations

Est. Max weight (lbs)	270		W=mg	m=W/g (lbf)	8.3851
Gravity (ft/s^2)	32.2			F=ma (lbs)	16.7702
Est. acceleration (ft/s^2)	2	Note: acceleration is half that of walking speed		$T_{6.5}$=F*radius (ft-lbs)	4.54193
Wheel/motor Diameter (in)	6.5			T_{8}=F*radius (ft-lbs)	5.59006
Wheel/motor Diameter (in)	8			T_{10}=F*radius (ft-lbs)	6.98758
Wheel/motor Diameter (in)	10				

These torque calculations, told us that we could use any of the three diameters with the smallest BLDC motor, of 350 watts, for our application. We opted for the 6.5 inch diameter

for a few reasons;
1. Cost effective – It was the least expensive
2. Customer Specifications – Customers prefer smaller wheels to prevent scuffing furniture
3. Weight reduction – Smaller wheel weighed less

MICROCONTROLLER

We have chosen to use an Arduino board for this project because of its open source and ease of use with prototyping. Using inputs from sensors an Arduino board can sense its environment and control outputs to things like lights, and motors. The three Arduino boards that were compared for this project can be found in the Table 3 along with some characteristics of each board, all information can be found on Arduino's website.

Table 3: Arduino Comparison (6) (7) (8)

Arduino Board	Microcontroller	Digital I/O Pins	PWM Digital I/O Pins	Analog Input Pins	Clock Speed (MHz)	Dimensions (mm)
Mini	ATmega328	14	6	8	16	30 x 18
Uno	ATmega328P	16	6	6	16	68.6 x 53.4
Mega	ATmega2560	54	15	16	16	101.52 x 53.3

Based on the board specifications the Arduino Uno was selected. The Uno was chosen over the Mega because of its smaller size and over the Mini because it has an on-board USB to Serial connection.

JOYSTICK

There are many options when it comes to choosing how to steer our project. After brainstorming some of the options we came up with are listed below:

- Joystick
- Touch Mouse pad (like on laptops)
- Buttons
- Toggle
- Foot pedal

In the discussions with the Maple Knoll residence they made it clear that they would like to use a more traditional joystick rather than one of the other options we suggested. From this we then had to decide if a wired or wireless option would be best. A summary of the pros and cons of both are shown below in Table 4 and Table 5.

Table 4: Bluetooth Pros and Cons

Bluetooth	
Pro	**Con**
no wires to get in the way	controller could get lost not being attached
can mount the controller anywhere	could be a lag in signal response
no wires to get damaged and need replaced	could miss a signal
	connection problems
	security problems
	could have problems connecting when turning on

Table 5: Wired Pros and Cons

Wired	
Pro	**Con**
no or less signal lag	have to run wires
no security issues	wires could get caught when trying to collapse walker
no lag in start time	if a wire gets damaged have to replace it
Easier to replace for non tech people	
Faster to setup and test	

Based on the pros and cons comparisons we decided to use a wired joystick. We then researched wired joystick options, the top options can be found in Table 6.

Table 6: Joystick Comparison (9) (10) (11) (12) (13)

Option	Cost	Hight Dimension	Hand Or Thumb Operation	Button?	Back Ordered?
3 Axis Joystick w/ Button	34.99	52 mm	Hand	Y	
Arcade Joystick	19.95	79 mm	Hand	Y	Y
Thumb Joystick	3.95	2 cm	Thumb	Y (hole thing can be pushed)	
Small Arcade Joystick	14.95	34 mm	hand	N	
Mini Analog Joystick - 10K Potentiometers	19.95	52.7 mm	Hand/finger	N	

We decided to use the last option, Mini Analog Joystick – 10K Potentiometer, because it was a size that would make it easy to use with your hand but wouldn't take too much space when mounted to the walker.

WHEEL CONTROL

After doing research there were a few different ways to control the hoverboard wheels that would potentially work:

- H-bridge
- Motor Shield
- Electronic Speed Controller (ESC)

An H-bridge was not chosen for this application due to our limited knowledge base of electronics and how to build an intricate circuit board. A motor shield like the Arduino motor shield (14) could handle a servo motor but the voltage required by the wheels was too high for motor shields that we found in our research. Electronic Speed Controllers (ESC's) come in a wide variety of voltage/amperage sizes and there for were chosen as the top option for controlling the wheels.

An ESC is typically used in R/C model cars where it is used to control the motor speed, direction, and can act as a brake (15). In this application, they control the speed of brushless DC motors using electronic protocol. The ESC can be used with a 3.3 V or 5 V microcontroller capable of running pulse-width modulation (PWM). PWM is a way to get analog results by digital means. A square wave is used to represent the voltage on and off cycle which can be have the duration on/off changed by changing the duty cycle.

For testing purposes we choose a 30A ESC which could be controlled using a microcontroller (16). A description of the testing for this ESC can be found in the Testing section. After successfully testing this ESC with the Hoverboard wheel we began to research ESC's that could handle the high voltage of the wheel. The three ESC's that were considered are shown in the table below.

Table 7: ESC Comparison (17) (18) (19) (20)

Name	Max Input Voltage	Amperage Rating	Reverse Capable	Dimentions (mm)	BEC Available
Mumba Max Pro Extreme	25.5	120	Yes	45.5 x 36.5 x 21.5	Yes
HobbyWing Seaking 80A-HV Brushless ESC for Boat		80	Yes	94 x 33 x 18	No
36/48 Volt 500-600 Watt Electric Scooter/Moped/Bike Brushless DC Motor Speed Controller	36/48		Yes	177.8 x 82.55 x 50.8	No

We decided to go with the Mumba Max Pro Extreme after a supplier issue with the HobbyKing Seaking 80A-HV Brushless ESC for Boat. The Mumba Max Pro Extreme also had a built in BEC that we could use to power the Arduino making it a better choice.

LAYOUT

The control box that will house the Arduino, both ESC's, and the batteries will be located under the seat of the walker, allowing it to be out of the way of the user. It will be attached using heavy duty Velcro for easy assembly. The batteries will be attached to the outside using the same heavy duty Velcro allowing them to be changed easily.

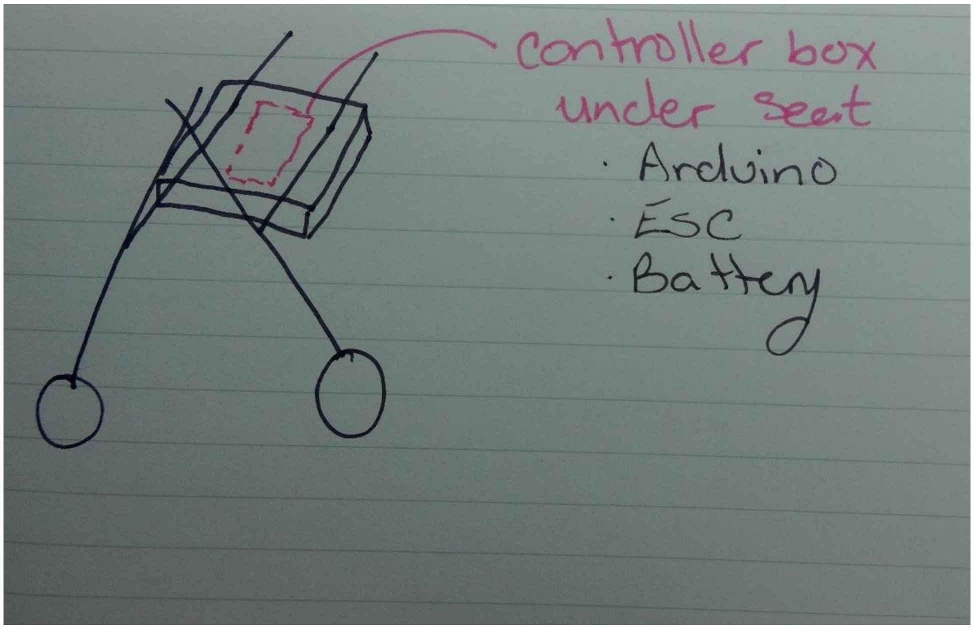

Figure 12: Controller Box Location

The joystick needs to be located in a position that will make it comfortable to use while sitting but not get in the way of the user when using the walker in walking mode. The first idea was to mount the joystick box to the handle using a bracket so that it could slide forward when in use and backward while walking, see Figure 13. Unfortunately, this was not an ideal location given the current handle design made it hard to attach the joystick box in this location and also make it steady.


Figure 13: Original Joystick Location

The second location that was easy to access was the outside of the main walker leg. This would allow the joystick to not be in the way and is the second best option for comfort while using the joystick.

MANUFACTURE AND ASSEMBLY

Wheel Mount

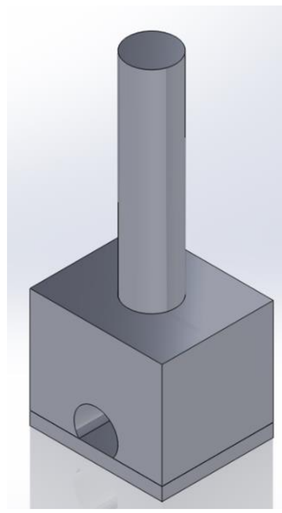

Figure 14: Wheel Mount Assembly

This device, Figure 14, was designed to be machined on conventional mills and lathes without needing CNC control. It was designed and machined in three parts, round stock, Figure 15, a square block base, Figure 16, and a retaining plate, Figure 17. Part dimensions' mimic commercially available part sizes of bar and round stock Aluminum 6061-T6, thus minimizing material removal, saving time and cutting cost.

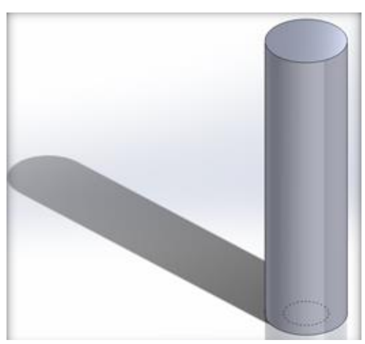

Figure 15: Round Stock

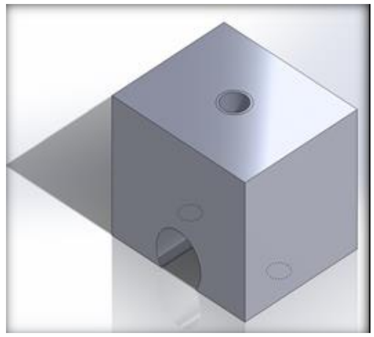

Figure 16: Square Block Base

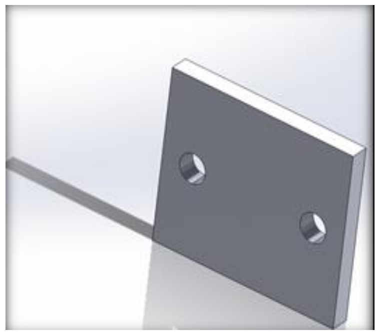

Figure 17: Retaining Plate

The square parts were rough cut with a band saw and then placed in an end mill, where all sides were milled to achieve proper exterior dimensions. A through-hole was drilled from the top of the square block base for the 3/8-16 bolt to pass through and then counter-bored to the appropriate depth. The part was then rotated 90 degrees and a 5/8ths end mill was plunged through the material to form the axle hole. The part was then rotated again, so the bottom was facing up and holes were drilled and tapped for the ¼-20 screws.

The round stock was turned down to the appropriate diameter in a lathe. The stock was then parted to create two parts of the correct length. Each part was then faced in the lathe. Then drilled and tapped for the 3/8-16 threads.

BRAKE

The brake was manufactured from ¼ inch thick steel scraps. These parts were chosen because they were readily available, easily cut and welded, and durable. The steel scrap was measured and cut to size according to design specifications and where the brake needed to meet the tire treads. Then these pieces were welded to create the L-shaped brackets, discussed in Design Analysis. The brackets were then welded to the original steel brake lever and a hole was drilled to attach the rubber bike brake to the bracket. Figure 18 and Figure 19, below, show the L-shaped bracket welded in place with the rubber bike brake attached with a cap nut.

Figure 18: Brake Mount (Front view)

Figure 19: Brake Mount (Side view)

FOOTREST MOUNT

The footrests where manufactured using a CNC and band saw. ASTM A36 steel was chosen as the material because it was available in the UC Victory Parkway shop, if time would have permitted aluminum would have been chosen instead. A scrap piece of ASTM A36 steel measuring 2 x 0.84 x 1.25 in. was found and using the CNC the piece was faced, and then holes where cut to correspond to the drawing. The drilling process can be seen in Figure 20 and Figure 21.

Figure 20: Footrest mount after 1/4”-20 holes have been drilled

Figure 21: Footrest during pecking process of 3/8 holes

After the holes were drilled the piece was taken to the band saw and cut into two pieces. This process was repeated to make a total of four mounts. The finished mounts where then attached to the pipe clamp using a 3/8” course thread bolt and the pipe clamp was attached to the walker. Two mounts where used per footrest and once attached the footrest was then attached using a ¼”-20 bolt and nut. This can be seen in the following figures.

Figure 22: Footrest Mount Assembly (side view)

Figure 23: Footrest Mount Assembly (front view)

Figure 24: Footrest Mount Assembly, Swinging to the side

Figure 25: Footrest Mount Assembly Finished

JOYSTICK BOX MOUNT

The mount that holds the joystick is constructed of aluminum angle stock. This provided an easy way to attach the joystick box to the walker. Slots where cut in one piece of the aluminum angle that would allow a pipe clamp to pass through it and be used to hold the unit to the walker. Pipe clamps where used so that they would be easy to attach and detach as well as be easy to replace. The two pieces of angle where then tack welded together at an angle so that the joystick box would be parallel to the ground once mounted. The joystick box was then riveted to the small piece of aluminum angle to provide a durable hold.

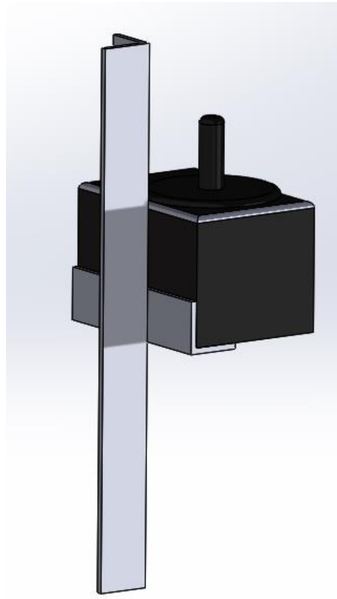

Figure 26: SolidWorks Rendering of Joystick Mount

Figure 27: Joystick Mount Assembled to Walker

CONTROLLER BOX

Holes where cut into the bottom of the control box to allow the Arduino to be bolted in place. Then holes where cut on either side of the box to allow the ESC's wires to enter the box, as well as small holes to mount the ESC's. Two large holes were also cut for the battery harness to exit the box and connect to the batteries on one side. The lid had a small hole cut into it to allow the on/off switch to be mounted.

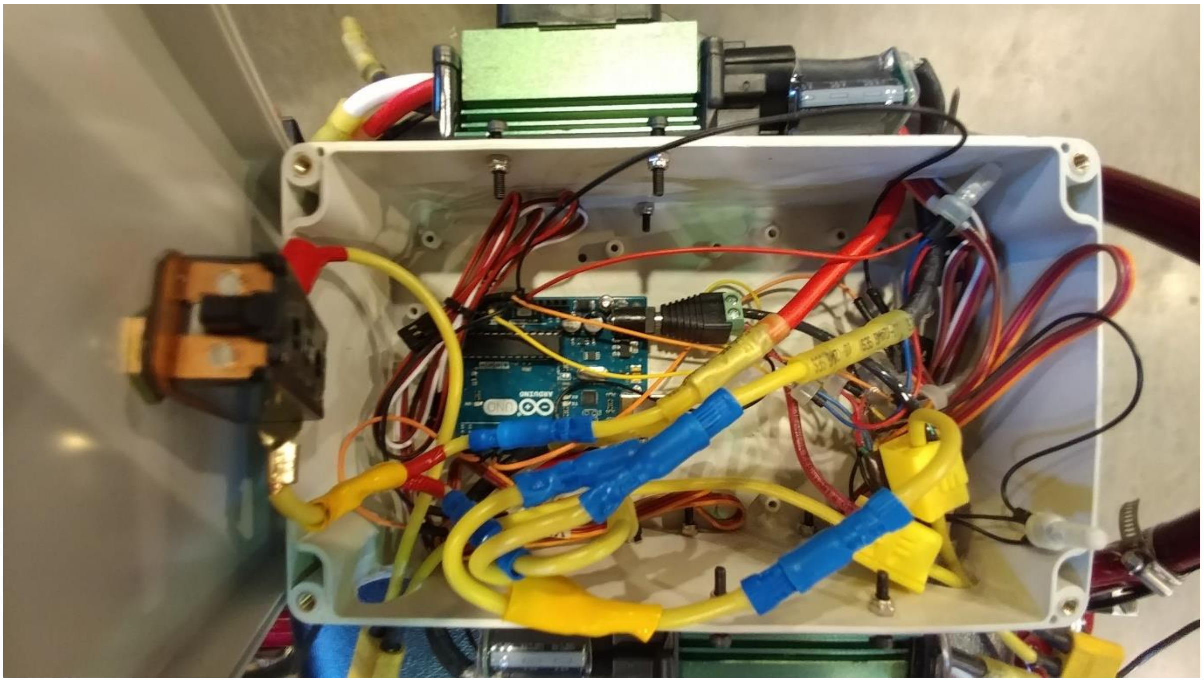

Figure 28: Controller Box

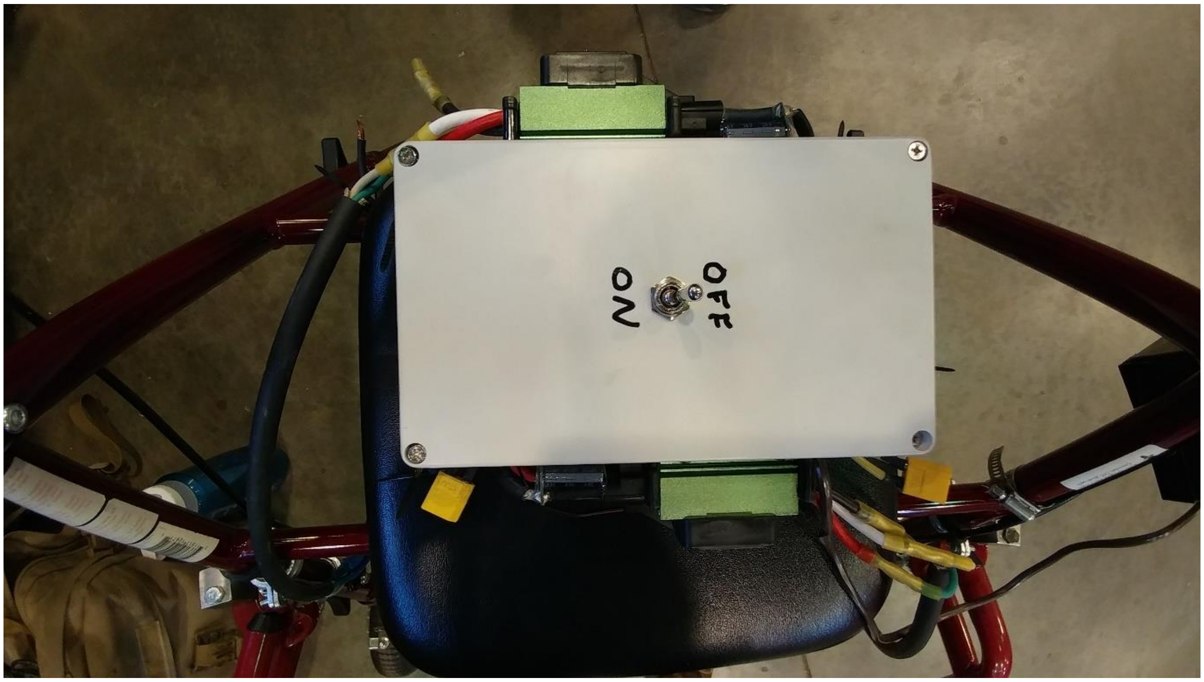

Figure 29: Controller Box On/Off Switch

TESTING AND EXPO

TEST ESC

After deciding that using an ESC would be the best option for our project we bought a 30A ESC, shown in Figure 30 (16), to test to make sure it could communicate with the wheels properly.

Figure 30: Electronic Speed Controller (ESC) used for testing

The three blue wires, shown on the left of the ESC, are connected to the three wires of the wheel making sure that the middle wire from the wheel is connected to the middle wire of the ESC. For an ESC that does not have reverse, like the one we are using for testing, if the motor spins in the opposite direction that you desire simply switch the outside wires. The red wire on the right of the ESC is for positive power and the black wire is for ground. The three small wires that are attached to the connector are for power (red wire), ground (white wire), and signal (black wire). In our application, we will only use the ground and signal wires. It is very important to make sure that the power wire is never connected to the Arduino while the Arduino is connected to a computers USB port because it can cause the USB port of your computer to be destroyed. We will connect the ground (white wire), and the signal (black wire) to ground and pin 9 on the microcontroller respectively. The PWM signal will be sent to the wheel from the microcontroller through the black signal wire. A potentiometer will be used to easily change the speed for testing purposes. Figure 31 and Figure 32 show the original test setup.

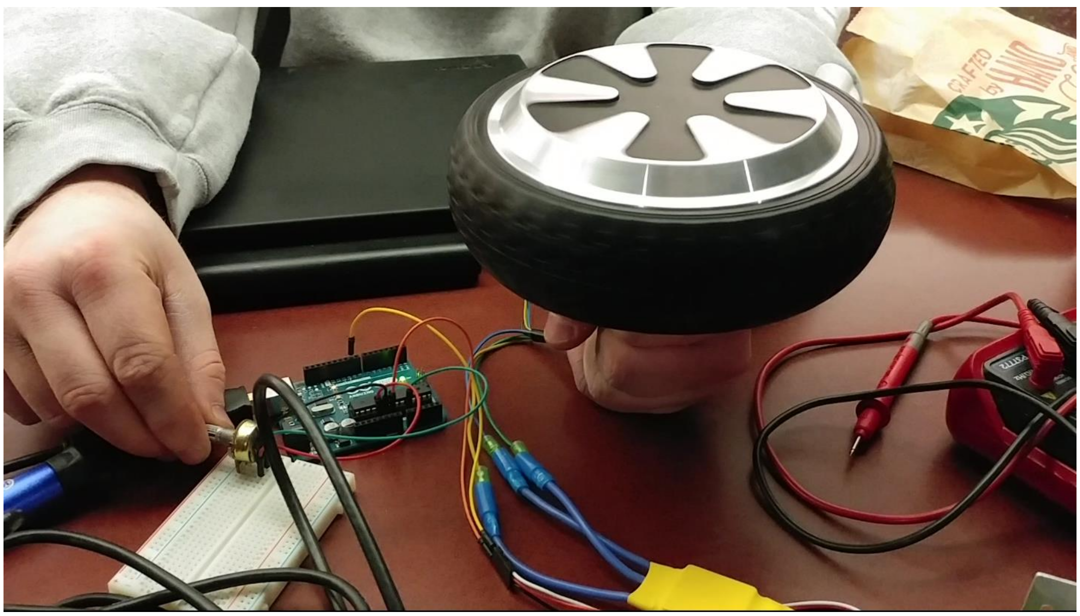

Figure 31: Test ESC Setup

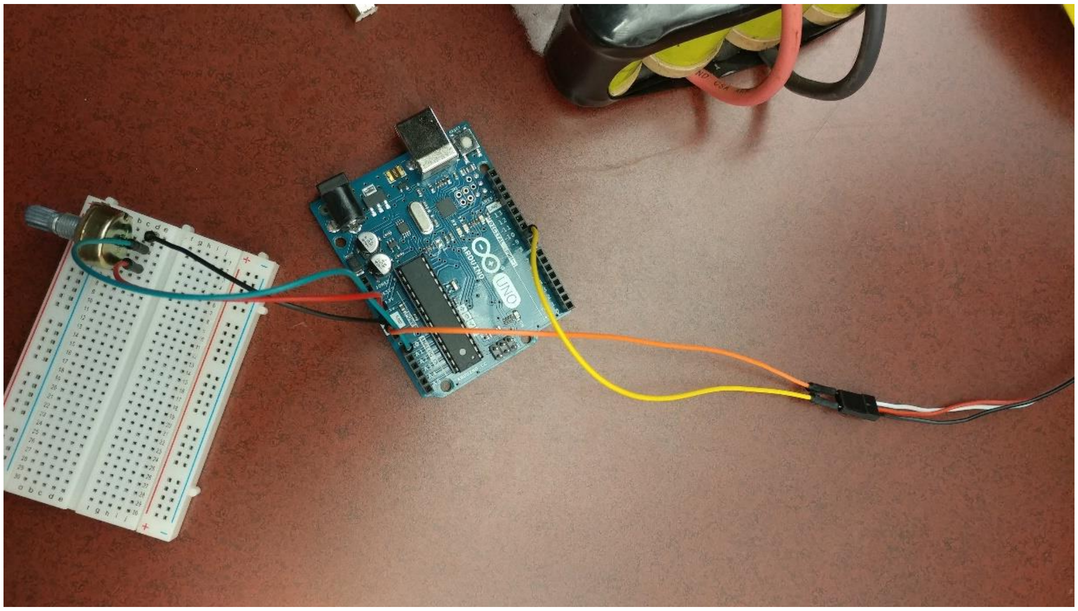

Figure 32: Test ESC Arduino and Potentiometer setup

TESTING MUMBA MAX PRO ESC

After successfully testing the 30A ESC and doing research as stated previously in the equipment selection under wheel control, a test setup was made for the Mumba Max Pro Extreme ESC. This test setup was the same as the previous test except that instead of using a potentiometer to control the speed it was hard coded into the program that you accessed using the Arduino serial monitor, Figure 33.

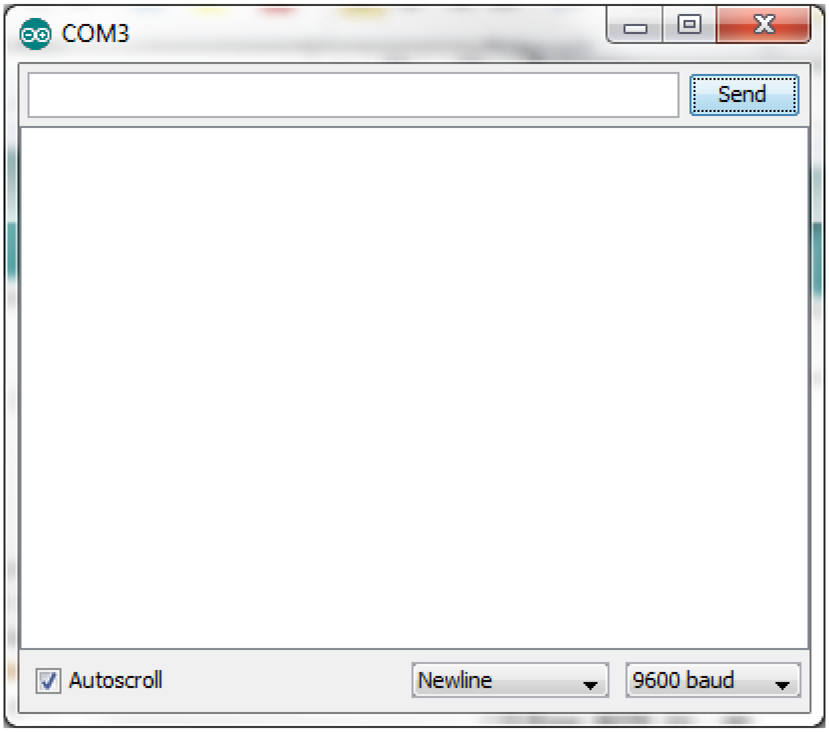

Figure 33: Arduino Serial Monitor

The original code used the values 180, 90, and 0 for full throttle, neutral, and brake respectively. The desired value was selected by using the serial monitor of the Arduino Uno to enter a “T” for full throttle, an “N” for neutral, and a “B” for brake. This setup was used to calibrate the ESC using the procedure documented in the material that was provided in the box. After the ESC was programmed the yellow light flashed to indicate that the calibration was finished and it was ready to be used. One wheel and ESC was tested at first to see how everything would work. Using the values listed above everything seemed to run correctly so we decided to change the internal settings of the ESC so that the acceleration would gradually build instead of going at full speed from a stop, another setting was changed so that the ESC would run in reverse. This reverse function would be called using the “B” brake command in the Arduino code. After making these changes and testing the ESC again an issue arose.

Issue:

The wheel would spin correctly when given the throttle signal on some occasions but during others it would not spin.

Solution:

1. Change the setting to control the acceleration back to factory settings which seemed to solve the problem most of the time.
2. Called the supplier of the ESC, Castle Creations, who suggested to change the ESC PWM signals to 1900, 1500, and 1100 for full throttle, neutral, and brake respectively because these are the values that it is expecting to receive.

After implementing these two solutions and recalibrating the ESC the wheel acted as expected in testing. With this we changed the settings within the second ESC to match those of the first and hooked it up to the Arduino and the second wheel. Now testing with both wheels and ESC's presented its own issues.

Issue:

1. Both wheels don't always spin continuously when sent a throttle signal.
2. When sent a throttle signal occasionally one wheel will spin continuously while the other will spin a short time then come to a stop.
3. When sent a throttle signal both wheels will spin a short time and then come to a stop.

Many solutions where tried to solve these issues as shown below.

Solutions:

1. Move the wires connecting to the Arduino to different PWM pins.
   a. This solution did not have any effect.
2. Change all ESC setting back to factory.
   a. This solution did not have any effect.
3. Take out Serial.print() statements from the Arduino code to see if this is causing a delay in sending the PWM signal.
   a. This solution did not have any effect.
4. Write a different code for the Arduino that allows you to enter any PWM signal using the serial monitor.
   a. This solution allowed us to more easily run the wheels using different PWM signals but did not solve our issue.
5. Using an Oscilloscope test the Arduino to make sure the correct PWM signal is being sent.
   a. As shown below in the following figures the Arduino is sending the proper PWM signal for 1900, 1500, and 1100 at 5 volts.

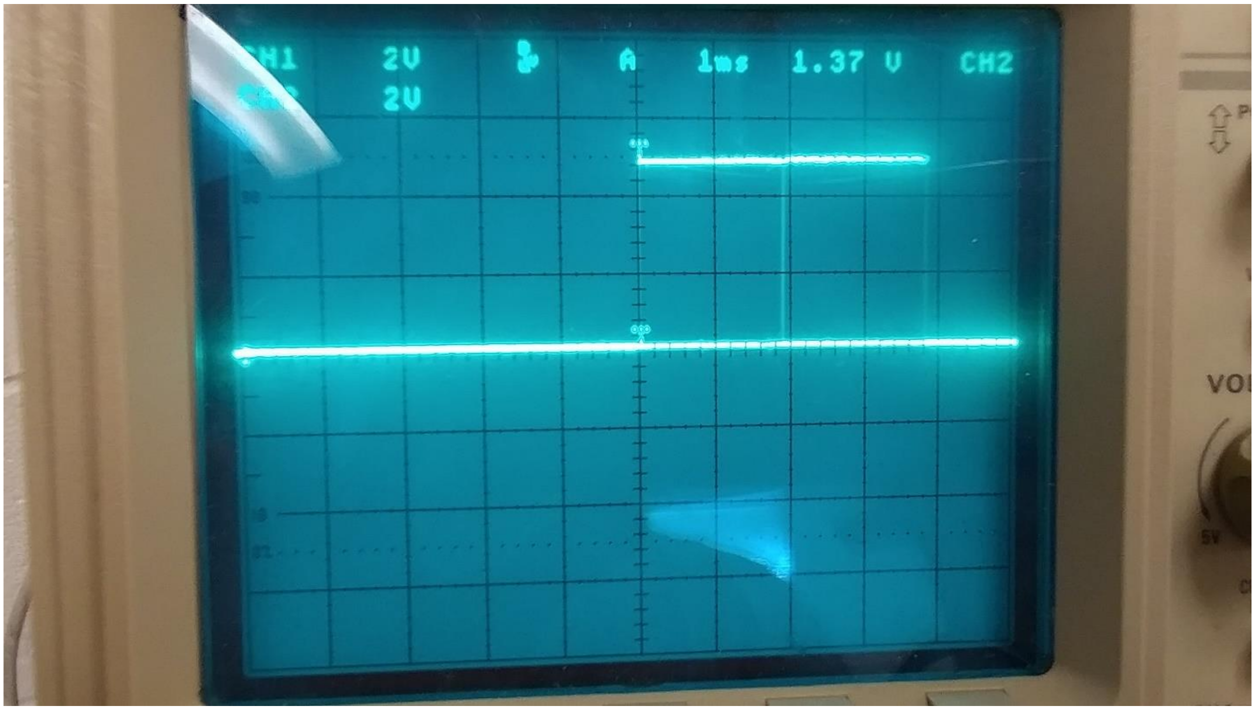

Figure 34: PWM signal from Arduino of 1900 at 5V

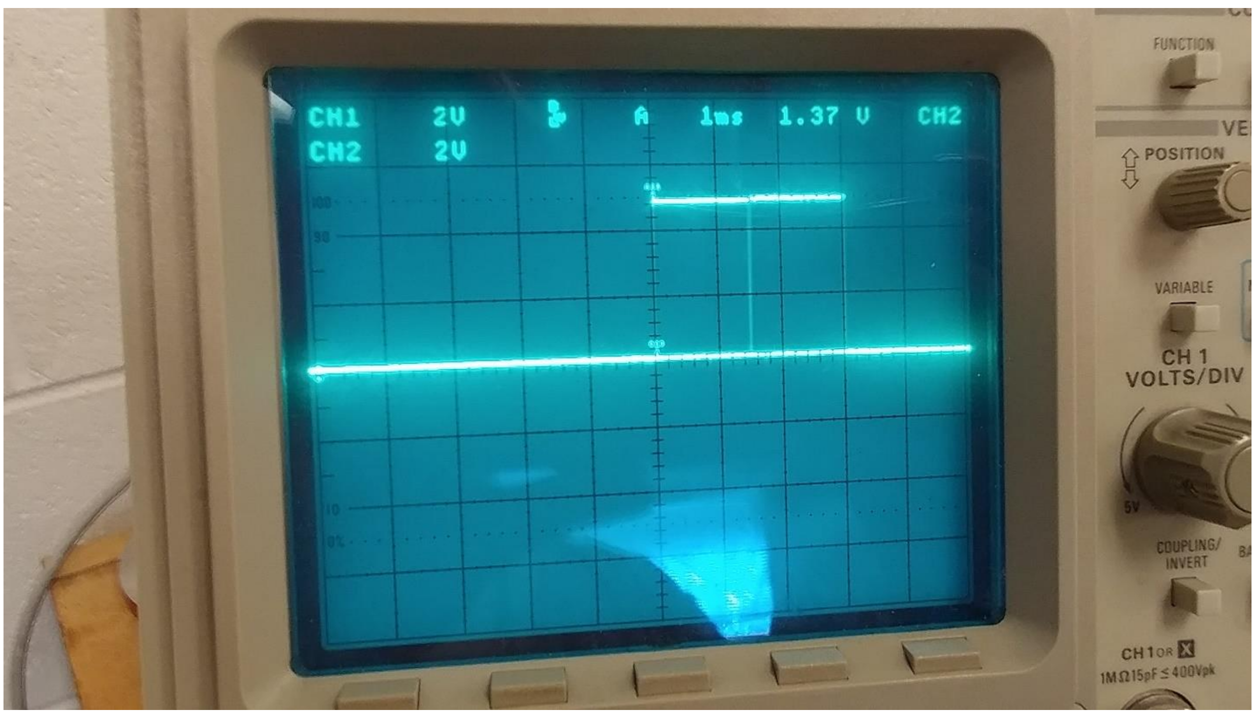

Figure 35: PWM signal from Arduino of 1500 at 5V

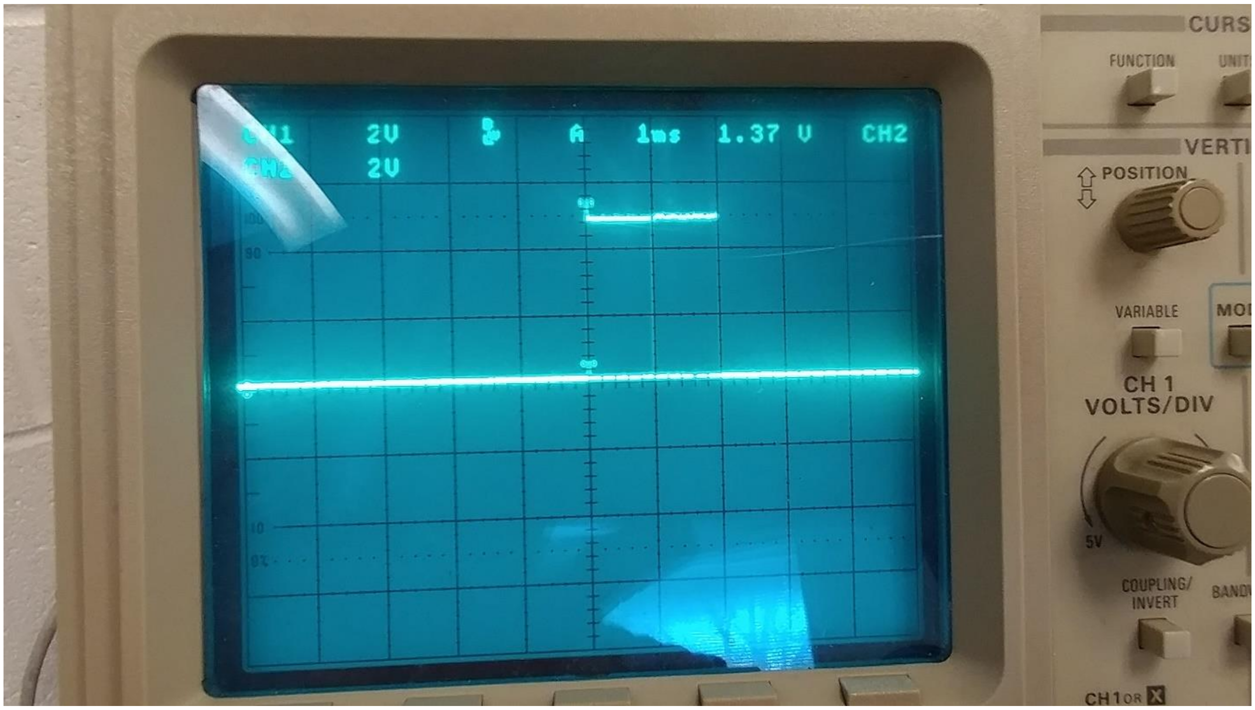

Figure 36: PWM signal from Arduino of 1100 at 5V

6. Send a PWM signal to one ESC then wait a duration of time then send a PWM signal to the second ESC.
    a. This solution did not have any effect.
7. Braid the three wires going into the motor to try and reduce possible noise.
    a. This solution did not have any effect.
8. Test using a different battery to see if there isn't enough current from the batteries used.
    a. This solution did not have any effect.
9. Send a throttle signal then as the wheels start to slow down send a neutral signal then send another throttle signal.
    a. When doing this pattern, the wheels would spin at a constant rate but this solution has its own issue because it would be unsafe to use, causing the user to be jerked forward from the initial throttle signal, then going into a neutral state, then back into a throttle state.

After trying these options and not finding a solution that was optimal the technical support team at Castle Creations was contacted to see if they could help solve the issue. They suggested changing the firmware within the ESC to the version 1.26 from version 1.46 as a solution. They had not heard of this problem before, and thought that a safety factor within the ESC may be causing the issue but could not know for sure. This solution seemed promising as the wheels would correctly rotate forward, go into neutral, and go in reverse when signaled to. Unfortunately, when applying pressure by placing a hand on the wheel while running they would come to a stop because it was a higher load than they were capable of handling.

TESTING MUMBA XLX

After finding out that the Mumba Max Pro Extremes were not going to work for our application and having a discussion with the employee of the local hobby shop he suggested we try using the Mumba XLX. This ESC is made for a 1/5th scale hobby car and can handle between 30-40 lbs. It was hoped that the weight distributed to each wheel would be near this range and would at least be able to run the walker without a person. These ESC's where ordered from a store in Illinois and arrived three days before the tech fair.

The setup was the same as with the Mumba Max Pro Extremes and the same code was able to be used. After successfully testing the ESC's with the wheels with no weight the microcontroller box was completed to so that we could do a final test the day of the tech fair. To our disappointment when trying to test with a person sitting in the walker it still did not work. It also had an issue when there was only the weight of the walker. One wheel acted like it wasn't getting the signal at the correct time or they would just make noise and not move. After further testing and making changes to the ESC's settings the walker was able to run for a short time without a rider. This however was the only time that it has functioned in such a manner.

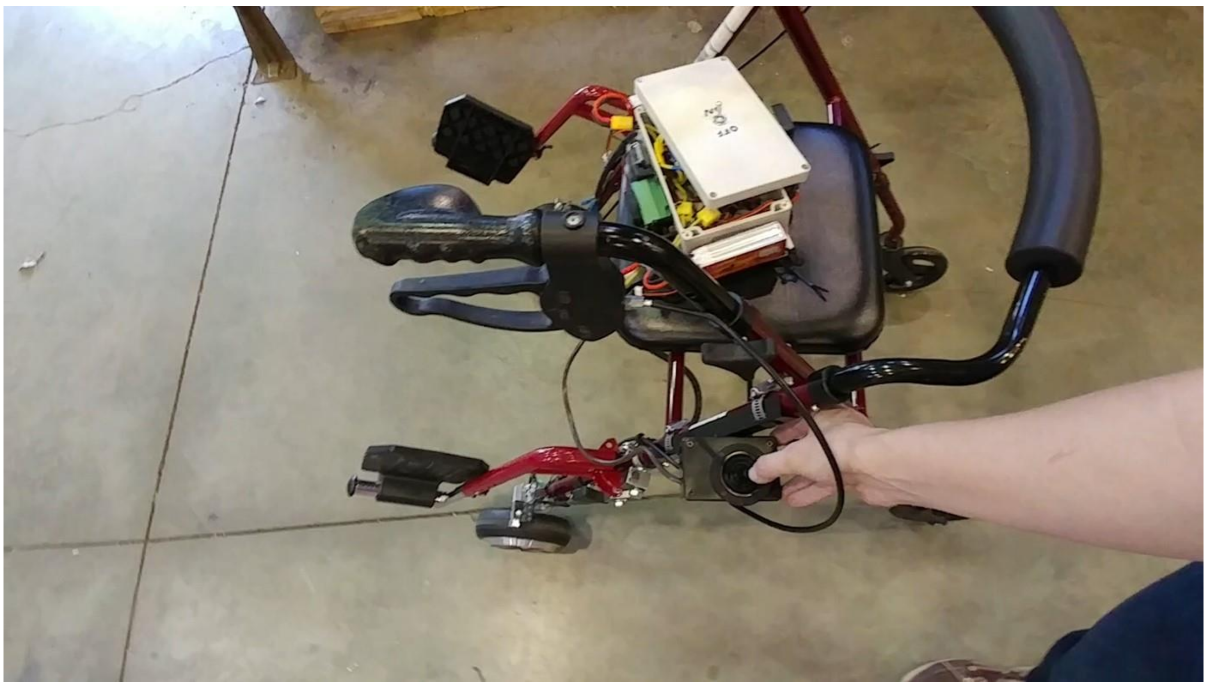

Figure 37: Mumba XLX During Successful Testing

JOYSTICK

The joystick was testing by first soldering wires to the two potentiometers that make up the joystick. Then the wires where connected to a breadboard making sure that the two outside wires went to ground and 5V power, while the middle wires went to two analog pins. A short code was then developed to monitor the output of the potentiometers to understand the range of the potentiometers and make sure they were calibrated correctly. The test setup can be seen in Figure 38**Error! Reference source not found.**. From there if statements where coded for forward, backward, and turning left and right. This was tested by moving the joystick and monitoring the output on the serial monitor.

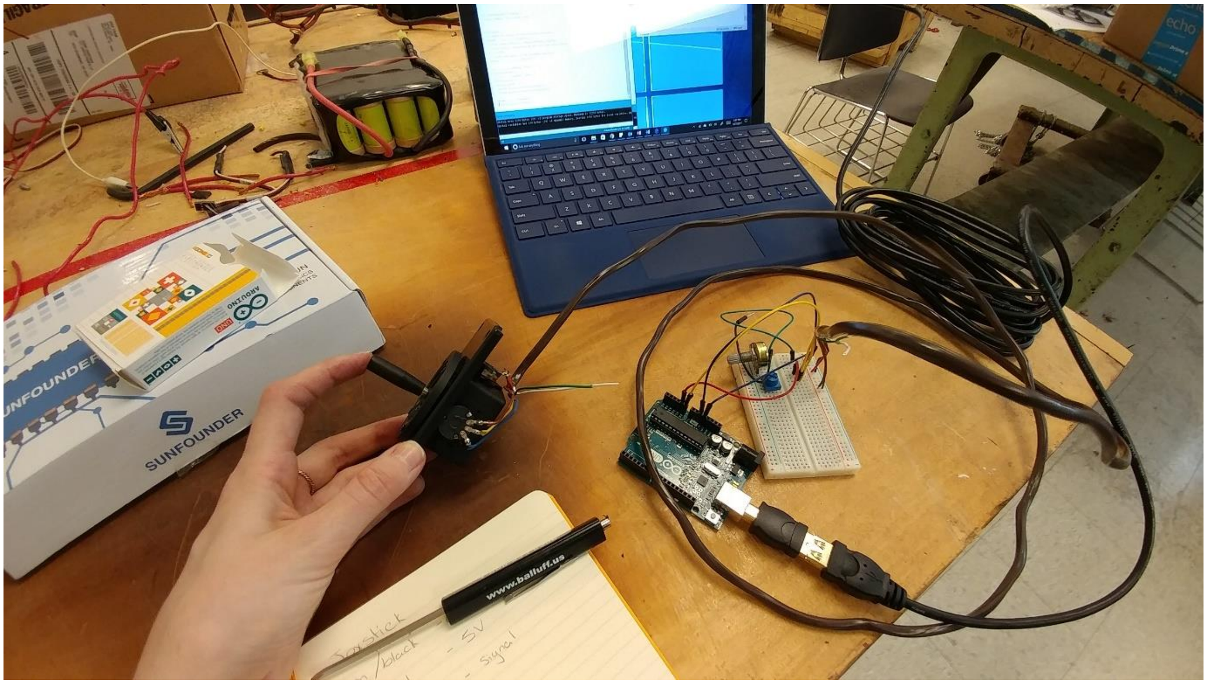

Figure 38: Joystick Test Setup

TECH FAIR

On April 6, 2017, we presented our design at the Tech Expo. The Tech Expo is an annual event at which students display team and individual capstone projects. Many people in attendance were impressed by our walker design and expressed to us an interest and a need for such a product on the market. Industrial Experts come from outside the university to judge the projects on display at the Tech Expo. Awards are given based on technical complexity, innovation, display, concept, and individual presentation. After several rounds of judging, we were awarded the Tisch Environmental Award of Innovation, one of the highest honors to be awarded at the Tech Expo.

PROJECT MANAGEMENT

PROPOSED BUDGET

Table 8: Motorized Wheels Kit Material Cost

Motorized Wheels Kit Material Cost			
Material	Qty.	Price	Total
Wheels/Motor	2	$ 100.00	$ 200.00
Braking System	2	$ 50.00	$ 100.00
Wheel/Motor way to Attachment	2	$ 100.00	$ 200.00
User Foot Rest	2	$ 60.00	$ 120.00
PLC	1	$ 44.04	$ 44.04
Steering Controller	1	$ 50.00	$ 50.00
Miss Electrical Components (i.e. wires, sensors, etc.)	2	$ 50.00	$ 100.00
Battery	2	$ 200.00	$ 400.00
Battery Attachment to Walker	2	$ 100.00	$ 200.00
	Total Price		**$1,414.04**

Table 9: Motorized Wheels Kit Labor Cost

Motorized Wheels Kit Labor Cost			
Labor	Hrs	Price	Total
Labor Price		$ 50.00	
PLC	40		$2,000.00
Programming	16		
Testing and debugging	24		
Build Wheel Attachment Assembly	4		$ 200.00
Build Foot Rest	4		$ 200.00
Build Steering Controller	3		$ 150.00
Build Battery Holder	4		$ 200.00
	Total Price		**$2,750.00**

Table 10: PLC Board Selection

PLC Boards (Arduino)	Costs				Average Cost	Deviation
Mini	$ 9.95	$ 6.95	$ 9.95	$ 9.95	$ 9.20	$ 1.13
Uno	$ 24.95	$ 22.00	$ 37.52	$ 22.94	$ 26.85	$ 5.33
Mega	$ 45.95	$ 45.95	$ 47.28	$ 36.99	$ 44.04	$ 3.53

ACTUAL BUDGET

Table 11: Actual Motorized Wheels Kit Material Cost

Material	Actual
Wheels/Motor	**$ 99.90**
hoverboard wheel/motors	$ 99.90
Braking System	**$ 5.99**
bicycle brake	**$ 5.99**
Wheel/Motor way to Attachment	**$ 43.74**
material for wheel mount	$ 43.74
User Foot Rest	**$ 84.03**
footrest	**$ 65.00**
mounting material	**$ 3.42**
mounting material and wheel wire	**$ 15.61**
PLC	**$ 31.35**
Arduino Uno	$ 31.35
Steering Controller	**$ 29.99**
joystick	$ 29.99
Miss Electrical Components (i.e. wires, sensors, etc.)	**$ 809.73**
ESC for testing	$ 14.43
ESC (2) Mumba Max and programming card end use	$ 275.41
ESC (3) Mumba Xlx	$ 406.58
BEC for power to arduino	$ 33.20
wire connectors	$ 6.41
wire for Joystick	$ 4.32
Bolts and Nuts for ESC's and Arduino	$ 6.25
Connectors for ESC (3)	$ 21.29
Wire and connectors	$ 15.91
Arduino Plug, bolts and nuts for arduino, spacers for arduino, New ESC	$ 201.38
Returned above ESC for credit to buy a different one	$ (181.89)
female bullet conectors	$ 6.44
Battery	**$ 66.89**
batteries and charger	$ 60.49
battery connectors	$ 6.40
Battery/PLC Attachment to Walker	**$ 17.72**
joystick, PLC boxes	$ 17.72
Total Spent	**$1,189.34**

SCHEDULE

Table 12: Project schedule and key dates

Task Name	Start	Finish
Smart walker Project	**Fri 6/17/16**	**Thu 4/27/17**
Initial meeting with Dr. Kumar and smart house team	Fri 6/17/16	Fri 6/17/16
Project proposal submission	Mon 7/25/16	Mon 7/25/16
Project Proposal Accepted	Wed 8/17/16	Wed 8/17/16
Design I	**Mon 8/22/16**	**Mon 10/10/16**
Start design I	Mon 8/22/16	Mon 8/22/16
Meetings	**Tue 9/6/16**	**Tue 10/4/16**
Background and Problem Statement	Mon 9/5/16	Mon 9/5/16
Customer Profile	Tue 9/6/16	Tue 9/6/16
Customer Features, Product Objectives and State of the Art	Tue 9/6/16	Tue 9/6/16
Design Report Draft 1	Mon 9/19/16	Mon 9/19/16
Customer Survey (4-Wheeled Walker Users)	Thu 9/29/16	Thu 9/29/16
Design Report Draft 2	Mon 9/26/16	Mon 9/26/16
Final design report	Mon 10/3/16	Mon 10/3/16
Design I complete	Tue 10/4/16	Tue 10/4/16
Design II	**Mon 10/10/16**	**Sat 12/3/16**
Start design II	Mon 10/10/16	Mon 10/10/16
Meetings	**Mon 10/3/16**	**Tue 11/29/16**
Budget	**Mon 10/3/16**	**Tue 10/18/16**
Wheel Conversion Kit	Mon 10/3/16	Wed 10/12/16
Handles Conversion Kit	Mon 10/10/16	Tue 10/18/16
House of Quality (HOQ)	**Tue 10/18/16**	
Wheel Conversion Kit	**Tue 10/18/16**	**Fri 10/21/16**
4-wheel walker comparison	Fri 10/21/16	Fri 10/21/16
Scooter comparison		
Motor Calculations	**Tue 10/18/16**	**Sun 10/23/16**
Torque to Move walker and person for wheel size	Tue 10/18/16	Tue 10/18/16
Torque made by wheels for selection	Tue 10/18/16	Tue 11/1/16
Choose Wheel's to Use For Design	Mon 10/24/16	Mon 10/24/16
Purchases	**Wed 10/26/16**	**Tue 11/8/16**
Wheels	Wed 10/26/16	Tue 11/8/16
Design II complete	Sat 12/3/16	Sat 12/3/16
Design III	**Mon 1/9/17**	**Thu 4/27/17**
Start design III	Mon 1/9/17	Mon 1/9/17
Concept Designs	**Mon 12/12/16**	**Wed 3/8/17**
Wheel Mount	Mon 12/12/16	Mon 1/16/17
Battery Mount	Wed 3/8/17	Wed 3/8/17
SolidWorks Drawing on Walker	Wed 11/9/16	Thu 3/30/17
Joystick mount	Thu 3/16/17	Mon 3/27/17
Purchases	**Sun 12/11/16**	**Fri 3/17/17**
arduino Board	Sun 12/11/16	Wed 12/14/16
batteries	Tue 2/14/17	Fri 2/17/17
battery charger	Tue 2/14/17	Fri 2/17/17
Joystick	Mon 3/6/17	Mon 3/6/17
BEC for Arduino battery	Mon 3/6/17	Mon 3/6/17
Project Boxes for Arduino/ ESC's and Joystick	Thu 3/16/17	Thu 3/16/17
footrest	Fri 3/17/17	
manufacture	**Sat 3/11/17**	**Mon 3/20/17**
Wheel mount	Sat 3/11/17	Mon 3/20/17
Battery mount	Fri 3/17/17	Mon 3/20/17
Test	**Mon 12/19/16**	**Thu 4/6/17**
ESC Concept Testing	Mon 12/19/16	Fri 1/13/17
ESC Testing	Mon 2/27/17	Thu 4/6/17
Joystick Testing	Mon 3/27/17	Thu 4/6/17
Wheel Mount Testing	Wed 3/29/17	Thu 3/30/17
Final Testing	Thu 4/6/17	Thu 4/6/17
Tech Expo	Thu 4/6/17	Thu 4/6/17
Project Presentation	Fri 4/14/17	Fri 4/14/17
Design III complete	Thu 4/27/17	Thu 4/27/17

RECOMMENDATIONS FOR FUTURE DEVELOPMENT

Our recommendations for further development of this project are as follows:

1. The next team should include an electrical engineer because of high electrical knowledge needed for further development.
2. Development of a custom circuit board including a custom speed controller capable of handling the 36V required by the motors and that can also house the microcontroller.
3. Possible development of a smaller and lighter wheel/motor combination that meets the specific torque requirements needed for the project.
4. Smaller lighter footrest design.
5. New handle design that can incorporate the joystick for better use location, comfort, and longevity.
6. Tracking capability of walking/riding data, possible saved to a micro SD card or have data sent to an app.
7. GPS tracking of unit for possible lost or missing users.

CONCLUSION

Mobility and independence for the elderly, in a lightweight and collapsible medium, was the main purpose. Our research and collaboration led us to designing a hybrid walker to wheelchair conversion kit. While our original goals were lofty and had many more design aspects and features, we were able to design and build a scaled down prototype, in an effort to prove our concept. Our prototype includes the basics assemblies required to convert a typical 4-wheeled walker to a motorized, sit down, wheelchair. These assemblies include the hardware and software requirements to control the device in either, walker or wheelchair, mode. We attempted to utilize an Arduino/ESC system along with two lithium ion batteries to power two wheel mounted motors. Unfortunately, the multiple ESC’s we tested proved to be incapable of handling the desired task. Further development and testing of this design and prototype is necessary. Key development areas would include designing and building, computer hardware specific to this project and more efficient wheel mounted motors.

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APPENDIX A

Example Survey for 4-wheeled walker meeting 1

Smart Walker Survey at Maple Knoll **September 29,2016**

Residence:

1. What do you like about your current walker?
2. What don't you like? What issues do you have?
3. What would you change if you could?
4. How often do you get tired?
5. How long before you're tired and need to sit?
6. How long do you sit before energy to get back up?
7. If walker could turn into a short term motorized wheel chair what features would you like to have?
8. How often do you need to adjust your brakes?
9. Does your walker provide the stability you feel you need?
10. Noise Level?
11. How would you prefer to steer a motorized wheel chair? Ie buttons, toggle, joystick, foot petal
12. Are you happy with the braking system? Any ideas?

Nurses/employees:

1. What are issues you typically see?
2. How often do you see falls associated with the walker and do you know the cause of the fall?

3. Could a better braking system or it being stationary when stopped help with falls?
4. Ideas for improvements?

EXAMPLE SURVEY TO OTHER RESIDENCE WITH 4-WHEELED WALKERS AND STAFF

<u>Smart Walker Survey at Maple Knoll</u> September 29, 2016

Hello! Our names are Leah Oty and Kristen Brown, we are Mechanical Engineering students from the University of Cincinnati. We are working on a project to create an improved wheeled walker by adding a motor to allow it to become a motorized wheelchair for a period of time. This would let you move around on your own for a while if you get tired and sit down.

We would appreciate any feedback you can give us about your walker, thank you.

1. What do you like about your current walker?
2. What don't you like?
3. What issues do you have?
4. What would you change if you could?
5. How often do you get tired?
6. How long before you're tired and need to sit?
7. How long do you sit before you have energy to get back up?
8. What features would you like to have in a walker that could be motorized?
9. What do you think about your current brakes?
10. Does your walker provide the stability you feel you need?
11. How would you prefer to steer a motorized wheel chair? For example, buttons, toggle switch, joystick, foot petal.

EXAMPLE SURVEY FOR RESIDENCE WITH SCOOTERS AND MOTORIZED WHEELCHAIRS MEETING 2

1. Who chose a scooter for you to use? Why?
2. Do you prefer the scooter over the walker? Why?
3. If a walker that was motorized for a period of time existed would you use it?
4. How often do you feel you would need to motorized function? (time sitting and using the motorized capability)
5. What features of the walker do you like?
6. What feature do you not like?
7. What features could be improved to make you like it and use it more?
8. What would be your preferred steering system? i.e. joystick, track pad, clicker

APPENDIX B

HOUSE OF QUALITY

			Engineering Requirements (units)														**Customer Satisfaction Rating** (0.00 - 1.00)			
		Importance wt.	Collapsable (Yes or No)	Weight (lb)	Capacity (Amps)	Hours Running (min)	Extended/ collapsed length (Yes or	Distance Traveled Before Stopping (in)	Can the motors be removed (Yes or No)	Can it be controled easily (Yes or No)	Turn Radius (deg)	Dollar ($)	Limited Speed (mph)							
	Customer Requirements		1	2	3	4	5	6	7	8	9	10	11	12	13	14	CP	A	B	C
1	Collapsible	0.20	9	1																
2	Light weight	0.17	1	9	1	1			3											
3	Long Battery life	0.07	3	3	9	9		1												
4	Shock Absorption	0.01		9			9			1										
5	Better Braking system	0.20	3	9	3	3		9	3	1										
6	Removable motor assembly	0.05	9	9	3	3		1	9	1										
7	Easy control System	0.05			1	1		3		9										
8	Manuverablity	0.05		3					1	3	9	3	1							
9	Cost Effective	0.15			3	3	1	1	3	3		9	1							
10	Speed Control	0.05		1	3	3		1		9		1	9							
	Total Importance	1.00																		
	Engineering requirement importance		3.23	4.48	2.2	2.2	0.24	2.27	2.06	1.76	0.45	1.55	0.65							
Performance	Current Product																			
	competitor A- 4-wheeled walker		Y	11	0	0	N		0	0	360	90	0							
	competitor B-Scooter		N	85		120	N		N	Y	45.5	700	4.25							
	New Product Targets		Y	25		2	N		Y	Y	360		4							

APPENDIX C

ARDUINO CODE FOR TESTING ESC

```
//This code is for testing an ESC with a brushless motor.
//  throttlePin: potentiometer connected to A0
//  ESC signal wire: connected to D9
#include <Servo.h>

Servo esc;
int throttlePin = 0;

void setup(){
esc.attach(9);
Serial.begin(9600);
}

void loop() {
int throttle = analogRead(throttlePin);
//Serial.println(throttle);

if  (throttle == 0) {
  //  do nothing no signal to esc
  Serial.println("ESC isn't getting anything");
  }


  else {

  throttle = map(throttle, 0, 1023, 0, 180);
  esc.write(throttle);
  Serial.println(throttle);
}


}
```