Transnavigators

Voice Controlled Wheelchair

Final Report

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Executive Summary

The Transnavigators' Voice Controlled Wheelchair is a multipurpose platform that can add voice control to nearly any existing chair. Users can attach their own wheelchair to the platform and then use Alexa to guide their vehicle throughout the room. The platform can fit any standard sized wheelchair and can carry a load of up to 300 lbs. A conceptual model is shown in Figure 1.

The platform will assist users by transporting their wheelchair to them and optionally bringing them to places throughout their room. Unlike most motorized wheelchairs, which are commanded using a joystick, users can command this wheelchair naturally, using voice commands.

Figure 1. Full System with Wheelchair

The two main preliminary designs considered were a motorized platform or direct motorization of an existing wheelchair's wheels. The platform design was ultimately selected for its modularity and simplicity. A center-wheel differential drive, a drive system where both drive wheels are controlled independently but rotate on a common axis, was selected because it allowed for the best mobility and turning ability. Torque and power requirements were derived from ADA specifications and self-set design criteria. The control system was built upon a framework called Robot Operating System (ROS) to simplify communication between different parts of the system. Open source packages eased development and increased productivity for the team.

The two largest issues from the project were that the wooden frame bent under load and that the set screws stripped the shaft they were mounted on. The wooden frame issue was solved by adding metal supports to the sides, which can be seen next to the wheels in Figure 1. The set screws issue was temporarily solved by tapping the shaft. To permanently fix these problems in the future, the wooden chassis should be replaced by a metal one and higher quality steel shafts should replace the ones purchased from Home Depot.

One open issue is that the Light Detection and Ranging (LIDAR) sensor is mounted too close to the ground. With even the slightest deviation, the LIDAR will see the floor and veer to try avoid the imaginary obstacles it sees. As it avoids the "obstacle" it maps walls around it and boxes itself in. This issue could possibly be fixed by mounting the LIDAR at the very front of the platform instead of underneath. The original reason the LIDAR was mounted beneath the device was so the LIDAR could scan all directions, but the final code only requires a clear forward view for obstacle detection and avoidance.

Over the 2017-2018 school year, the Transnavigators designed and built a moving wheelchair platform that recognizes voice commands by an Amazon Echo and responds with precise movements that satisfy the metrics specified in the A3 document. Future improvements to the project would include redesigning the chassis to hold the LIDAR, making the chassis out of metal, use an indoor positioning system to give the platform the ability to find the user, and find a different means of control other than Alexa. The project is in a great place to be continued in the following years.

Introduction

The Transnavigators' Voice Controlled Wheelchair is a device that can increase the independence of wheelchair users. Millions of Americans use a wheelchair daily, whether it be in a hospital, their own home, or elsewhere. With this device, users can convert their existing wheelchair into one that responds to voice commands. In situations where their wheelchair is far away, users can simply direct their wheelchair to them using Amazon's Alexa. In addition, after they get onto their chair, users can use directional commands to navigate to a desired location. Ideally, this will eliminate the need for wheelchair users to be assisted in transit or for workers to deliver wheelchairs to patients. For example, the voice controlled wheelchair has possible applications in a hospital where patients can guide their wheelchair over to them using Alexa. The patient would then either take the wheelchair off the platform and propel themselves manually or continue using voice commands to have the wheelchair move for them. The platform is designed so when not in use, it can be stored conveniently.

Integrating the wheelchair platform with Alexa makes it an Internet of Things (IoT) device. The Internet of Things is a collection of connected devices that uses the Internet to exchange data. Using Alexa to control the wheelchair gives it the ability to be controlled from rooms away assuming it is connected to the Internet. At the time of this writing there are no other voice controlled IoT wheelchairs in existence. As the world accelerates toward the use of automation and IoT technology, this wheelchair platform will find a place in future hospitals and smart homes.

This report aims to explain in detail the decisions made by the team over the past two semesters, the issues encountered and how they were overcome, and future steps and recommendations for this project.

Background

Some progress has been made in the way of autonomous wheelchairs, which can navigate to patients. This progress is a consequence of the research and development of autonomous cars, which can be applied to wheelchairs. In 2009, MIT's Computer Science and Artificial Intelligence Laboratory created a voice-controlled autonomous wheelchair from an existing electric wheelchair.[1] In 2016, the Singapore-MIT Alliance for Research and Technology developed and tested an autonomous wheelchair in Singapore's Changi General Hospital.[2] The prototype was a modified electric wheelchair that uses a touch screen for navigation controls and maps a room using three LIDAR sensors. LIDAR is a surveying method that uses light to detect the distances to nearby objects, typically used for collision avoidance and navigation in autonomous cars.

Other autonomous wheelchairs are being tested. The WHILL NEXT is an autonomous wheelchair designed by Panasonic and WHILL Inc.[3] It is controlled via smartphone and uses image recognition to navigate and detect obstacles. It borrows its futuristic design from other WHILL wheelchairs and technology from HOSPI, an autonomous delivery robot at Changi General Hospital.[4] Its primary use is to provide a fleet of wheelchairs to travelers at an airport moving on a single path. The WHILL NEXT can also sync with nearby wheelchairs to form a column and return to its home base when done.

The idea of having an autonomous wheelchair is not new. A patent was filed in 2002 for a computer-controlled power wheelchair navigation system.[5] With five years left on the patent, advancements in other fields are now making the idea practical to implement. Automobile manufacturers are developing autonomous cars, which require low cost LIDAR sensors. Several companies such as Velodyne and Quanergy are trying to drive down production costs of LIDAR sensors to meet the demands of automobile manufacturers and consumers.

There have also been recent developments in indoor positioning systems (IPS). GPS is inaccurate indoors, so a different system must be used for positioning. Bluetooth Low Energy and Wi-Fi IPS have been adopted for indoor positioning, using cell phones for retail advertising and analysis. DecaWave developed a sensor with applications in IPS using ultra-wideband transceivers for tracking items or vehicles in industrial applications.[6] As the patent grows closer to expiration and LIDAR and other sensing technology improves with autonomous vehicle development, the market potential for autonomous wheelchairs will expand.

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[1] Teller, Seth et al (2009).
[2] Teo, Pauline (2017).
[3] Panasonic Corporation (2017).
[4] Panasonic Corporation (2015).
[5] Fehr, L. (2002).
[6] DecaWave (2015).

Discussion

Choosing System Solution

The platform design was chosen after considering several other solutions at the start of the project. The initial idea was to motorize a self-propelled wheelchair by attaching a motor to its wheels. A conceptual sketch of this idea is available in Appendix B-1. The benefits of this design are that it can be low profile and allow the wheelchair to still be used normally if desired. However, machining the wheels can be difficult. There is no good method to retrofit the motors to free-spinning wheels. For the motors to drive the wheelchair, the wheels need to be modified for power transmission. Since the wheels must be detached to modify them, the wheels need to be removable from the motors and welding is not an option. This means we need to cut the wheels' hub to fit a new type of shaft such as a square shaft or a keyed shaft. It is unclear if the wheel hubs can be machined with the available tools, which adds risk if pursuing this route. Another problem was allowing the user to disengage the wheels. For the wheelchair to operate normally, the gears would have to move apart so the user isn't driving the motor.

Another idea considered was to create an attachment for a wheelchair that would drive it. The main problem with this design is that it has tight space tolerances and requires many attachable components. The motor and all other electronics would have to be embedded in this attachment with a profile low enough that would not restrict movement. The other parts of the system such as the LIDAR sensor would have to be mounted separately from a good vantage point. Having separate components would make setting up the system complicated, which was not the goal of this project.

The largest flaw with retrofitting a self-propelled wheelchair with voice control was machining components directly to an existing wheelchair and disengaging the motors. The largest flaw with the attachable motorization was the complexity of the design. One other concerning flaw with both designs was determining where to mount the LIDAR so that it could detect obstacles were without interfering with or being obstructed by the user. The platform does not have any of these flaws. The user can attach their existing wheelchair to the top, thus simplifying the design of the drivetrain and chassis. This also allows the LIDAR to be easily mounted to the bottom of the platform where the only obstructions will be the wheels. The following sections on chassis design and drivetrain design discuss the design process related to developing the platform.

Chassis Design

There were several considerations when designing the chassis. It needed to be wide, rigid, and strong enough to hold the wheelchair. The design must have the space to accommodate the electrical components and have enough bottom clearance for the LIDAR sensor while remaining as low as possible to the ground for the stability and comfort of the rider. In addition, it should be powerful enough to climb 5-degree inclines all while remaining reasonable to manufacture and not excessively heavy.

First Iteration

This design was inspired by robot vacuums such as the Roomba. It is a short platform made from aluminum which users could place their wheelchairs onto and ride. Aluminum was chosen due to its favorable strength to weight ratio. The platform uses differential drive to let the platform turn in place, giving it a wide range of motion.

Early on, it was clear that the LIDAR would need special mounting on the platform. For this design, the LIDAR was mounted on the bottom rather than the top because most things that would need to be avoided touch the ground. The wheels only slightly restrict the LIDAR's range of view. If it were mounted on the top, the LIDAR's field of vision would change as the user sits in the chair and operates it.

Unfortunately, this design was impractical because the motors were too large to fit inside the chassis of 2.25 inches. Another problem lies with the size of the castor wheels. The small castors cannot roll over small bumps. An obvious flaw with this design is that it does not provide any additional structural support within the chassis. This design is shown in Appendix B-2.

Second Iteration

This design was created to directly address LIDAR clearance and the chassis construction concerns. It replaced the metal top with wood and used aluminum square channels for structure and support. This would make the chassis cheaper to fabricate, easier to construct, and more structurally sound.

The driven wheels were changed to six inches in diameter and the castors to four inches in diameter. All wheels were mounted completely below the platform to prevent the wheels from getting stuck on small obstacles. These changes led to issues involving the height, stability, and comfort of the user. This design is shown in Appendix B-3.

Third Iteration

This design tried to find a middle ground between the first and second iteration. The structure of the chassis reflected that of the first iteration, but the size of the wheels was pulled from the second iteration. The new driven wheel was made six inches in diameter while the castor wheels were three inches in diameter. Slightly smaller castors were chosen because of the need to constrict the swivel space and allow the supports to be as close to the wheels as possible. This design is shown in Appendix B-4.

Fourth Iteration

This was an alternative design that tried to drastically reduce the height of the top of the platform by sinking the surface that the wheelchair would be sitting on between the wheels. ADA specifications state that the distance between the outer face of the large wheels on an adult wheelchair is 26 inches. The minimum width of a door is 32 inches.[7] The swivel radius of the castors was just under 3 inches. These measurements indicated that the tolerance for fitting this platform through a door was too tight and unfeasible. This design and dimension consideration is shown in Appendix B-5.

Fifth Iteration

This design returned to a model similar to the third iteration except with alterations to the drive system and increased clearance for passing through doorways. This design used gears, which requires more difficult machining since the placement of holes and creation of gears must be exact. With the added gears, less space was available in the middle meaning that this design does not allow a wheelchair to be rolled onto it. The chassis' width was decreased by two inches to provide more clearance through doorways since the wheelchair will no longer be rolled onto it. This design is shown in Appendix B-6.

Sixth Iteration

This design was created to address the needs arising during the machining process. It utilizes 2x4 lumber and 1/2" and 1/8" plywood for structural materials. The drive train utilizes sprockets and chain. Chain and sprockets were chosen as the power transmission system because it is easy to adjust and has high tolerances which reduce the precision required when drilling holes for bearings and shafts. Since sprockets are being used, the drive elements can be condensed into a small width and provide enough space for the wheelchair to be rolled on top of the platform. This design also began to analyze the space and placement of the motors and other electronic components other than the LIDAR as shown in Appendix B-7.

Seventh Iteration

This design reverts to the use of gears for the power transmission system because of spatial constraints. The size of the sprockets and gears could not exceed six inches, the diameter of the driving wheel, which limits how aggressive the gear reduction can be. Sprockets need to be spaced far enough to ensure appropriate tension in the chain thus having multiple stages takes up a significant amount of room. Directly meshing gears require no spacing between gears making it a more compact power transmission system. The gears and wheels purchased utilized set screws for power transmission with the shaft, which failed unfortunately. They would strip the steel shaft under high load. This issue was first combatted by filing a flat portion on the shaft for

[7] Department of Justice (2010).

the screw to sit more securely on. When this also resulted in stripping, the shaft was tapped allowing the set screw to nest firmly in the steel rod.

During testing, the thin plywood on the outsides of the platform bent and caused the wheels to touch the sides of the frame. The sides are load bearing structures and made out of 1/8" plywood, a material that was not strong enough to support the load. The problem was resolved by mounting metal plates along the outside near the wheel and adding beams between the main support 2x4 and the plywood siding.

Changes were made to the design according to the resources available. To account for inclines or other ground inconsistencies, spring castor wheels were used in the front corners of the platform. Large spring castors purposed for gates were used to save money. The wheels intended for motorization could only be mounted to the end of the shaft, so the drive wheels were moved outside the frame.

In addition to reinforcements and drive train changes, additional features such as a wheelchair attachment, battery attachment, and an emergency stop button were added. The wheelchair is attached to the platform using toggle clamps that lock the large back wheels in place. The batteries are secured to the platform with designated wooden corners to sit in as well as a two-inch thick Velcro strap holding the batteries to the platform. For safety, an emergency stop button was created. A recycled breadboard button was installed as an emergency stop. To make the button more accessible, a button holder and button cap was 3D printed and attached it. This was glued to a quick clamp that allowed the button to be easily attached to a wheelchair. A schematic of the final platform iteration can be seen in Appendix B-8.

Drive System

The drive system chosen was a differential drive system utilizing two independently driven wheels in the middle of each side of the platform with 360-degree swiveling castors on each corner. This design was chosen over three other tank drive trains and one mecanum after evaluating each design using the weighted design matrix shown in Table 1. The criteria each drive train was scored on was its overall simplicity, stability, cost, maneuverability, ease of programming, and weight. A description of criteria can be seen below in Table 2.

Table 1. Drivetrain Design Matrix

Drivetrain Design	Simplicity (x5)	Stability (x5)	Cost (x4)	Maneuverability (x3)	Programming Ease (x3)	Weight (x2)	Total
Tank: Center drive wheel direct to motor- one on each side, 4 castors on corners	8	9	5	6	6	5	151
Tank: Four driven wheels, motor at center of each side, chain driven	7	7	5	6	5	5	133
Tank: 6 wheels, back four driven by chain, one motor on each side	7	9	4	6	5	5	139
Tank: Tank treads/tracks, two motors- one on each side	6	9	4	6	5	4	132
Mecanum: 4 mecanum wheels each driven independent of each other	5	7	3	9	4	5	121

Table 2. Description of drivetrain design matrix criteria

Criteria	1	5	10
Simplicity	Overly complicated and intricate mechanical design, requires special machining, programming is difficult	Neutral/Average	Most simple mechanical design and programming possible
Stability	Very wobbly and prone to tipping	Neutral/Average - 50% chance of stability issues (tipping, wobbling)	Extremely stable, no wobbling or tipping possible
Cost	Extremely expensive to manufacture, parts are expensive and numerous, far exceeds conceived budget	Neutral/Average - on conceived budget	Cheapest configuration wrt type and amount of materials and machining, much less than conceived budget
Maneuverability	Very clunky movement, large turning radius, difficult to move around obstacles	Neutral/Average	Extremely maneuverable, able to navigate tight turns or move in a variety of directions
Programming Ease	Difficult to program and control movement	Neutral/Average	Easy system to program and control
Weight	Weight to size/volume ratio is extremely high	Neutral/Average	Weight to size/volume ratio is extremely low

Drive Train

Two AmpFlow E30-150 motors were chosen to drive the wheelchair. When sizing motors for a vehicle operating at a constant speed, the most important calculation to consider was the necessary power required to move the wheels up an incline. The free body diagram shown in Figure 2 was used to calculate the amount of force needed to hold a constant speed on a slope within ADA specifications, 4.8° or 1:12.[8] For all calculations a weight of 300 pounds was used.

The force needed to overcome rolling resistance was calculated using the following equation:[9]

$$F_{roll} = \frac{fW}{R} \tag{1}$$

where *f* is the coefficient of rolling friction, *W* is the weight on the wheel, and *R* is the radius of the wheel.

Due to the undeterminable location of the center of gravity, it was assumed that the back two sets of wheels took 40% of the weight each while the front two casters took the remaining 20% of the total load. The rolling friction coefficients were conservatively assumed to be $8.52 * 10^{-3}m$ and $4.22 * 10^{-3}m$ for the solid tire drive wheel and standard front and back casters, respectively.[10] The total force needed to overcome rolling friction and the x-component of the weight was calculated to be 41.7 pounds. The force required to initiate motion is generally 2.5 times as large, ballooning the required force due to static friction to approximately 104 pounds.[11] To make sure slipping would not occur the maximum force due to static friction was also calculated and determined to be approximately 194 pounds, which exceeds the magnitude required.[12]

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[8] Department of Justice (2010).
[9] Lippert, Dave et al (2012).
[10] Christophe Sauret et al. (2012).
[11] Lippert, Dave et al (2012).
[12] Hirai Ikuko and Gunji Toshihiro (2001).

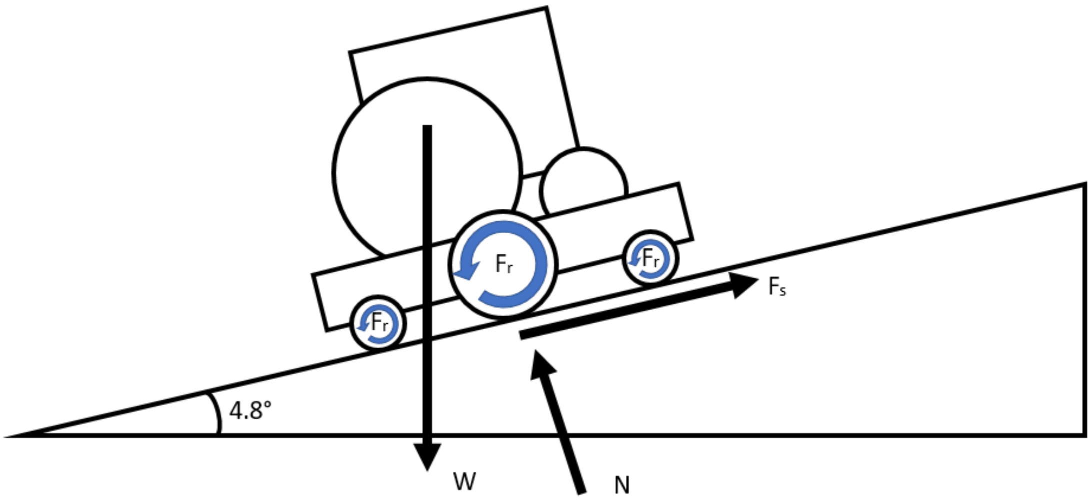

Figure 2. Free body diagram of a six-wheel drive system holding a wheelchair and an operator on the maximum slope ramp within ADA specifications. $W = Total\ Weight$ and is acting straight down at a location-assumed center of gravity, $N = Normal\ Force$, $F_s = Force\ due\ to\ Static\ Friction$ between the wheels and the assumed carpet floor, and $F_r = Force\ Needed\ to\ Overcome\ Rolling\ Resistance$.

To determine the power the motor would need to output, a desired speed of 4 mph was selected. This speed is around that of existing motorized wheelchairs and slightly faster than walking speed, making it an appropriate goal. It is also the upper speed limit of Class 2 motorized wheelchairs in the United Kingdom as stated by their Highway Code.[13]

Power was calculated using the following equation:

$$P = F_{static} * v \tag{2}$$

where F_{static} is the friction required to maintain a constant speed and v is the desired cruising velocity.

The power required to maintain a speed of 4 mph was calculated to be approximately 166 Watts. The AmpFlow E30-150 motors were selected because they have a peak efficiency at a power output slightly higher than what was calculated as shown in Figure 3. This buffer aims to serve as a safety factor since conservative values were used in the calculations. Several variables such as the tires' moments of inertia and power loss from the gears were assumed to be negligible. The selected motor also has a peak power output of 725 Watts, which will be necessary for powering the startup of the vehicle.

The desired rpm of the drive wheel at a maximum speed of 4 mph was calculated using the following equation:

$$\omega = v/R \tag{3}$$

After conversions, the ideal angular velocity of the wheel was calculated to be approximately 224 rpm. The rpm of the motor when it outputs around 166 Watts is approximately 5,250 rpm as

[13] Department for Transport (2015).

shown in Figure 3. The required gear ratio to convert between the two can be calculated using the following equation:

$$Gear\ Ratio = \frac{\omega_{in}}{\omega_{out}} \quad (4)$$

An ideal gearing down ratio of approximately 23.4:1 was calculated to operate the vehicle at 4 mph. A relatively close gear ratio of 20:1 was implemented in the project by coupling a 5:1 gear pair with a 4:1 one. When purchasing gears, it was important to make sure they had the same pressure angle and normal pitch to ensure smooth meshing during operation.

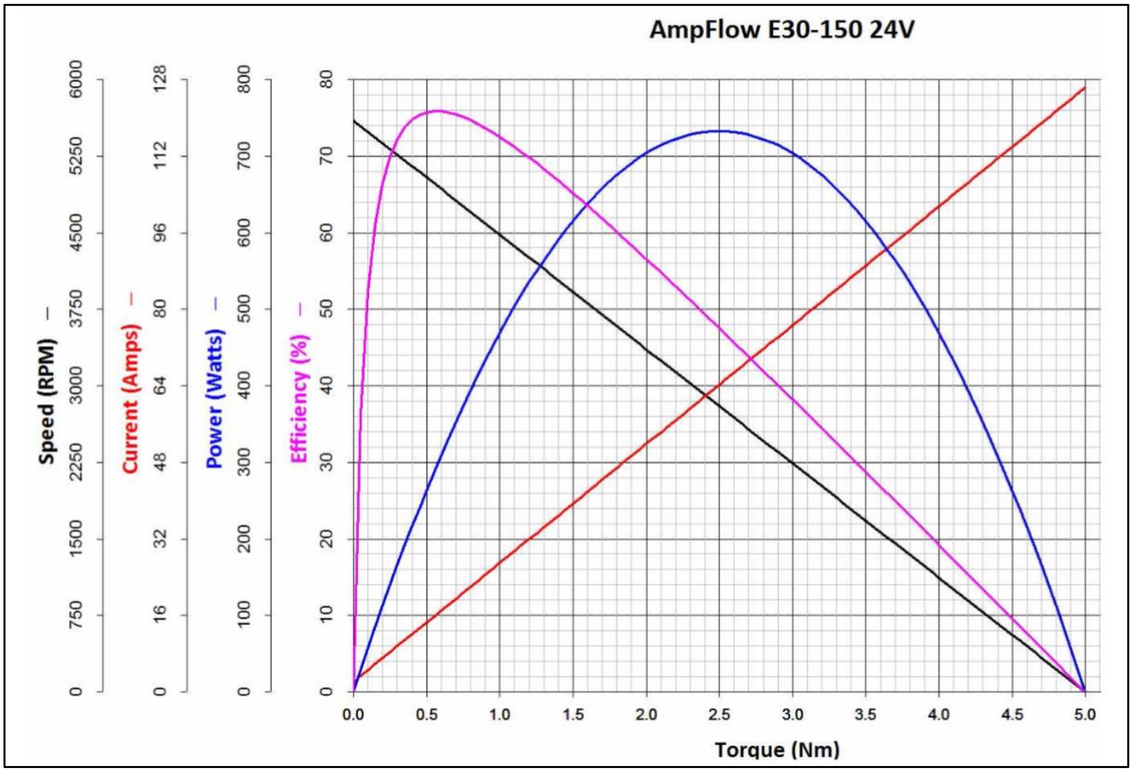

Figure 3. Motor performance graphs for AmpFlow E30-150 as displayed on their website.[14]

Power System

The wheelchair platform runs on a 24 V system. Two 35 Ah 12 V Absorbed Glass Mat (AGM) batteries were purchased and connected in series to provide power for all components on the platform. The current draw of the entire system was calculated to be about 264 A peak during motor startup and 44 A continuously assuming that four DC-DC converters are used to power the electronics and drawing maximum current and the two motors are running at peak efficiency. These numbers are broken down in Table 3. The acceptable duration of drive time between charges for the wheelchair was determined to be between 15 and 30 minutes, so 35 Ah batteries were fine for this purpose. A lead acid battery was chosen to power the system mainly because

[14] AmpFlow (2012).

they are relatively inexpensive and can supply the large starting currents required of the motors. The battery decision matrix is shown in Table 4 and the criteria is shown in Table 5. The specific type of lead acid battery chosen was an AGM battery. AGM batteries are a type of valve regulated battery (VRLA).[15] VRLA batteries do not need to be maintained like flooded batteries and can be positioned in any orientation without the danger of spilling. These are desirable features for the wheelchair because the mounting the batteries and their maintenance do not need to be considered. In addition, these types of batteries are commonly used in motorized wheelchairs.

Table 3. Power requirements

Device	Voltage	Idle Current	Sys. Current	Peak Current	Recommend Current
Motor E30-150[16]	24V		17 A	127 A	
Motor E30-150	24V		17 A	127 A	
Raspberry Pi Model B	5 V	400 mA		1.2 A	2.5 A
Neato xv LIDAR Sensor	5 V	40 mA	135 mA		
Neato xv LIDAR Motor	3.3 V		60 mA		
Arduino Uno	9-24 V		500 mA	1A	
Rotary Motor Encoder (A6B2-CWZ3E-1024)	5-12 V		100 mA		
Rotary Motor Encoder (A6B2-CWZ3E-1024)	5-12 V		100 mA		

To step down the battery voltage to an acceptable level for the electronics, a set of LM 2596S DC-DC 3A Buck Adjustable Step-down Power Supply Converter Modules were purchased. Other alternatives considered included the LM2576 chip, a switching voltage regulator, and LM7805 chip, a linear voltage regulator. The LM2576, though efficient and cheap, could not be built on a breadboard and had to be soldered to a well-designed PCB according to several references.[17] The LM7805 chip though simple to incorporate into the system, was unable to supply the 2.5 A of current recommended for the Raspberry Pi.[18] The converters purchased were advertised to provide a regulated output voltage and supply up 3 A of current with an input of 3 – 40 V.[19] After testing the converters though, the voltage was shown to drop significantly with the current drawn, even with currents well within its rated range. See Table 6 and Figure 4 for testing results.

A high-level diagram of the complete power system is shown in Figure 5. For a detailed schematic, see Appendix C.

[15] Northern Arizona Wind & Sun (2014).
[16] AmpFlow (2012).
[17] Simkard (2011).
[18] Texas Instruments (2003).
[19] Vvbuy (2017).

Table 4. Battery Matrix

Battery Type[20]	Energy Density (x1)	Voltage Stability (x4)	Peak Current (x9)	Self-Discharge (x2)	Recharge Time (x1)	Cost (x8)	Reliability (x3)	Operating Temperature (x1)	Total
Nickel-Cadmium	5	8	9	7	8	8	7	6	231
Nickel Metal-Hydride	6	8	9	6	6	7	6	6	217
Lead Acid[21]	4	6	10	9	2	9	10	5	245
Lithium-Ion	9	5	6	8	6	5	4	8	165
Lithium-Ion Polymer	8	5	5	8	6	4	6	5	150

Table 5. Description of battery design matrix criteria

Criteria	1	5	10
Energy Density	Small amount of energy per kg/liter	Neutral/Average	Large amount of energy per kg/liter
Voltage Stability	Discharge affects voltage a lot	Neutral/Average	Holds a stable voltage while discharging
Peak Current	High ESR	Neutral/Average	Low ESR
Self-Discharge	Discharges quickly on the shelf	Neutral/Average	Holds its charge well on the shelf
Recharge Time	Charges very slowly	Neutral/Average	Charges Quickly
Cost	Expensive	Neutral/Average	Cheap
Reliability	Easily Damaged	Neutral/Average	Robust
Operating Temperature	Sensitive to fluctuations in Temperature	Neutral/Average	Insensitive to changes temperatures

[20] Chester, Simpson (2011).
[21] Northern Arizona Wind & Sun (2014).

Table 6. LM 2596S DC-DC 3A Buck Adjustable Step-down Power Supply Converter Module Testing Results

Voltage (V)	Resistance (Ω)	Current(A)	Power (W)
5.07	OC	0.00	0.00
4.83	10.90	0.44	2.14
4.76	8.10	0.59	2.80
4.62	5.30	0.87	4.03
4.25	2.80	1.52	6.45
3.92	1.83	2.14	8.40
3.69	1.40	2.64	9.73

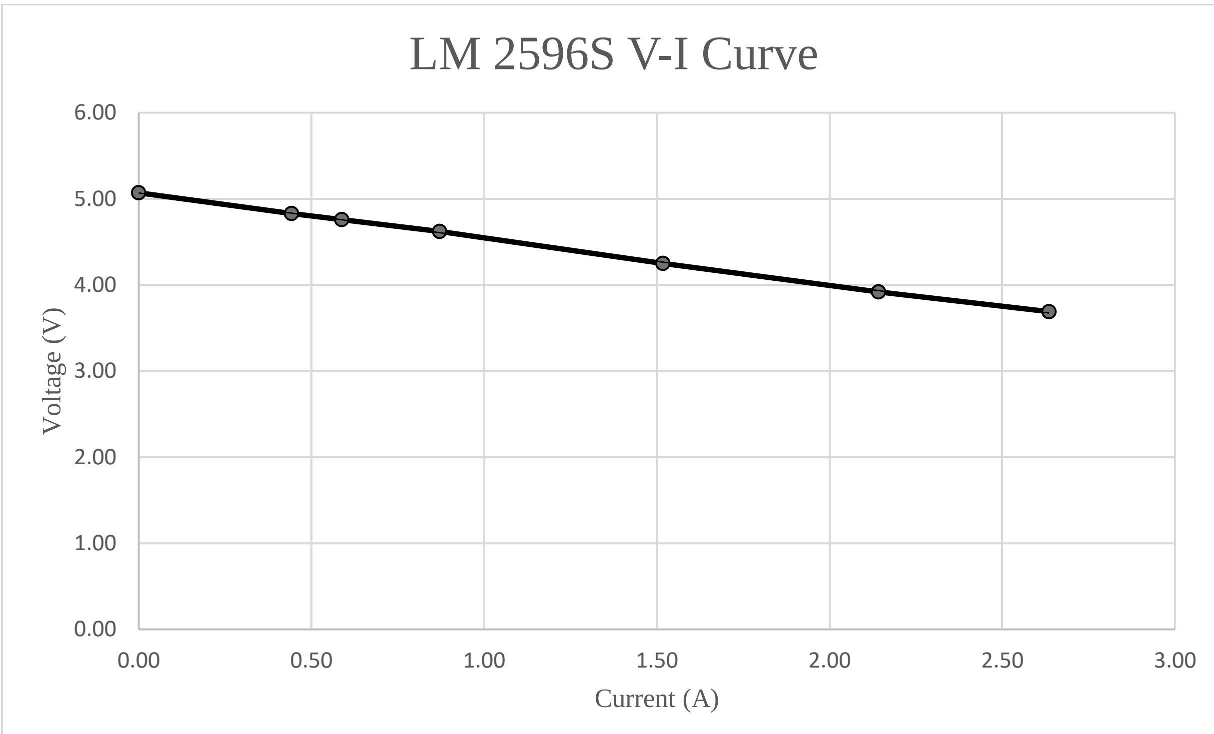

Figure 4. LM 2596S DC-DC 3A Buck Adjustable Step-down Power Supply Converter Module Voltage vs Current Graph

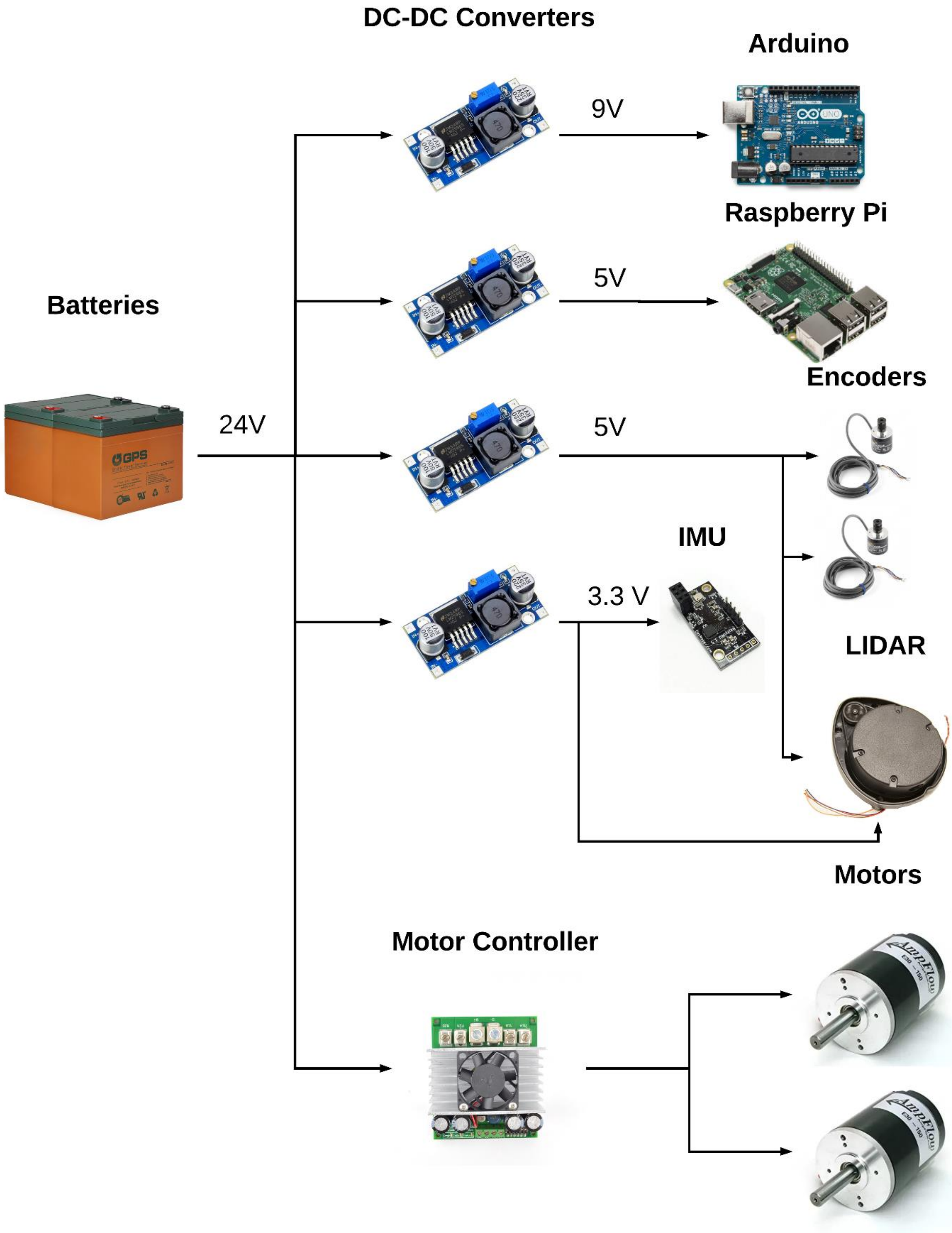

Figure 5. High Level Power Diagram.

Electrical Components

Onboard electronics are responsible for controlling the mechanical system. Figure 6 shows an overview the electrical system and its interfaces. Several different sensors are used to determine the current state of the wheelchair. LIDAR is used to detect obstacles, an IMU unit is used to determine current orientation and encoders are used to determine the rate the wheels are spinning. With the sensor data, the platform can determine information such as its current position, velocity, acceleration, and orientation and can detect obstacles. All the data from these sensors is gathered by a small computer called a Raspberry Pi. The Pi processes the data and determines what velocity it wants the platform to move at. It sends this data to a microcontroller called an Arduino. The Arduino is in a tight control loop with the motors and encoders to keep the wheels spinning at the desired velocity. Figure 6 shows a high-level overview of the electrical system containing the components and their interfaces.

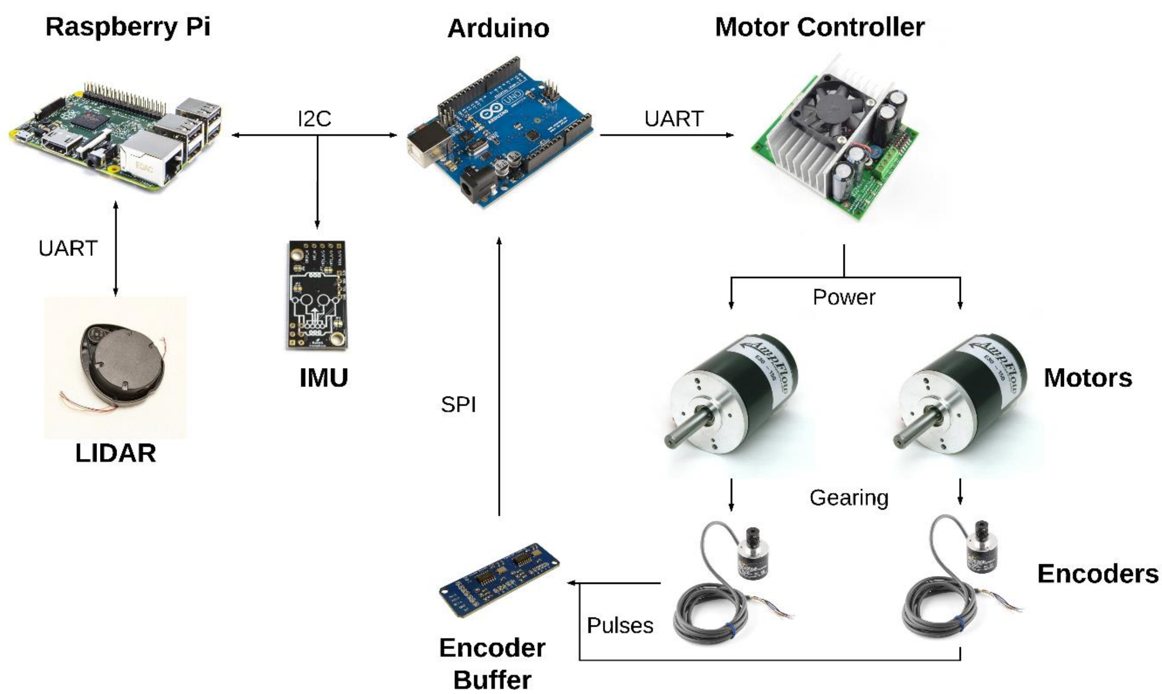

Figure 6. Electrical Components and their Interfaces

Raspberry Pi

At the heart of the system is a Raspberry Pi. The Raspberry Pi is a small single-board computer often used for DIY projects. It has processing power comparable with a cheap laptop and runs off an ARM Broadcom processor. [22] On the platform, the Pi is running Ubuntu, a distribution of Linux and uses Robot Operating System (ROS), a popular robotics middleware, for navigation.

The Raspberry Pi communicates with the Arduino and the IMU using I2C and with the LIDAR using UART. Although the Arduino uses 5 V logic and the Raspberry Pi uses 3.3 V logic, the I2C lines connecting them does not require a level shifter.[23] The reason is that the Raspberry Pi is running as the master and the Arduino is running as the slave. The Raspberry Pi has internal 1.8 kΩ pullup resisters connected to its 3.3 V power rail on its I2C pins, and since the Arduino has no pullup resisters on it, there are no issues. During testing, there were errors with the I2C connection with the Arduino. Sometimes these errors would lead to the Arduino disconnecting from the I2C bus. The cause of these errors was due to a defect in the Raspberry Pi's implementation of the I2C protocol. The Raspberry Pi does not implement clock stretching correctly.[24] When the slave device pulls the line low, the Pi does not ensure that the next clock cycle has the correct length. To work around this issue, the Raspberry Pi's I2C baud rate was reduced from 100 kHz to 25 kHz. This gave the Arduino more time to process the data and prevented it from using clock stretching, eliminating I2C errors.

Arduino Uno

The Arduino Uno is a popular open source microcontroller board. [25] It runs off the ATmega328P processor and contains 14 digital pins, 6 analog pins, and a 16 MHz clock. Several of these pins can be used for more specialized functions and implements its SPI, I2C, and one UART interface.

The sole purpose of the Arduino is to keep the wheels spinning at their desired velocity and relay encoder information back to the Raspberry Pi. The Arduino communicates with a Raspberry Pi over I2C. The Arduino is configured as the slave with the address 0x04 and the Raspberry Pi is configured as the master. Over the interface, the Arduino accepts requests for setting the desired velocity of each motor and requests for getting the current counts of each encoder. The Arduino is in a control loop with the encoders to ensure the wheels are spinning at the desired velocity. The Arduino interfaces with the Sabertooth 2x60 motor controller to control the power sent to each motor and a Dual LS7366R Quadrature Encoder Buffer to get the counts from each encoder.

Quadrature Encoders

Quadrature Encoders are necessary to ensure that the wheels are spinning at the correct rate. This is arguably the most important sensor on the platform. It is used primarily for determining the distance that the wheelchair has travelled and to ensure the wheels are maintaining a constant

[22] Raspberry Pi Foundation (2018).
[23] OscarLiang (2018).
[24] Advamation mechatronicx (2013).
[25] Arduino (2018).

velocity. A quadrature encoder is a type of sensor that senses rotational motion on a shaft. [26] It senses angular velocity by producing a pulse every couple of degrees, specified by the encoder's pulse per revolution (P/R) rating. It senses direction by sending out pulses on two channels, Channel A and B, that are 90 degrees out of phase with each another. The direction can be determined by which channel is leading. If Channel A leads Channel B, the shaft is rotating clockwise and visa versa. Quadrature encoders also send out a pulse on another channel, Channel Z, every time the shaft makes a full rotation.

When selecting an encoder, its resolution needs to be greater than the maximum speed of what it is measuring. In the current design, the encoders are mounted to the same shaft as the wheels. The motor spins at 5600 rpm and there is a 20:1 gear down from the motor to the wheels. The encoders purchased have a resolution of 6000 rpm, which is well above the speed that the wheels will be spinning. These encoders are 1024 P/R Quadrature encoders. [27] They send out 1024 pulses on each channel every full revolution of the shaft. Since pulses can be counted on the rising and falling edge of each pulse on Channel A and Channel B, the encoders give a resolution of 4096 pulses per revolution. With these pulses and the time difference between readings, the platform can determine its relative position, relative orientation, and its current velocity and acceleration.

Light Detection and Ranging (LIDAR)

LIDAR is a device used to detect obstacles around the wheelchair. The Neato XV-11 LIDAR was chosen because it was the cheapest option and works for indoor navigation. It uses a safe Class 1 laser to emit light pulses and an imager to detect when the light reflects back.[28] It can triangulate the distance to the nearest object tangent to the laser as shown in Figure 7 and collects a full 2D scan by rotating along its z-axis. This sensor is used to detect obstacles in real-time to avoid collisions with people or objects. All ranging data is sent over UART.

[26] Dynapar (2018).
[27] Yumo (2015).
[28] Neato (2013).

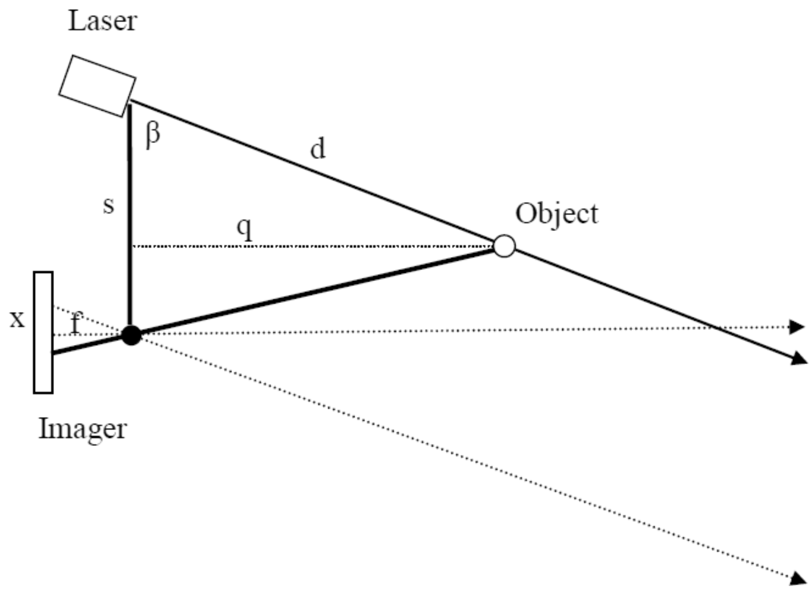

Figure 7. LIDAR triangulation diagram[29]

Inertial Measurement Unit (IMU)

The inertial measurement unit (IMU) is needed to establish the wheelchair's orientation and acceleration, independent of the wheels. An IMU consists of an accelerometer, gyroscope, and magnetometer.[30] The magnetometer is used as a compass to establish the current orientation. The IMU sensor purchased, the Berry IMU, consists of a LSM9DS1, a chip containing a magnetometer, accelerometer and gyroscope, and a BM180, a pressure sensor. These sensors interface over an I2C bus. More specifically, the magnetometer and accelerometer are assigned an address of 0x1E, the gyroscope an address of 0x6A, and the pressure sensor an address of 0x77.

Motor Controller

A motor controller was purchased to regulate the voltage and current supplied to the motor during operation. The motor runs at 24 V, draws 17 A continuously at peak efficiency, and draws peak currents of up to 127 A. An alternative besides buying a motor controller was building an H-bridge using power transistors. Because designing and properly building the circuit up to specifications seemed too difficult, purchasing a motor controller seemed like the best option. Finding a reasonably priced motor controller to handle peak currents of 127 A was difficult. The motor controller selected was the Sabertooth 2x60A regenerative motor driver.[31] This motor controller can power two brushed DC motors each with 60 A continuously. Although the motor controller can only handle up to 120 A peak, it was advertised to have overcurrent protection, so it would not burn out if more current is drawn.

[29] Konolige, Kurt et al (2008).
[30] Ozzmaker (2015).
[31] Dimension Engineering (2011).

Encoder Buffer

An encoder buffer chip was purchased to count the encoder pulses. Directly counting pulses from the Arduino using interrupts was not feasible because the 1024 P/R encoders send out pulses faster than the Arduino can count. The buffer purchased was a Dual LS7366R Quadrature Encoder Buffer.[32] This chip contains two LS7366R 32-bit quadrature counters. Each counter contains an SPI interface used for reading and resetting the counters.

Software Systems

The wheelchair is controlled using several programmable modules. All data flows that the system considers is shown in Figure 8. The platform receives movement commands from AWS, odometry information from the encoders, vision data from the LIDAR, and inertial data from the IMU. With all this data, the platform decides how it wants the motors to move. The main systems are the voice control system, the primary control system, and the velocity control system. The purpose of the voice control system is to recognize voice commands and relay them to the platform. The primary control system takes the voice data along with other sensor data and determines what velocity it wants the wheels to move at. The velocity control system is responsible for keeping the wheels spinning at this desired velocity.

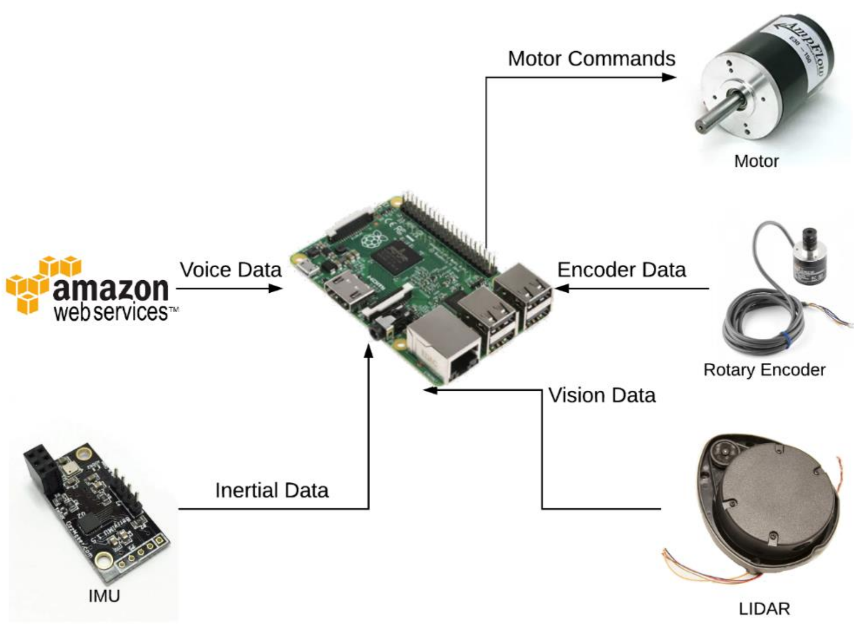

Figure 8. Data flows

[32] SuperDroid Robots (2017).

Primary Control System

The primary control system controls all subsystems. The source code can be found at https://github.com/Transnavigators/TROSnavigator. It uses Robot Operating System (ROS), a collection of frameworks for robotics software development. ROS provides several services like message passing, hardware abstraction, and pre-built packages for commonly used algorithms which all assist in writing robotics code. A few other alternatives considered were ROS 2, Mobile Robot Programming Toolkit, Microsoft Robotics Developer Studio, and PolySync, but none of these options had as much community support and built-in hardware support.

ROS message passing works by sending messages on topics which run over TCP. This allows multiple computers to be a part of a single ROS cluster. There are various standard messages used across all ROS nodes to make each ROS node hardware agnostic. Since ROS nodes only use ROS topics as inputs and outputs, the algorithms used for localization and hardware are modular. For more information about ROS, the book *Programming Robots with ROS* is an excellent resource.[33]

The main task was to write ROS drivers for the sensors and actuators and tie the wheelchair with the ROS ecosystem. The ROS drivers for sensors communicate with the devices over serial busses, translate the data into standard units, and publish messages to other nodes. The ROS driver for the motor subscribes to a topic for desired velocities, translates the messages from that topic into I2C messages, and tells the Arduino what speed to move each motor at. Another ROS node subscribes to a MQTT topic from AWS IoT and passes the message to ROS. These nodes and their relationships can be seen in Figure 9.

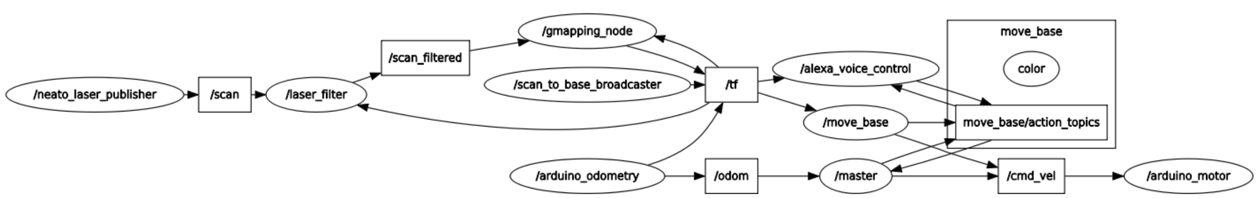

Figure 9. The ROS computation graph for Transnavigators' Voice Controlled Wheelchair

One problem that ROS solves is transforming between coordinate frames. When writing drivers, data from the sensors are relative to the location of the sensor. This data needs to be put in a single frame of reference, which is where tf comes in. The tf package lets ROS nodes publish transforms between frames of reference and keeps track of them over time. When a ROS node needs to translate between coordinate frames, it can use tf to do this. This makes it easy to have dynamic transforms such as those required for a robot arm joint. Although the wheelchair does not have joints, it does have several sensors such as the LIDAR that use static transforms to transform from their position to the base of the wheelchair.

Several normally difficult problems were solved though premade ROS nodes. Since ROS is open source, people can publish their solutions to common problems, allowing others to use them. The

[33] Gerkey, et al (2015).

most popular ROS nodes tend to be actively developed, making them robust and well-documented.

One problem ROS solved was reading the LIDAR data. All the information about the XV-11 LIDAR unit is from a hackathon, so the documentation is not ideal.[34] Thankfully, a ROS driver was already made for the XV-11 LIDAR.[35]

The initial plan was to use an indoor positioning system to determine the initial position of the wheelchair. Then, a ROS node named AMCL would run adaptive Monte Carlo localization and update the location of the wheelchair against a floorplan of Shiley. However, indoor positioning is a developing technology and reliable systems do not exist yet.

Without an initial position, there is a localization and mapping problem. Simultaneous localization and mapping (SLAM) algorithms can solve this problem by creating a map and keeping track of the location of the wheelchair. An algorithm from OpenSLAM called GMapping was used, which conveniently has a ROS wrapper.[36] This algorithm uses Rao-Blackwellized particle filters to solve the SLAM problem.[37] A Rao-Blackwellized particle filter is a special kind of particle filter that stores particles as Gaussian distributions on one dimension, making it more computationally efficient than other SLAM algorithms. The GMapping algorithm also resamples the particle map periodically to minimize memory and CPU usage.

Once the gmapping node was running, another problem presented itself. LIDAR sensor is not always accurate. There is noise occasionally where the sensor will see an obstacle for one frame or not have a reading at all. There is also a veiling effect where the LIDAR will see the wrong point if it is pointed at the edge of an object. To solve these problems, a scan shadows filter and interpolating filter was put between the input laser scan data and the gmapping node.[38] The scan shadows filter checks if the angle between two consecutive points is greater than a threshold and removes it if so. The interpolating filter compensates for this missing data by interpolating between the surrounding good points. There is another filter which serves to block the wheelchair's wheels from being seen by the LIDAR. It is a box filter which filters out any points within the dimensions of the wheelchair. This introduces blind spots where the wheels touch the ground, but the blind spots were small and could be ignored without any serious consequences.

The next step is to feed the filtered LIDAR data into a map. The map must be translated into a representation useful for planning where the wheelchair can go. A local and global costmap was generated using the ROS node costmap_2d. The local costmap keeps track of gmapping's output and assigns infinite weight to obstacles seen by the LIDAR. It also ascribes a higher cost to moving close to obstacles so the wheelchair prefers to move a healthy distance away from obstacles. When it an obstacle moves away, it removes that obstacle from the costmap and the wheelchair is free to move where the obstacle used to be. Another costmap is generated for the

[34] Xv11hacking (2016).
[35] Perko et al (2018).
[36] Gerkey (2018).
[37] Grisetti et al (2016).
[38] Foote (2018).

global surroundings. It keeps a history of all the places the wheelchair has been, but it updates less frequently.

Using the costmap, the ROS node base_local_planner runs the Trajectory Rollout and Dynamic Window algorithms for navigation on a 2D plane.[39] The Trajectory Rollout algorithm is a particularly efficient navigation algorithm which simulates several short potential paths and selects the best one using a weighted cost function.[40] The Dynamic Window approach reduces the possible velocity commands to those reachable in a short time based off the maximum acceleration of the wheelchair.[41] Another ROS node navfn runs Dijkstra's algorithm to find the shortest path in a graph using the global costmap as a graph.[42]

These two planners work with the ROS node move_base, which provides an interface to other ROS nodes to move the wheelchair. It uses the global planner to find the basic path the wheelchair should take while the local planner handles collision avoidance.

Once these nodes were setup correctly, the wheelchair could move autonomously and avoid obstacles. Unfortunately, the LIDAR was mounted incorrectly, so the LIDAR saw the floor as an obstacle that followed it as it turned. It would keep turning to avoid the "obstacle", occasionally bolting forward if there was an opening in the local costmap. This can be seen in Figure 10. The red line on the top right is the intersection between the plane of the LIDAR and the floor. Since fixing this problem would require a redesign of the chassis, the backup plan was used which ignores LIDAR data and moves without obstacle avoidance. The backup plan's graph can be seen in Figure 11. It only uses the arduino_odometry, arduino_motor, alexa_voice_control, and a master node.

[39] Lu et al (2018).
[40] Gerkey, B. P., & Konolige, K. (2008).
[41] Fox, D., Burgard, W., & Thrun, S. (1997).
[42] Lu et al (2018).

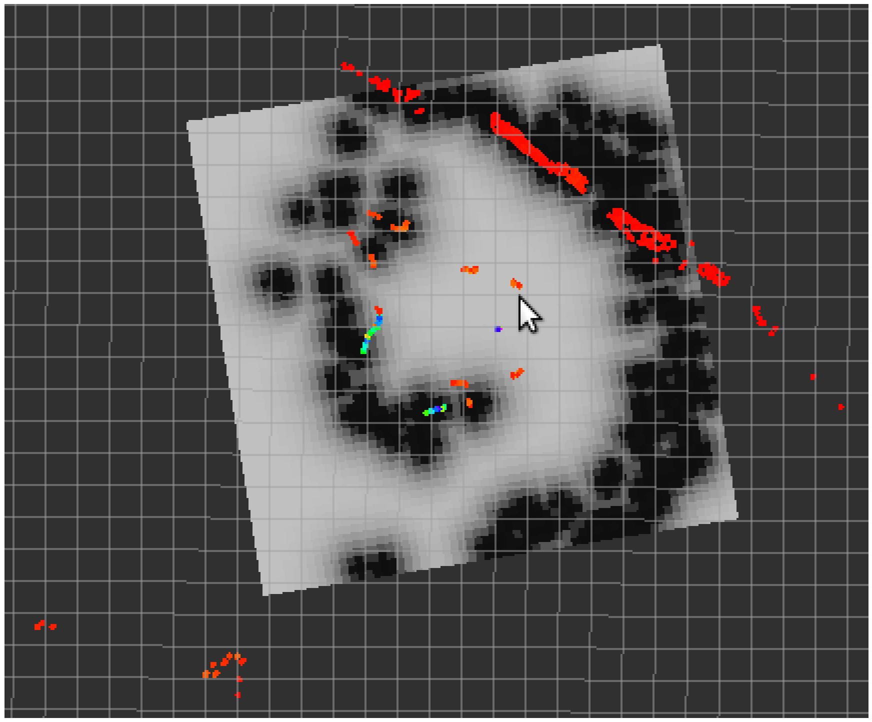

Figure 10. A screenshot of the local costmap during testing. The LIDAR is tilted towards the platform's back-right corner. It sees the ground as shown by the long collection of red points. As the platform is turns left, it remembers the points it previously detected and generates the local costmap. The black blobs are considered obstacles in the local costmap.

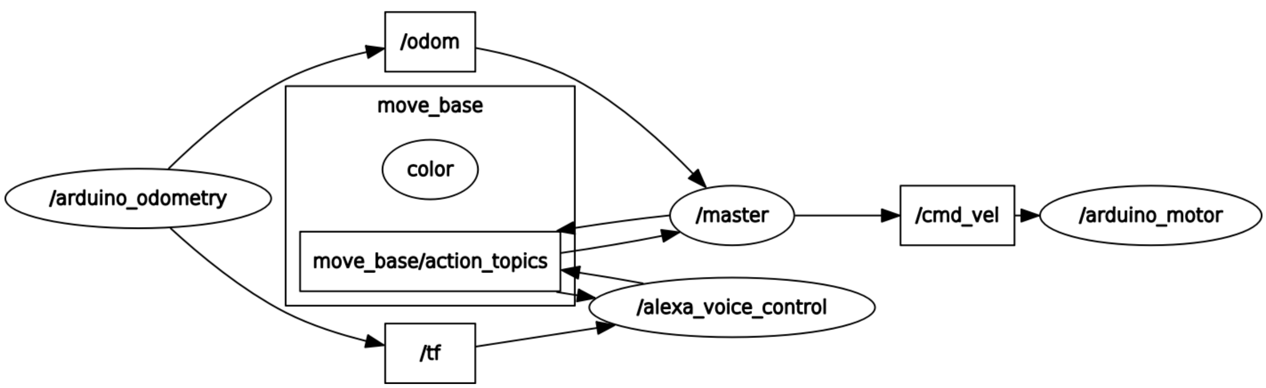

Figure 11. The backup plan's ROS computation graph.

Voice Control System

The voice control system is responsible for recognizing the user's voice commands and transmitting voice data to the platform. Amazon Web Services (AWS) was chosen to host and provide this service because it is free, and an Alexa skill was developed and deployed. The flow of data through this system is as follows. Voice commands are recorded by an Echo Dot, which sends this data to Amazon Alexa. Alexa processes the speech into JSON, a data-interchange format.[43] This data is then routed through Amazon's serverless computing platform, AWS Lambda, and sent through Amazon's tool for the Internet of Things, AWS IoT, to a small computer, the Raspberry Pi, where the speech data is used for controlling the wheelchair. A diagram of the data flow described is shown in Figure 12.

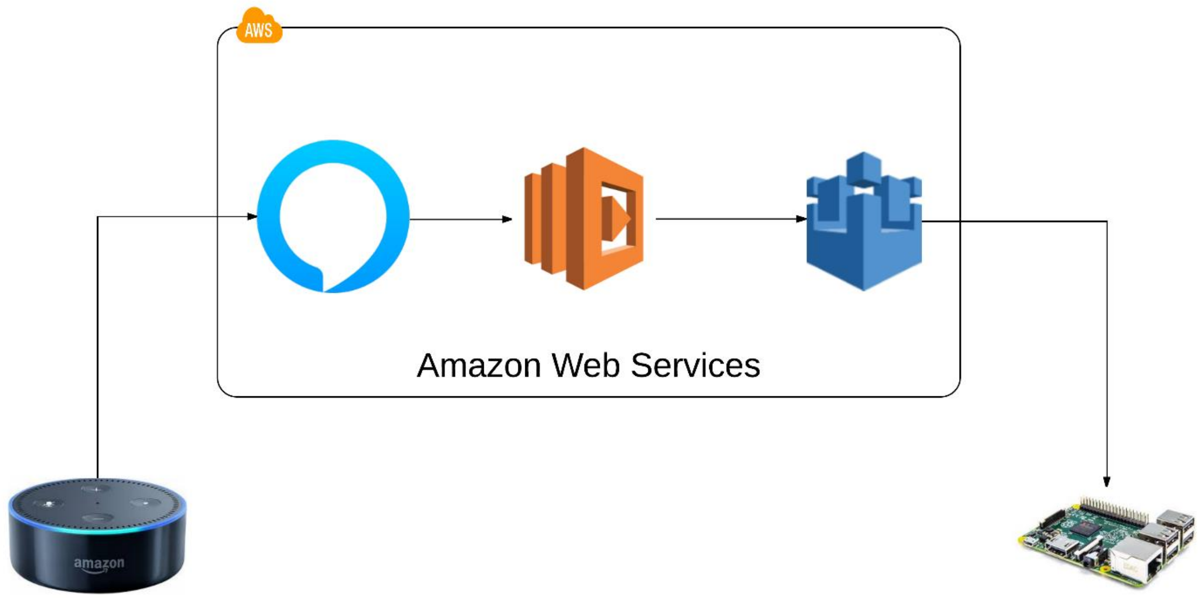

Figure 12. Voice Control System

The Alexa skill has an invocation name of "wheelchair." A screenshot of the skill as it appears in the Alexa skills page is shown in Figure 13. The skill is designed to recognize nearly every utterance for each intent it recognizes. Users can command the chair by invoking the skill and saying an intent or combining the invocation and intent in the same command. For example, the following are equivalent:

- User: "Start my wheelchair"
- Alexa: "Welcome to the Transnavigators' Voice Controlled Wheelchair"
- User: "Move forward 10 feet "
- Alexa: "Moving forward 10 feet"

and

- User: "Tell my wheelchair to move forward 10 feet"
- Alexa: "Moving forward 10 feet"

[43] McCauley, R. (2016).

One fundamental limitation of Alexa is that skills exits automatically after a preset timeout.[44] The current timeout is 8 seconds, and this value cannot be changed. The reason way the timeout exists is to ensure that skills do not spy on the users by staying open forever. The result of this limitation is that the user needs to resay “Start my wheelchair” if the movement command takes longer than 8 seconds or stick with commands that combine the invocation name and the intent.

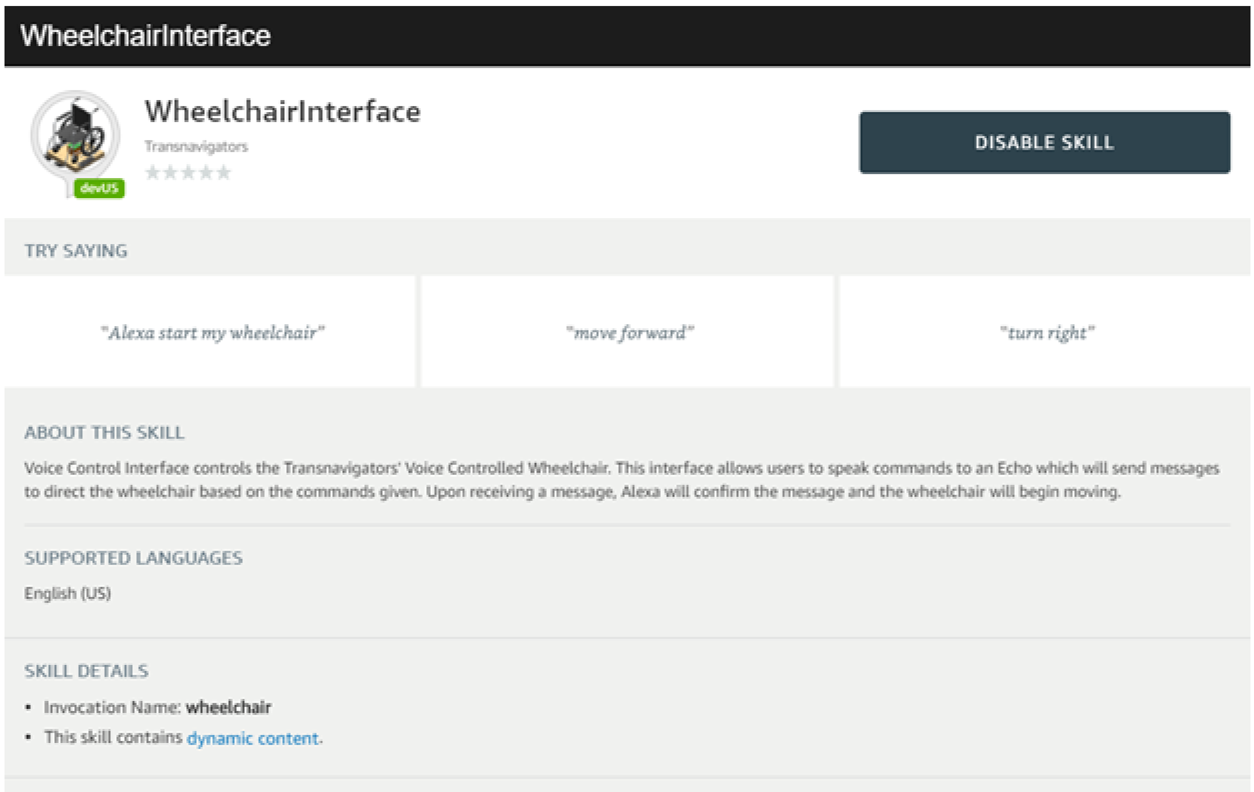

Figure 13. Wheelchair Skill in Alexa

The current interface recognizes intents that the current system does not fully support yet. These intents are left in for anticipation of future upgrades. If invoked, the Echo responds to the user notifying them that the feature has not been implemented yet. Currently, moving forward a specified number of feet/meters and turning a specified number of degrees/radians are fully supported. The source code is stored on https://github.com/Transnavigators/AlexaVoiceControl.

Alexa Interface

The Alexa Interface is a JSON file that runs in Amazon Alexa that defines intents and utterances that Alexa should recognize. It is designed to include the most widely used phrases for each valid intent. The interface defines eight different intents for interfacing with the wheelchair. The intents are as follows:

- **MoveForward** : Moves forward
- **Turn** : Turns the wheelchair a certain number of degrees

[44] Vishnu (2016).

- **Stop** : Overrides the default Stop Intent for stopping the wheelchair
- **MoveTo** : Moves to a specified location (unimplemented in the final version of the chair)
- **LocateMe** : Finds the user (unimplemented in the final version of the chair)
- **AMAZON.CancelIntent** : Cancel required for certification (Closes the skill)
- **AMAZON.HelpIntent** : Help required for certification

Lambda Function

A NodeJS script called the Lambda Function runs on AWS Lambda to route data from Alexa to the wheelchair. The function processes the data from Alexa, sends speech output back to Alexa confirming the user's intent, and transforms the data into a format that the wheelchair can recognize. The resulting messages are published to the MQTT topic /Transnavigators/Pi using AWS IoT. The JSON output of the Lambda Function for each motion intent is as follows:

MoveForward

```
{
  "type" : "forward"
  "distance" : How far to move forward
  "distanceUnit" : Units for the distance number ("meters" or "feet")
(optional: empty means feet)
}
```

Turn

```
{
  "type" : "turn"
  "direction" : "left" or "right"
  "angle" : Number of degrees to turn
  "angleUnit" : "degrees" or "radians"
}
```

Stop

```
{
  "type" : "stop"
}
```

MoveTo (unimplemented in the final version of the chair)

```
{
  "type" : "move"
  "location" : Where to move to
}
```

LocateMe (unimplemented in the final version of the chair)

```
{
  "type" : "locate"
}
```

Velocity Control System

The velocity control system keeps the platforms' wheels spinning at their desired velocity. The system receives desired velocities from the Raspberry Pi and uses the output from the encoders to ensure that the wheels are spinning at the correct rate. The Arduino is the microcontroller controlling this system and the code is available at https://github.com/Transnavigators/Transduino.

Debug Mode

When the debug macro is defined, the Arduino is placed in DEBUG mode. In this mode, the user can view debug messages from the Arduino using the Serial Monitor. Pin 2 is configured to use Software Serial to send data to the motor controller in order to free the Arduino Uno's sole UART interface for communication with the computer. As a result, the following change must be made when switching between debug and production mode:

- **Debug Mode:** Pin 2 -> S1
- **Production Mode:** Pin 1 (TX) -> S1

Raspberry Pi Interface (I2C)

The Arduino communicates with the Raspberry Pi over I2C. The Raspberry Pi acts as the master and the Arduino acts as the slave. Over the interface, the Arduino receives the desired speed of each wheel and sends the current counts of each encoder. The Arduino is configured with an address of 0x04.

Data Format

The following are data formats for communicating between the Arduino and the Raspberry Pi.

1. Sending a speed (m/s) to the motors:

- Write an 'm' (move) and two 32-bit float speeds (one for each motor) to the Arduino

Register (1 byte)	**Motor 1 Speed (4-byte float)**	**Motor 2 Speed (4-byte float)**
'm'	Desired speed of Motor 1 (m/s)	Desired speed of Motor 2 (m/s)

2. Getting the current encoder counts

- Request data from the Arduino, optionally sending an 'e' (encoder)

Register (1 byte)
'e'

- The Arduino will reply with

Encoder 1 Count (signed 32 bit integer)	Encoder 2 Count (signed 32 bit integer)
Cumulative number of pulses seen by Encoder 1	Cumulative number of pulses seen by Encoder 2

Motor Controller Interface (UART)

The Arduino communicates with the Sabertooth Motor Controller using a UART interface. During normal operation, data is send from the Arduino's pin 1 (TX) to the Sabertooth's pin S1. In debug mode, a Software Serial interface is used to send data to the motor controller in order to free the Arduino only UART interface for printing debug messages over USB. In this instance the Arduino transmits data using pin 2 (or whatever SW_SERIAL_PORT is set to).
The Sabertooth is physically configured with an address of 128 as is reflected in SABERTOOTH_ADDRESS. Its baud rate (BAUD_RATE) has been set to 115200.

- **Sabertooth's address:** 128 (SABERTOOTH_ADDRESS)
- **Baud rate for UART interface:** 115200 (BAUD_RATE)
- **UART Tx pin:** 1 (normal), 2 (debug SW_SERIAL_PORT)

Encoder Interface (SPI)

The Arduino communicates with the Quadrature Encoder Buffer over SPI. The buffer chip is used to count pulses for each encoder because the 1024 P/R encoders send out pulses faster than the Arduino can count.

The select pin for Encoder 1 is 7 (ENCODER1_SELECT_PIN) and the select pin for encoder 2 is pin 8 (ENCODER2_SELECT_PIN).

- **Encoder 1's select pin:** 7 (ENCODER1_SELECT_PIN)
- **Encoder 2's select pin:** 8 (ENCODER2_SELECT_PIN)

Speed Control

The power sent to each motor is calculated using feedback from the encoders. The current speeds of each wheel are calculated every iteration of the main loop, and the powers sent to each motor are adjusted accordingly by one level in the corresponding direction. As shown in Figure 14, by using constant power changes, any errors caused by bad data or other glitching will have only a momentary effect on the system and not cause large fluctuations in the current speed of the chair.

In addition, a timeout is applied on the motors to stop the platform from moving if the Arduino has not received a command in a long time. This timeout is a safety feature that prevents the chair from moving if the something happens to the Raspberry Pi or the I2C interface.

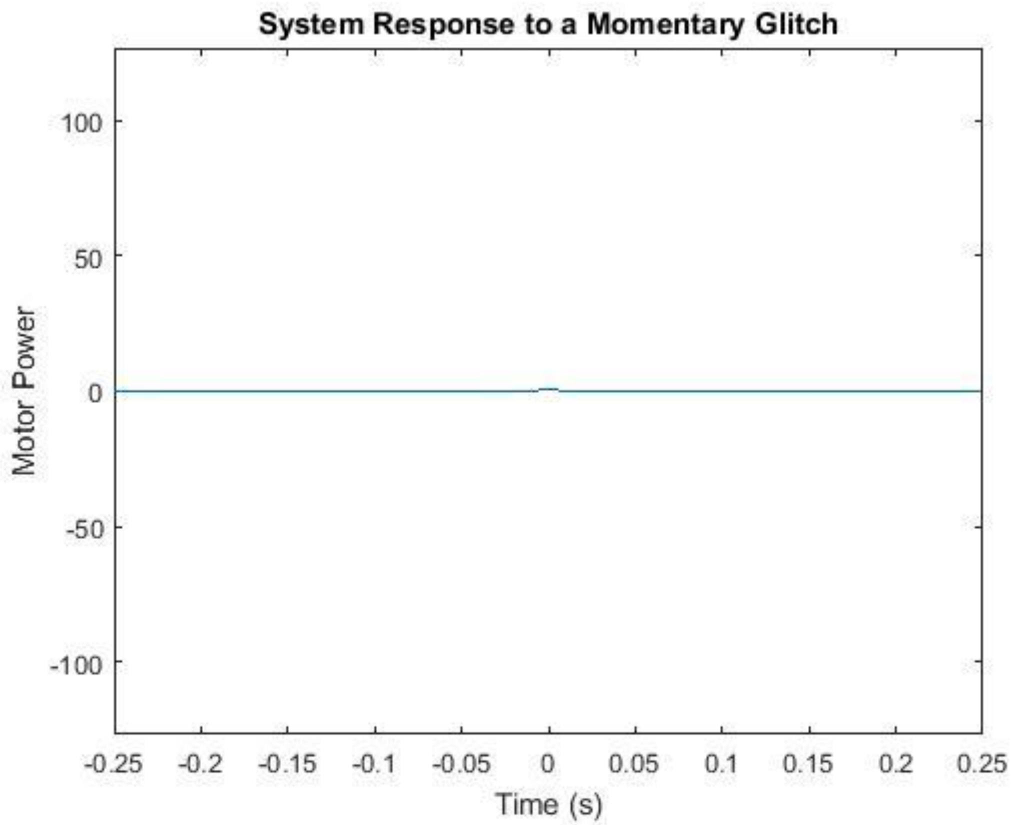

Figure 14. The system’s response to a momentary velocity calculation glitch at time t=0. Notice that a glitch only affects the motor’s power for a very short time (one iteration of the main loop)

Limitations

The following are known potential issues with the code. Problems arising from these issues may cause minor glitching but should not cause any major effects on the overall system.

One potential issue is that the encoder buffers’ counters can overflow. The encoder buffer chips use a 32-bit counter. If the wheelchair moves in one direction at maximum velocity, after about 87 minutes, the counts will overflow and cause a momentary decrease or increase in velocity. Since the control system only uses constant power changes, this effect will be almost unnoticeable to the user as the system will correct itself on the next iteration of the loop. Another potential problem with the wrapping is that the Raspberry Pi will also get this encoder data. The code on the Raspberry Pi accounts for wrapping though.

Another issue is with the micros() function. The micros() function returns a unsigned 32-bit number containing the number of microseconds since the Arduino booted.[45] Every 72 minutes the micros() function will overflow. In the code, the current velocity of the wheels is calculated using the encoder counts and time difference between them. The function micros() is used to get this time difference. When micros() overflows, the velocity calculated will be nearly zero. Because the system uses constant power changes, overflow will only cause the power to drop by one level during the overflow iteration. During the next iteration though the power will correct itself.

Another issue is that the wheels sometimes oscillated around the desired velocity during testing. This was happening because some mechanical components such as the gears were loose. The result was that the wheels were oscillating at the same frequency that the gears were. When the platform was under load though, it had enough damping that there were no oscillation issues during system testing.

Testing Results

Full system testing was performed in the lobby areas on the third and first floor of Shiley Hall. Testing was performed using the backup software system as shown in Figure 11 due to the LIDAR mounting issues described previously. The wheelchair platform was tested for its ability to process commands and execute them. The commands to move forward and turn were tested. During testing, a tape measure was set to fifteen feet and placed on the ground to verify that the platform moved the correct distance and in a straight line.

The following test was performed on April 6, 2018. A basic diagram of the test is shown in Figure 15:

1) The wheelchair platform and Echo Dot are turned on.
2) The front edge of the platform was positioned at one end of the tape measure.
3) The user sits in wheelchair mounted to the platform. Filming of the test begins.
4) The user says, “Alexa, start wheelchair” and waits for a response from the Echo Dot.
5) The user says, “Move forward fifteen feet.”
6) The Echo Dot confirms the command and the platform moves as specified. Once the platform stops moving, the front of the platform was compared with the markings on the tape measure
7) The user says, “Alexa, start wheelchair” and waits for a response from the Echo Dot.
8) The user says, “Turn right.”
9) The Echo Dot confirms the command and the platform turns as specified, the angle of the final position of the platform was compared to its initial.
10) Stop filming.

[45] Arduino (2018).

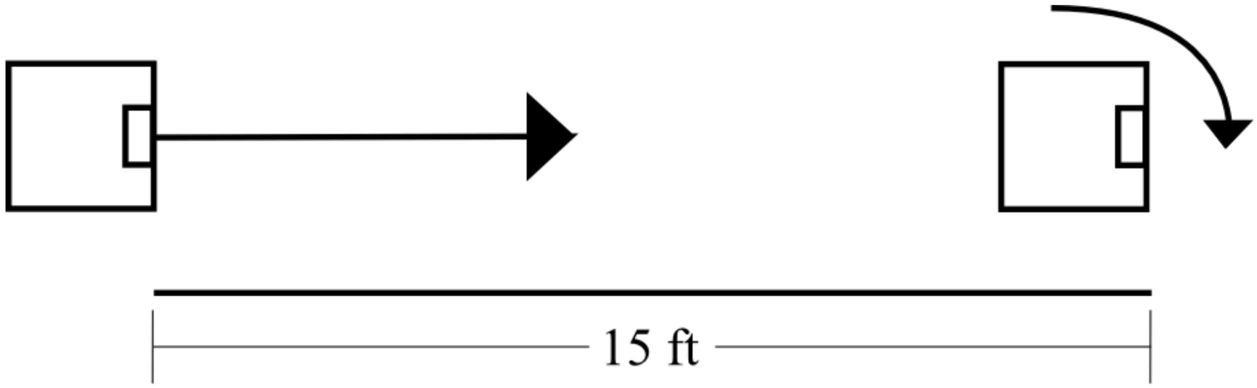

Figure 15. Diagram of Wheelchair Test Path

Full system testing revealed issues with network latency. Due to high network traffic in certain parts of Shiley, the time it took for the Echo Dot to send voice commands to AWS and be recognized was around eight and twelve seconds. In addition, sometimes the Dot would disconnect from the Internet entirely and the chair would be unable to receive commands.

The test was overall successful. The platform could both move forward at the specified distance while correcting for veering and turn the specified angle within the metrics stated in the project's A3 document. See Appendix A for a copy of the A3 document. A video of the test described can be seen on the website, https://engineering.projects.up.edu/donaldsa18/. Images of the tests are shown in Figure 16 and Figure 17.

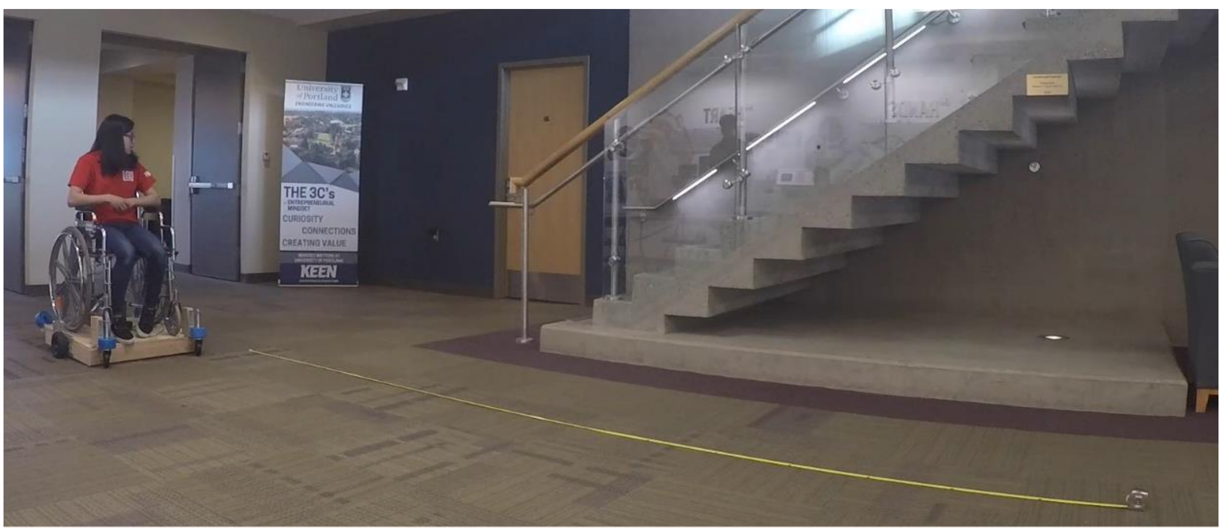

Figure 16. Photo from prototype testing. Courtney is sitting in the wheelchair prior to testing.

Figure 17. Photo from prototype testing. Courtney after the “Move forward 15 feet” and “Turn right” commands.

Unresolved Issues

Full autonomy was not achieved in the prototype. The main reason for this was that the LIDAR mount was improperly designed and required nearly impossible tolerances for proper mounting. Fixing the mounting issue would require a total mechanical redesign. Currently, the LIDAR is mounted on the bottom of the platform 0.56 inches from the ground. Because it so close to the ground, the LIDAR needs to be mounted very precisely. If the LIDAR is not mounted with the correct tolerance, it will see the ground and interpret it as a wall. Another issue with the current design that affects the LIDAR is that under load, the spring casters depress and cause the front of the platform to nearly touch the ground. When the casters depress, the entire platform tilts forward and so does the LIDAR.

As shown in Figure 18, just a 1° mounting error in any direction will make the LIDAR see a wall at 32 inches in the direction of the tilt. As the tilt increase, the “wall” will get closer to the platform. Spring-loaded casters further exasperated the issue since they cause the platform tilt slightly under its own weight. Washers were shimmed underneath the LIDAR to counteract this tilting, but the tolerances were too tight to completely fix the issue. The width of one washer was too thick for finetune shimming necessary for leveling the sensor. In addition, even if the LIDAR was level, it would still see the ground since the floor is not perfectly flat and since the casters depress slightly when the platform starts and stops. Thus, a major redesign is needed to fix the issue.

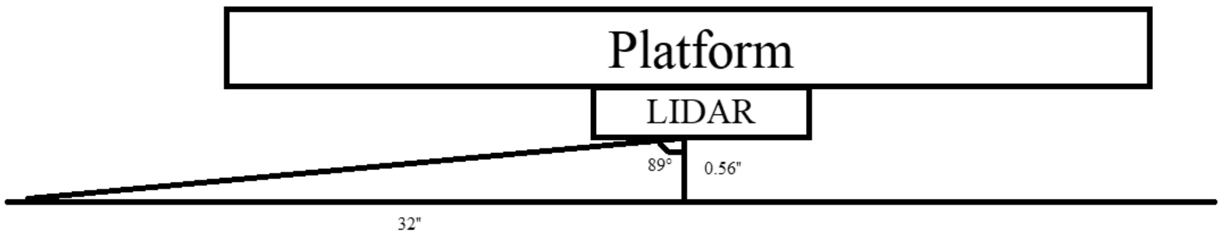

Figure 18. Mounting Error Tolerance: A mounting error of just 1° makes the LIDAR see a "wall" 32 inches away from it

Engineering Standards

The project was tailored to meet the requirements laid out in the American Disabilities Act (ADA).[46] The biggest restriction taken from this document was that "Ramp runs shall have a running slope no steeper than 1:12" (ADA 405.2). This degree of inclination was mainly used to determine the minimum power that the motors required to carry the desired load of 300 pounds. Another restriction taken from this document was that "Door opening shall provide a clear width of 32 inches minimum" (ADA 404.2.3), which was kept in mind while finalizing the design of the chassis.

Professional Responsibility

An ethical and professional responsibility this project continuously stresses is safety, which needed to be considered during the design and testing process. This includes the safety of not only the rider, but also the people and the property around the platform while it is in motion. The desired top speed was set relatively low, an emergency stop button was installed, the height of the platform was designed to a minimum, foam bumpers were attached to the corners to protect the infrastructure, toggle clamps were added to the design for securing the user to the platform, and many more steps were taken to ensure no one and nothing was harmed.

[46] Department of Justice (2010).

Schedule

The original schedule planned for this project can be seen below in Table 7. An aggressive approach was desired for this project; A goal of producing a prototype by the end of the first semester to reserve the second for iterating and working out bugs. Unfortunately, the project fell behind schedule and the prototype was not completed until the middle of the second semester. There were a couple of issues that came up Fall semester that were unexpected. The project budget was approved later than accounted for in the timeline, which pushed everything that required hardware or materials back. Also, the designing duration of the project (the chassis, the communication system, the motors and batteries, etc.) was much more complex than anticipated and required more time than was allotted. During Spring semester, many more issues arose again impeding progress. By Founder's Day, however, a working prototype was completed, a working test video was filmed, and a successful presentation was given. The schedule of the steps taken over the course of Spring semester can be seen in Table 8.

Table 7. Timeline of both semesters ending with Founder's Day presentations on April 4, 2018

Task Name	Duration	Start	Finish
CS: Define voice interface	3 days	Thu 9/14/17	Mon 9/18/17
CS: Testing software for IPS	17 days	Thu 9/14/17	Fri 10/6/17
ME: Brainstorm Wheelchair Designs	9 days	Thu 9/14/17	Tue 9/26/17
CS: Communication between AWS and Pi	5 days	Tue 9/19/17	Sun 9/24/17
EE: Research Controlling Motors	19 days	Thu 9/21/17	Tue 10/17/17
CS: Software system block diagram	15 days	Mon 9/25/17	Fri 10/13/17
ME: Initial Design	1 day	Wed 9/27/17	Wed 9/27/17
EE: Create Schematic of System	8 days	Thu 9/28/17	Mon 10/9/17
Finalize Budget	2 days	Thu 9/28/17	Fri 9/29/17
CS: Simulation: Render 2D shapes/points	7 days	Fri 9/29/17	Mon 10/9/17
CS: Finalize location tech	5 days	Mon 10/9/17	Fri 10/13/17
EE: Hardware system block diagram	22 days	Wed 10/18/17	Thu 11/16/17
Buy Everything	11 days	Mon 10/23/17	Mon 11/6/17
CS: Simulation: Make basic room using shapes	14 days	Tue 10/24/17	Fri 11/10/17
CS: Simulation: Make model for wheelchair & LIDAR	4 days	Tue 10/24/17	Fri 10/27/17
CS: Simulation: Wheelchair movement	7 days	Mon 10/30/17	Tue 11/7/17
CS: Simulation: Introduce Error	3 days	Mon 10/30/17	Wed 11/1/17
CS: Simulation: Self-calibration	7 days	Thu 11/2/17	Fri 11/10/17
EE: Test Hardware	7 days	Tue 11/7/17	Wed 11/15/17
ME: Obtain Motors and Wheelchair	1 day	Tue 11/7/17	Tue 11/7/17
CS: Simulation: Realistic physics	7 days	Wed 11/8/17	Thu 11/16/17
CS: Simulation: Pathfinding	21 days	Wed 11/8/17	Wed 12/6/17
ME: Build Motor Circuit	7 days	Wed 11/8/17	Thu 11/16/17
ME: Build Mount	7 days	Wed 11/8/17	Thu 11/16/17
Fall report	11 days	Fri 11/17/17	Fri 12/1/17
ME: First Prototype Built	16 days	Fri 11/17/17	Fri 12/8/17
CS: Test simulation many times	6 days	Thu 12/7/17	Thu 12/14/17
ME: Testing Movement	4 days	Mon 12/11/17	Thu 12/14/17
Integration	35 days	Mon 1/15/18	Fri 3/2/18
Testing	21 days	Mon 3/12/18	Mon 4/9/18

Table 8. Final timeline for the second semester ending with the spring report deadline during dead week

Task Name	Duration	Start	Finish
CS: Create Alexa Node	1 day	Tue 1/23/18	Tue 1/23/18
ME: Cut Wood for Chassis	1 day	Thu 1/25/18	Thu 1/25/18
CS: Make Triangulation Software	2 days	Thu 1/25/18	Fri 1/26/18
CS: Develop Interface Between Arduino and Raspberry Pi	3 days	Thu 1/25/18	Mon 1/29/18
EE: Order the Berry IMU and Encoder Chips	1 day	Wed 1/31/18	Wed 1/31/18
ME: Drill Bearing Holes	1 day	Thu 2/1/18	Thu 2/1/18
ME: Install Drive Train	1 day	Mon 2/5/18	Mon 2/5/18
CS: Implement TF Navigation Stack	5 days	Tue 1/30/18	Mon 2/5/18
CS: Work on Arduino Code for Encoders	5 days	Tue 1/30/18	Mon 2/5/18
CS: Have Network Fixed	0 days	Thu 2/8/18	Thu 2/8/18
ME: Test Drive Train	5 days	Tue 2/6/18	Mon 2/12/18
CS: Unit test different nodes	5 days	Tue 2/6/18	Mon 2/12/18
All: Integrate Drive Electronics	1 day	Tue 2/13/18	Tue 2/13/18
EE: New Encoder Testing	1 day	Tue 2/13/18	Tue 2/13/18
EE: Electronic Component Testing	0 days	Thu 2/15/18	Thu 2/15/18
ME: Assemble Chassis	1 day	Thu 2/15/18	Thu 2/15/18
ME: Design Wheelchair Attachment Method	21 days	Fri 2/9/18	Fri 3/9/18
CS: Integrate Nodes	9 days	Mon 2/12/18	Thu 2/22/18
ME: Purchase Materials for Wheelchair Attachments	7 days	Mon 3/12/18	Tue 3/20/18
ME: Construct and Integrate Attachments on Chassis	5 days	Thu 2/15/18	Wed 2/21/18
All: First Prototype	0 days	Thu 2/22/18	Thu 2/22/18
CS: Map Floor Plan	3 days	Thu 2/22/18	Mon 2/26/18
All: First Prototype Integration Testing	5 days	Thu 2/22/18	Wed 2/28/18
CS: Create Berry IMU Node	20 days	Thu 2/1/18	Wed 2/28/18
CS: Integrate Triangulation and LIDAR Nodes	5 days	Thu 3/1/18	Wed 3/7/18
ME: Drive Train and Chassis Changes/Iterating	16 days	Thu 2/22/18	Thu 3/15/18
CS: Working Navigation	18 days	Thu 3/8/18	Mon 4/2/18
All: Integration Testing	2 days	Tue 4/3/18	Wed 4/4/18
All: Final Prototype	1 day	Thu 4/5/18	Thu 4/5/18
All: Create Presentation	4 days	Thu 3/29/18	Tue 4/3/18
All: Practice Presentation	2 days	Wed 4/4/18	Thu 4/5/18
All: Run through Presentation	0 days	Fri 4/6/18	Fri 4/6/18
All: Tweak Presentation	2 days	Fri 4/6/18	Mon 4/9/18
All: Founders Day	0 days	Tue 4/10/18	Tue 4/10/18
All: Spring Report	0 days	Fri 4/27/18	Fri 4/27/18

Budget

The budget request was initially planned around building a mostly wood prototype by the end of fall semester and then transitioning into a final product constructed mostly of aluminum for a higher strength to weight ratio.

Some money was saved by using donated items (Wheelchair, Amazon Echo, etc.). While building the wooden prototype, however, a countless number of issues were fixed with either the purchasing of sensors, braces, or other supporting hardware. With extra time, a perfectly working wooden prototype could have been created then transferred to a metal chassis. The final cost of the project was $2,128.16 leaving the unused funds at $93.46. All purchases over the course of the project and how they compare to the requested budget can be seen in Table 9. The Shiley Credit Card was returned to Lisa Basset on April 11th, 2018.

Table 9. Final budget for the project. Grey items were not purchased

Project Materials/Supplies	Expected	Bought for	Shipping
Localino v2.0 Kit	$410.64	$ 410.40	$ 16.75
12 Volt/80 Amp Hour Battery	$316.98	$ 153.98	$ 36.59
NEATO LiDAR	$119.00	$ 69.00	$ 12.75
Localino v2.0 Tag	$102.66	$ 102.60	$ -
DC Motor(24 V)	$188.72	$ 158.00	$ -
Collars	$118.32	$ 25.90	$ -
6 mm Rotary Encoder	$79.90	$ 79.90	$ -
Gears	$131.40	$ 434.00	$ 13.92
Amazon Echo Dot	$49.99	$ -	$ -
DC-DC Converter (LM2576-3.3WU)	$9.41	$ 33.12	$ -
Motor Controller (120 A peak)	$189.00	$ 188.95	$ -
Arduino	$27.95	$ 10.90	$ -
Raspberry Pi	$35.22	$ -	$ -
Casters	$40.04	$ 52.90	$ -
High-Strength Rubber Wheels	$19.36	$ 38.92	$ 13.52
36" long, 1/2" diam. Metal Shaft	$28.01	$ 13.99	$ -
36" x 36" x 1/2" Plywood Board	$5.00	$ 33.98	$ -
2" x 4" x 36" Plank	$30.00	$ 6.10	$ -
Fasteners	$30.00	$ 38.24	$ 7.48
Pool Noodles	$8.49	$ -	$ -
36" x 36" Aluminum Plate 1/2"	$30.08	$ -	$ -
36" Aluminum Square Tube	$53.40	$ -	$ -
Miscellaneous Electrical Engineering Materials	$30.00	$ 87.93	$ 15.08
General Components	$50.00	$ 66.55	$ 6.71
Shipping	$118.05		$ 122.80
	$2,221.62	$2,128.16	$93.46

Pro Forma

With the assumptions stated below in Table 10, the 10-year IRR of the project calculates out to 20%, which is phenomenal. Unfortunately, this is not a realistic outcome. The percentage of people that need a voice controlled wheelchair is probably much, much lower than 0.01%. Due to the low demand this product would need to be marketed as mainly an improvement to the quality of life for those in hospitals and nursing homes. While this is possible, the prototype that was built over the past year is not at that quality yet. The team believes that this project, and this technology in general, will have a place in society someday. The world is trending more towards automation and the Amazon Echo continues to out sell its competitors year after year.[47] With the proper sensors and for the proper consumers, a voice-controlled moving platform that can carry anything could be commonplace sometime in the future.

The income statement (Table 11), balance sheet (Table 12), and statement of cash flows (Table 13) predicted for the first 10 years of operation can be seen below.

Table 10. List of financial assumptions used to calculate the rest of the Pro Forma.

Input Assumption		
1	**Equity**	60%
2	**Debt**	40%
3	**Interest Rate**	4.5%
4	**Return on Equity**	15%
5	**WACC**	10.80%
6	**State Tax Rate**	6%
7	**Federal Tax Rate**	21%
8	**Combined Tax Rate**	25.74%
9	**Revenue Sensitive Rate (excise tax etc.)**	0.00%
10	**Book Life/Book Dep.**	20.0%
11	**Income / OpeEx Growth**	0.0%
12	**Property Tax Rate (Oregon average)**	1.5%
13	**Incremental O&M**	957,100
14	**Inflation Factor**	0.0%
15	**Investment Cost**	143844
16	**Revenue**	990,000
17	**Initial Capital (Equity)**	86306.4
18	**Initial Debt**	57537.6

Other assumptions include the following:

Selling Price = $3,000; Wheelchair User Population = 3,300,000 People[48]; Hitting 0.01% of Population per Year.

[47] Voicebot.ai (2018).
[48] KD Smart Chair (2015).

Table 11. Income statement for the first ten years of business

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**
Revenue	990,000	990,000	990,000	990,000	990,000	990,000	990,000	990,000	990,000	990,000	990,000
Operations & Maintenance	957,100	957,100	957,100	957,100	957,100	957,100	957,100	957,100	957,100	957,100	957,100
Operating Income (EBITDA)	32,900	32,900	32,900	32,900	32,900	32,900	32,900	32,900	32,900	32,900	32,900
Depreciation	28,769	28,769	28,769	28,769	28,769	-	-	-	-	-	-
Interest Expense	2,589	$2,116	$1,621	$1,104	$564	$0	$0	$0	$0	$0	$0
Net Income (EBIT)	4,131	4,131	4,131	4,131	4,131	32,900	32,900	32,900	32,900	32,900	32,900
Net Income (EBT)	1,542	2,015	2,510	3,027	3,567	32,900	32,900	32,900	32,900	32,900	32,900
Property Taxes on Net Plant (1.5%)	1,726	1,295	863	432	-	-	-	-	-	-	-
Income Tax (25.74%)	397	519	646	779	918	8,468	8,468	8,468	8,468	8,468	8,468
Net Income After Taxes	(581)	202	1,001	1,816	2,649	24,432	24,432	24,432	24,432	24,432	24,432

Table 12. Balance sheet for the first ten years of business

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11
Assets											
Plant and Equipment Beginning	143,844	115,075	86,306	57,538	28,769	-	-	-	-	-	-
Depreciation	(28,769)	(28,769)	(28,769)	(28,769)	(28,769)	-	-	-	-	-	-
Net Equipment Net Plant End	115,075	86,306	57,538	28,769	-	-	-	-	-	-	-
Cash-Accumulated Net Cashflow	17,670	40,094	53,639	69,378	88,253	117,957	140,256	164,688	189,119	213,551	237,982
Net Total Assets	132,746	126,400	111,176	98,147	88,253	117,957	140,256	164,688	189,119	213,551	237,982
Liabilities and Owners Equity											
Common Stock	86,306	86,306	86,306	86,306	86,306	86,306	86,306	86,306	86,306	86,306	86,306
Retained Earnings (Cumulative Net Income)	(581)	(379)	622	2,438	5,087	29,518	53,950	78,381	102,813	127,244	151,676
Debt	47,020	36,030	24,544	12,542	0	0	0	0	0	0	-
Deferred Taxes	-	4,443	(296)	(3,140)	(3,140)	2,133	-	-	-	-	-
Net Liabilities and Owners Equity	132,746	126,400	111,176	98,147	88,253	117,957	140,256	164,688	189,119	213,551	237,982
Total Liabilities	132,746	126,400	111,176	98,147	88,253	117,957	140,256	164,688	189,119	213,551	237,982
Debt to Equity Ratio	35%	29%	22%	13%	0%	0%	0%	0%	0%	0%	0%

Table 13. Cash flow statement for the first 10 years of business

	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	
Operating Activities											
Net Income	-581	202	1,001	1,816	2,649	24,432	24,432	24,432	24,432	24,432	24,432
Depreciation	28,769	28,769	28,769	28,769	28,769	-	-	-	-	-	-
Deferred Taxes	-	4,443	(4,739)	(2,844)	-	5,272	(2,133)	-	-	-	-
Cash Provided by Operating Activities	28,188	33,414	25,030	27,741	31,418	29,704	22,299	24,432	24,432	24,432	24,432
Investing Activities											
Project	(143,844)	-	-	-	-	-	-	-	-	-	-
Cash Used in Investing Activities	(143,844)	-	-	-	-	-	-	-	-	-	-
Financing Activities											
Initial Capitalization	86,306										
Debt Issued	57,538										
Debt Retired	(10,517)	(10,991)	(11,485)	(12,002)	(12,542)	-	-	-	-	-	-
Cash Provided by Financing	133,327	(10,991)	(11,485)	(12,002)	(12,542)	-	-	-	-	-	-
Net Cash Flow	(86,306)	17,670	22,423	13,545	15,739	18,875	29,704	22,299	24,432	24,432	24,432
NPV at investor hurdle rate			$18,044								
IRR on Net Cash Flow			20%								

Recommendations

Mechanical System

There were several design issues in the mechanical system that hindered testing and affected the performance of the platform. One issue was that the chassis was made out of wood. Wood is not a very stiff material. Under just the weight of the platform itself, the thin wood on the sides of the platform would bend, causing the wheels to bow and would lead to the bearings popping out. The issue was mitigated by adding metal braces to the sections of wood under the most stress. A more permanent solution though would be to make the entire chassis out of metal since it is stronger and can be machined more precisely. In addition, a metal chassis would allow the bearings to be welded directly to it. A possible metal chassis design is shown in Figure 19.

Another issue was that the gears and wheels that were purchased used set screws for power transfer. Under load, the gears were subject to such high torques that they stripped the shafts they were connected to. Several fixes, such as flatting the shaft and locktighting the screws to the shafts down failed after several tests. One promising solution was tapping the shaft and driving the set screws into the holes, but even those became loose and leading the team to believe that the set screws snapped. The power transfer issue may be fixed by using alternatives that do not rely on set screws such as a keyed shaft or a hex shaft and retaining clips.

Another issue was the spring casters. When the platform was under load, it was continuously tilted forward and nearly touched the ground. This tilting also interfered with the vision of the LIDAR because as the platform tilted, so did the LIDAR. An alternative to spring casters that still allows the platform to go up ADA ramps is a suspension system for the driven wheels. This way, the platform will not tilt under load or while going up inclines and the LIDAR will stay parallel to the ground.

A final recommendation would be to redesign the LIDAR mount. An obvious but simple fix is to raise the LIDAR further from the ground so that the mounting tolerances do not need to be as tight. Another possible fix is to mount the LIDAR to the front of the platform. This would remove vision from the front of the platform, but as long as the platform never goes in reverse, it should not be an issue.

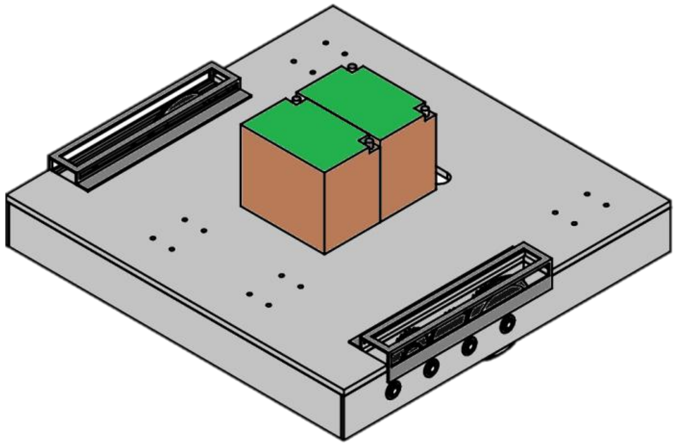

Figure 19. Metal chassis design

Positioning System

Locating the user would a be nice feature for the wheelchair platform to have. With such a feature, the user could invoke commands such as "Bring me my wheelchair" and "Bring me to the couch." Commands such as these would make the wheelchair more usable. In order to implement such features, an accurate positioning system is needed. Some research has been done in this area and a comparison of several positioning systems considered are shown in Table 14.

The first type of positioning system researched was the Global Positioning System (GPS). GPS normally is not very accurate, but enhancements exist that can give very precise positions, namely, Differential GPS (DGPS) and Real Time Kinematic (RTK). These technologies use special GPS receivers, which can correct errors in the satellite signal by using data received from reference stations with a known location. Preliminary research indicated that using any type of Global Positioning System (GPS) would not work for the wheelchair because GPS is not accurate indoors.[49] Signal attenuation and refraction through walls interfere with GPS calculations.

Next, Indoor Positioning Systems (IPS) were investigated. Several IPS services were available for free online including Wi-Fi based, beacon based, geomagnetic, and a combination of these. After testing the free services, none were found to be as accurate as they were advertised.

More research lead to the Decawave's DWM1000 chip, which is a chip designed specifically for positioning systems. Numerous online articles and videos demonstrated its accuracy. There are two companies actively developing positioning systems based on this chip. Since both companies' products are very expensive, an alternative of buying the DWM1000 chips and mounting them was considered. There is open source firmware and PCB Eagle schematics on

[49] National Coordination Office for Space-Based Positioning, Navigation, and Timing (2017).

GitHub, which are supposed to work with the chip.[50] Since the firmware on GitHub is not being actively maintained and can only support locating one object, and since building the board was too much of a technical risk, buying a system seemed like the best option. The system built by Localino was the cheapest, so this system was chosen and tested.

Localization with the Localino system, requires a network of anchors and tags. Anchors are positioned in static, known positions around the room and tags are attached to the objects being tracked. For 2D positioning, three anchors are required. The supplied Localino firmware makes the anchors broadcast ranging data from the tags to the IP address 192.168.4.255. A network needed to be set up, which can accept and route these packets correctly and a server needed to read the packets, process the ranging data using software supplied by Localino, and transmit location data to the Raspberry Pi. An overview of the Localino system is shown in Figure 11.

There were several problems with the Localinos. The main problem was with Wi-Fi. The Localinos used a low powered ESP826 Wi-Fi module so the Wi-Fi connection would drop occasionally. However, the current Wi-Fi firmware is configured to go into a setup mode whenever it cannot connect to a network with the SSID “localino.” Once a Localino goes into setup mode, it creates an ad hoc Wi-Fi network and waits for someone to open a web interface and configure it. Unfortunately, there was no way to disable this behavior without changing the firmware. The Localino firmware is closed source, so it was not possible to resolve this problem. As a result, a Localino would randomly disconnect within ten minutes of turning it on, making it impossible to run the trilateration algorithm.

Security is also a concern with the Localinos. The firmware requires that a network names “localino” be present with a fixed password available in the documentation. The individual Localinos also had management interfaces open by default without a password. If this system were to be used in a hospital, it would need to fix these problems by having an initial setup routine where network settings can be flashed to the chip.

One recommendation would be to replace the Localinos with Decawave’s DWM1001 board. It uses Bluetooth instead of Wi-Fi, avoiding the problem the Localinos had. This system is also cheaper. This board and its accompanying sample code was not available though when the Localinos were purchased.

Another recommendation would be to revisit the IPSs. Since the Pi has access to Wi-Fi, Bluetooth, and an IMU, it likely has enough sensors to give room level accuracy. ROS could be used to automatically train these systems. With this level of accuracy and the LIDAR sensor, it may be possible to get an initial location fix without a dedicated IPS.

One extension would be to add a Real Time Kinematic (RTK) GPS sensor to help it function outdoors. At the same time, a vehicle-grade LIDAR like a Velodyne LIDAR would have to be installed to make it safe to use outdoors. The Neato XV-11 LIDAR’s laser is not powerful enough to function outdoors and it’s short range and low scan rate does not provide enough data to prevent all possible collisions.

[50] Thotro (2017).

Table 14. Comparison of Location Technology

Technology	Name	Advertised Accuracy[51]	Pros	Cons	Cost	Testing Results	Notes
GPS	RTK	1cm	Accurate	Cost and indoor performance	$50ea[52]	N/A	GPS does not work indoors[53]
GPS	Differential GPS	10cm	Accurate	Cost and indoor performance	-	N/A	GPS does not work indoors
GPS	Phone GPS	5-8m	Cheap	Low precision	Free	N/A	GPS does not work indoors
Wifi	Find[54]	10ft	Free	Android required	Free	Unreliable	Inconsistent data
Bluetooth BLE	Bluetooth beacons	1.5m	Accurate	Not scalable	$2.60ea[55]	Unreliable	Inaccurate with sparse beacons
Geomagnetic	IndoorAtlas[56]	"High"	Free	Tedious mapping	Free	~10m	Inaccurate
Combination	Proximi[57]	1-2m	Accurate	Not scalable	Free	~8m	Inaccurate
LIDAR	LIDAR	3cm[58]	Cheap	Unreliable and complex	$119	N/A	Requires landmark system
Visual	Face recognition	~90%[59]	Cheap	Unreliable and complex	$48	N/A	Requires mounted camera
Sound	Sound localization	Unknown	Cheap	Unreliable and complex	-	N/A	Multipath interference
DWM1000	Pozyx[60]	10cm	Accurate	Expensive	599 €	N/A	Too expensive
DWM1000	Localino[61]	10cm	Accurate	Expensive	435 €	Wifi Bad	Selected this – Wifi issues

[51] Koskiola, A. (2016).
[52] NavSpark (2017).
[53] National Coordination Office for Space-Based Positioning, Navigation, and Timing (2017).
[54] Find (2016).
[55] Shenzhen Eastwin Trading Ltd. (n.d).
[56] IndoorAtlas (2016).
[57] Proximi.io (2016).
[58] Konolige, Kurt et al (2008).
[59] Learned-Miller, Erik et al (2016).
[60] Poxyz (2016).
[61] Heuel & Loeher (2017).

Alexa

Voice control is a central part of this project. Although Alexa worked, the time it took for the Echo Dot to send a message to AWS was long at times. The Echo Dot had trouble understanding commands at a distance during testing as well but this issue could also be because of background noise and Wi-Fi issues. This could pose a problem especially while the wheelchair is running since it is loud.

One recommendation would be to replace the current voice control system with a ROS node running Python's SpeechRecognition library and a microphone. Using this library would make it easy to change the speech recognition engine for testing and failover. The SpeechRecognition library supports speech recognition APIs from Sphinx, Google, Bing, IBM, and other companies as well as offline speech recognition software.[62]

For instance, if Wi-Fi goes down and an online speech recognition service is no longer available, the node would be able to switch to offline processing. Although the offline processing may not be as accurate as online services, it would still work.

It is also possible to experiment with the different services. Some services have features suited for recognizing voice commands which could be leveraged to make a more robust interface.[63] These services could be tested in parallel and compared by their latency and accuracy.

Security is also a problem inherent with voice recognition. As it stands, there is no authentication built into Alexa, so anyone who can say commands is recognized as a valid user. No current products on the market have a solution to this problem because there is no easy solution. The Echo Dot is also vulnerable to other threats like DolphinAttack, where voice commands are played outside the range of human hearing.[64]

[62] Python Software Foundation (2018).
[63] Wit.ai (2018).
[64] Zhang (2017).

Conclusion

The Transnavigators' Voice Controlled Wheelchair gives users the ability to control their wheelchair using voice commands. Since the platform fits nearly any type of existing wheelchair, users can continue to use whatever chair they may have. The wheelchair is controlled with voice unlike most motorized models that are controlled by joystick. There were many issues during the design and implementation of the wheelchair platform, but overall the project was a success and the prototype performed with in the metrics specified in the A3. Based off testing, an Alexa controlled wheelchair is not a feasible option in places with high network traffic or unreliable Wi-Fi, but would likely work in a personal setting. While the current prototype is crude, the project is in a great spot to be continued to be worked on. With the changes suggested and the purchase of higher quality sensors, this device may one day be a staple in society.

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Appendices

Appendix A: A3 Document

A3 Project Plan	Project Title:	Team Members/Majors:
EGR 484	Transnavigators: Voice Controlled Wheelchair	ME: Jarren Takaki, Courtney Otani CS/EE: Matthew Yuen, Anthony Donaldson

Faculty Advisor:	Industry Advisor:	Instructor:	REV NO./DATE
Dr. Albright Dr. Symons	Ryan Jefferis	Chris Galati	#8, Jan 25, 2018

PROJECT DEFINITION:
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can use Alexa to guide their wheelchair to them. In addition, after they get on their wheelchair, the patient can use directional commands to navigate to a desired location.

ANALYSIS OF CURRENT CONDITION
Currently, there are in-home care nurses who help patients with disabilities into their wheelchairs. Two wheelchairs have been designed recently to improve mobility. MIT made a self-driving wheelchair this year. The A-SET Mind Controlled Wheelchair addresses the problem of controlling a wheelchair in patients suffering from Locked-in Syndrome by interfacing the wheelchair controls with an EEG headset. This lets us know that alternative methods of controlling a wheelchair are feasible. There have also been recent innovations made in home automation such as the development of the Echo Dot and open-source software developed for interfacing with them. We will be able to use these open-source libraries to assist with our research and development. In addition, motorized wheelchairs have been fully developed over the years. Progress made in robotics gives us a basis to work with.

PROJECT GOALS
The wheelchair will be able to respond to voice commands from an Echo Dot and navigate autonomously to the user.
Specifications:
- Send and receive messages from Amazon's AWS services
- Circumnavigation of obstacles

Measurements:
- Motion parameters (distance, directional) tolerance
- Travel at ~5mph
- Climb 4.8 degree slopes

RESOURCES REQUIRED
- Echo Dot ($49.99)
- Arduino ($27.95)
- Raspberry Pi ($35.22)
- LiDAR ($119)
- Localino v2.0 ($513.30)
- AWS Services ($0)
- Motors ($188.72)
- Motor controllers ($239.70)
- Battery ($158.49)
- General hardware ($473.42)
- Electronics/Wires ($57.73)
- Misc. ($186.05)
- Shipping ($118.05)

Total $2,221.62

ACTION PLAN (ACTIVITIES AND MILESTONES):

Project Goals/Deliverables	Actions/Metrics	Who	When
• Component testing	• Define the voice interface (Recognize essential words: Move, forward, turn, stop, come to me) • Communication between AWS and the microcontroller • Test electrical components • Build and motorize chassis	All	02/15/2018
• First prototype	• Integrate mechanical and electrical components • Motorized wheelchair capable of moving forward and turning as specified by the voice interface	All	02/22/2018
• Final prototype • Final report and presentation	• Circumnavigation • Debugging and ensuring reliable and accurate performance within project goals	All	03/29/2018

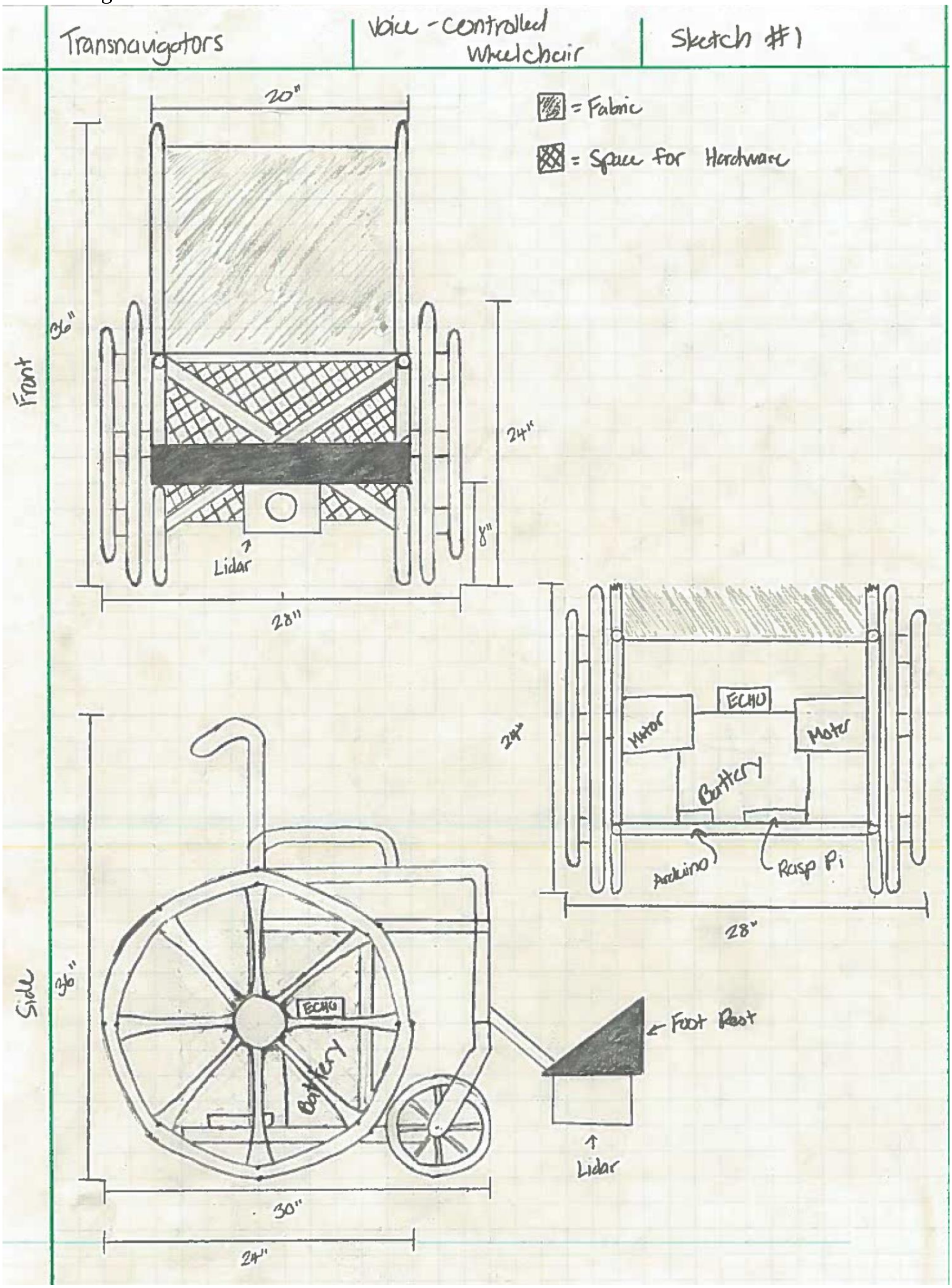
UNRESOLVED ISSUES
Continuing this project, other senior design groups could modify the software to drive outdoors and other unmapped locations. This would make the wheelchair effectively an autonomous wheelchair, which would give the user full mobility in urban environments.
Another group could design a system to open doors based on proximity to the wheelchair or another way to open manual doors. Some disabled people are unable to open doors, so this would allow users to navigate indoors with full autonomy.
Another senior design group could implement additional methods of controlling the wheelchair such as through an EEG headset for patients unable to use voice control, an embedded touchscreen, or an app.

FOLLOW-UP AND REVIEW
We will know that we have accomplished our goals once the wheelchair can respond to voice commands from a nearby Amazon Echo, and avoid obstacles. Our project will increase the mobility of patients with disabilities.

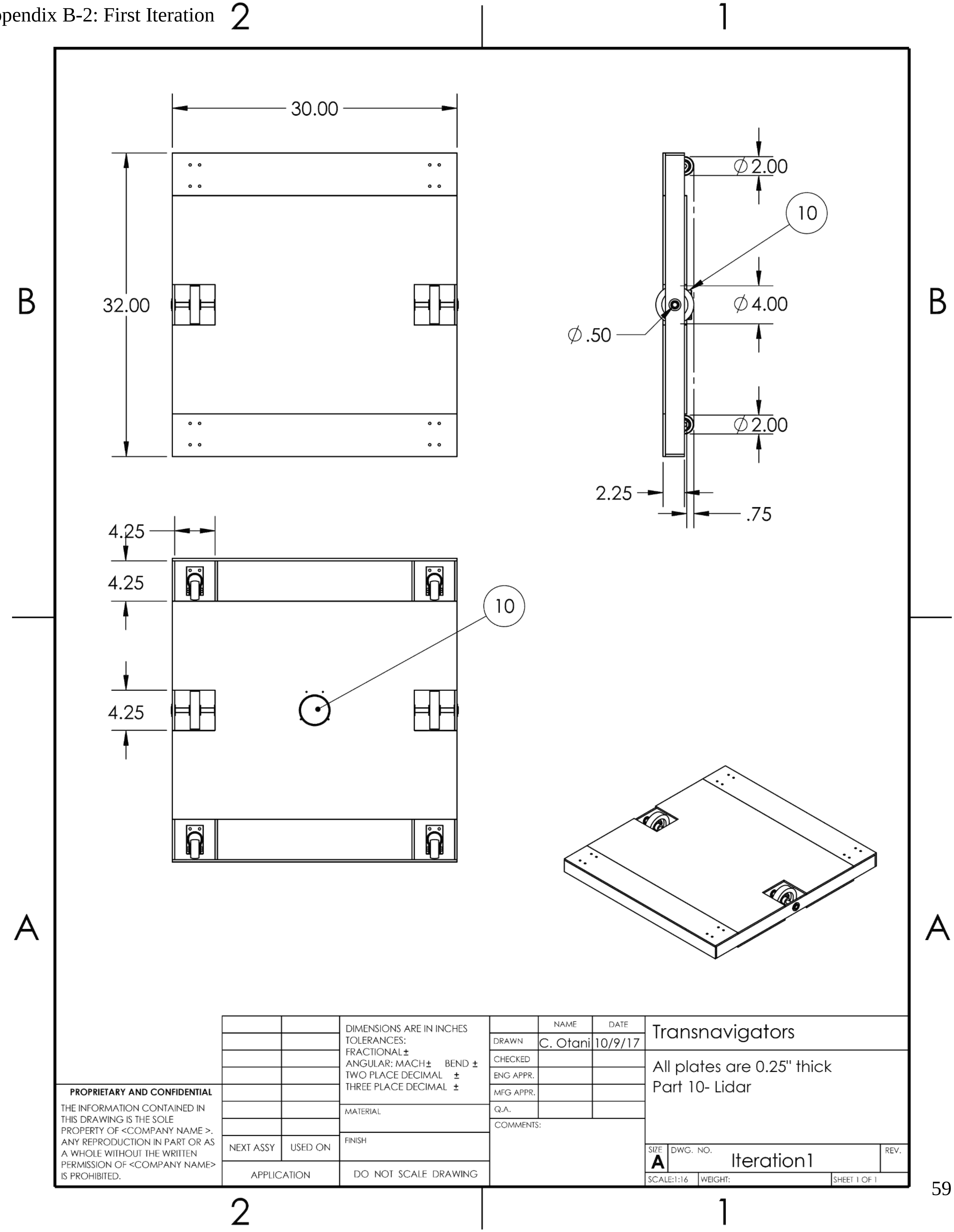
Metrics:
- Veering (from straight line path) tolerance: (±5 degrees)
- Motion parameters (distance, directional) tolerance: (±15%)

Appendix B: Chassis Design

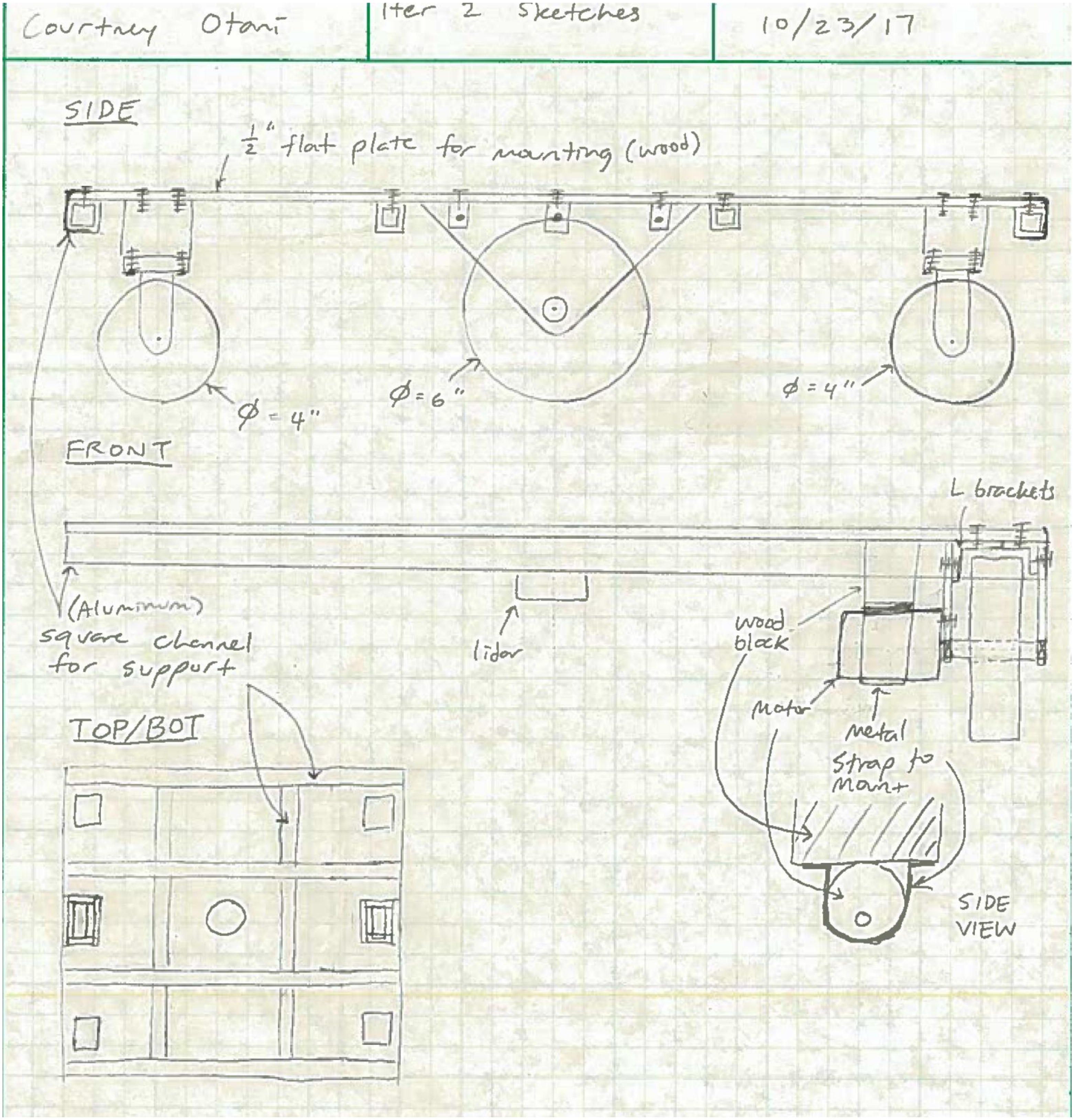
Appendix B-1: Original Idea



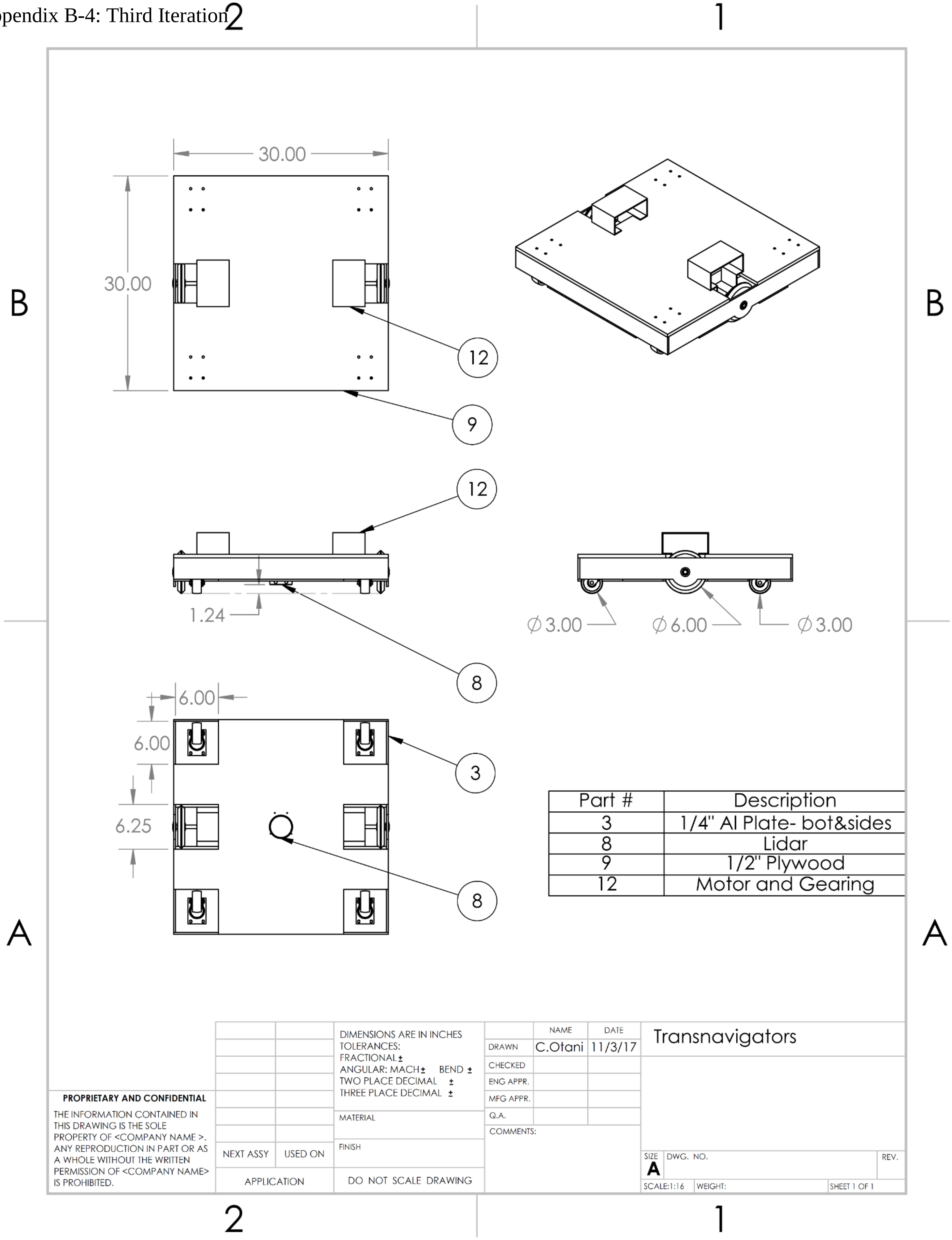
Appendix B-2: First Iteration



Appendix B-3: Second Iteration



Appendix B-4: Third Iteration



Appendix B-5: Fourth Iteration

Courtney Otani	4th Iteration Design Chassis + Drive	11/6/17

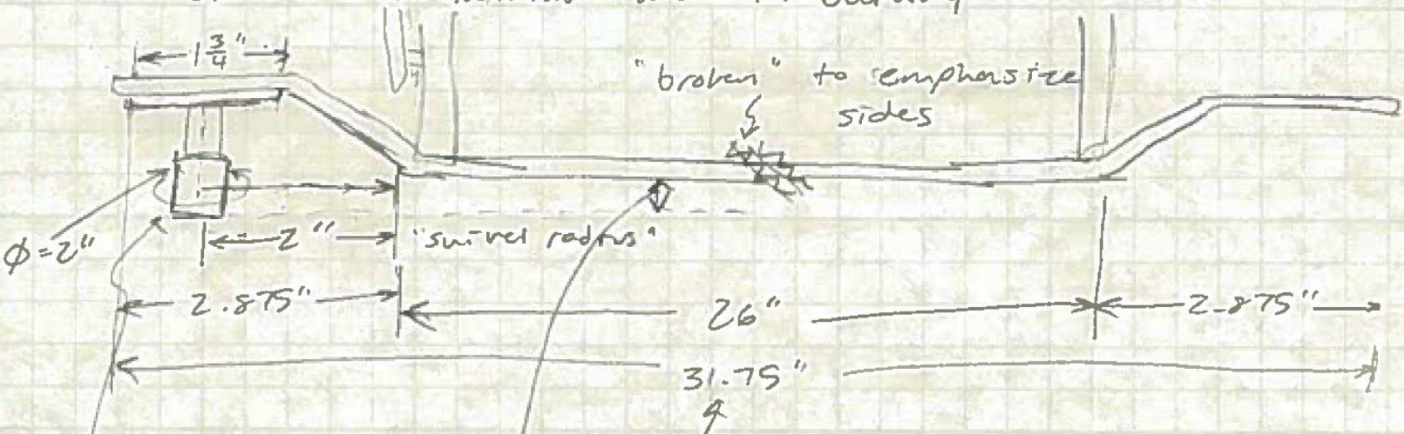
Width of doors = 36", 32" ← measured dorm doors; main, bedrooms

width of wheelchair = 28" ← Medline Excel k1 Basic, measurement by Jarren

ADA standard = 26" — think this includes wheel handles

outside wheel to outside wheel (the big wheels)

ADA standard is 32" minimum width for doorway



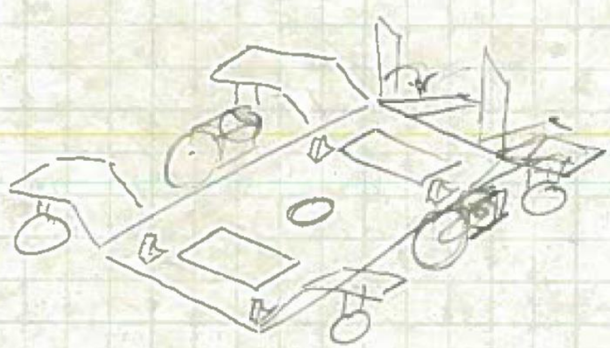
lowest profile swivel found

this clearance needs to be able to accomodate

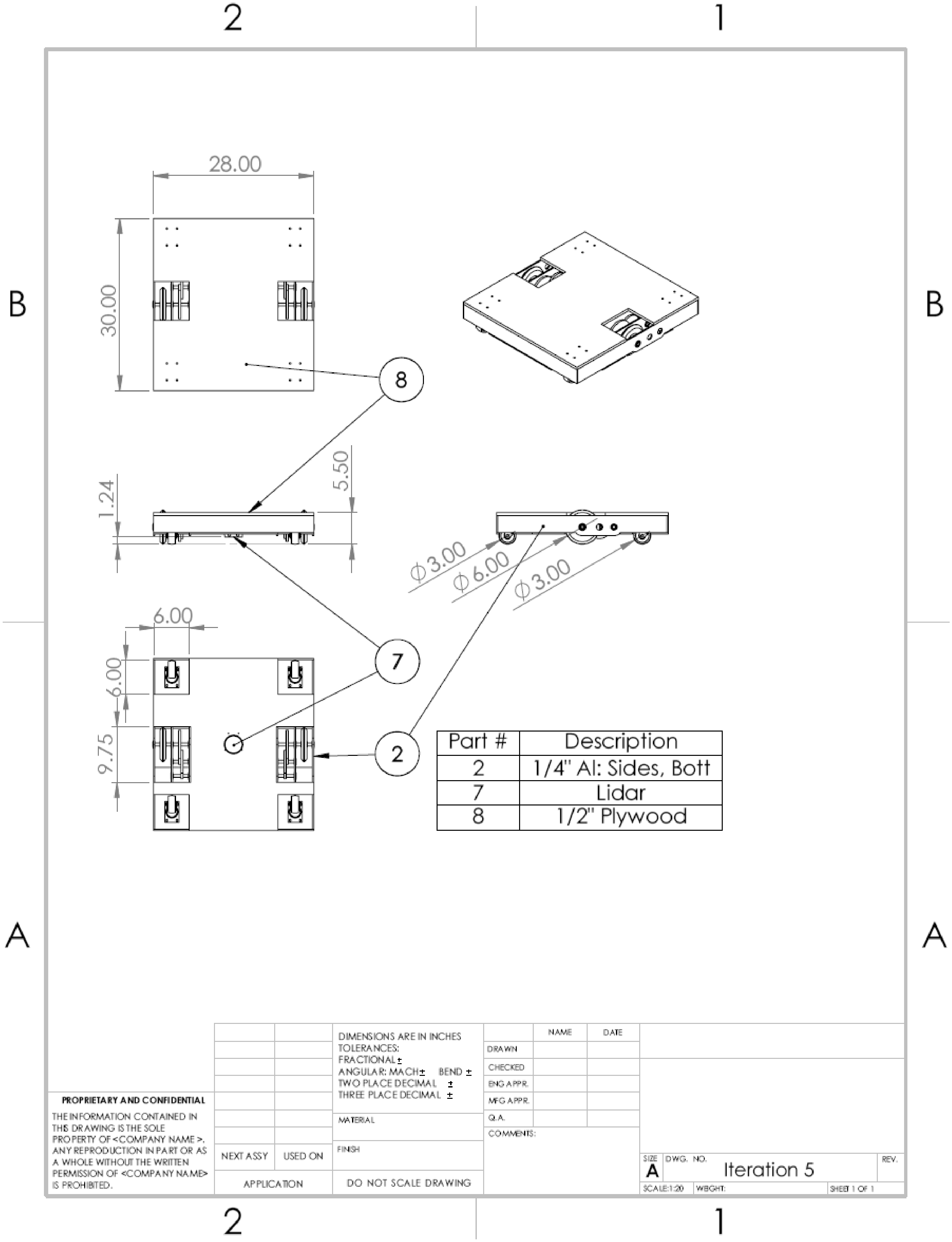
- lidar ← must stay in scope
- going on ramps ← can go to this new design if get rid of this criteria

if saying this, need this dim/clearance to be about 2"

Extra Note on wheels:
Driven wheel width = 2"

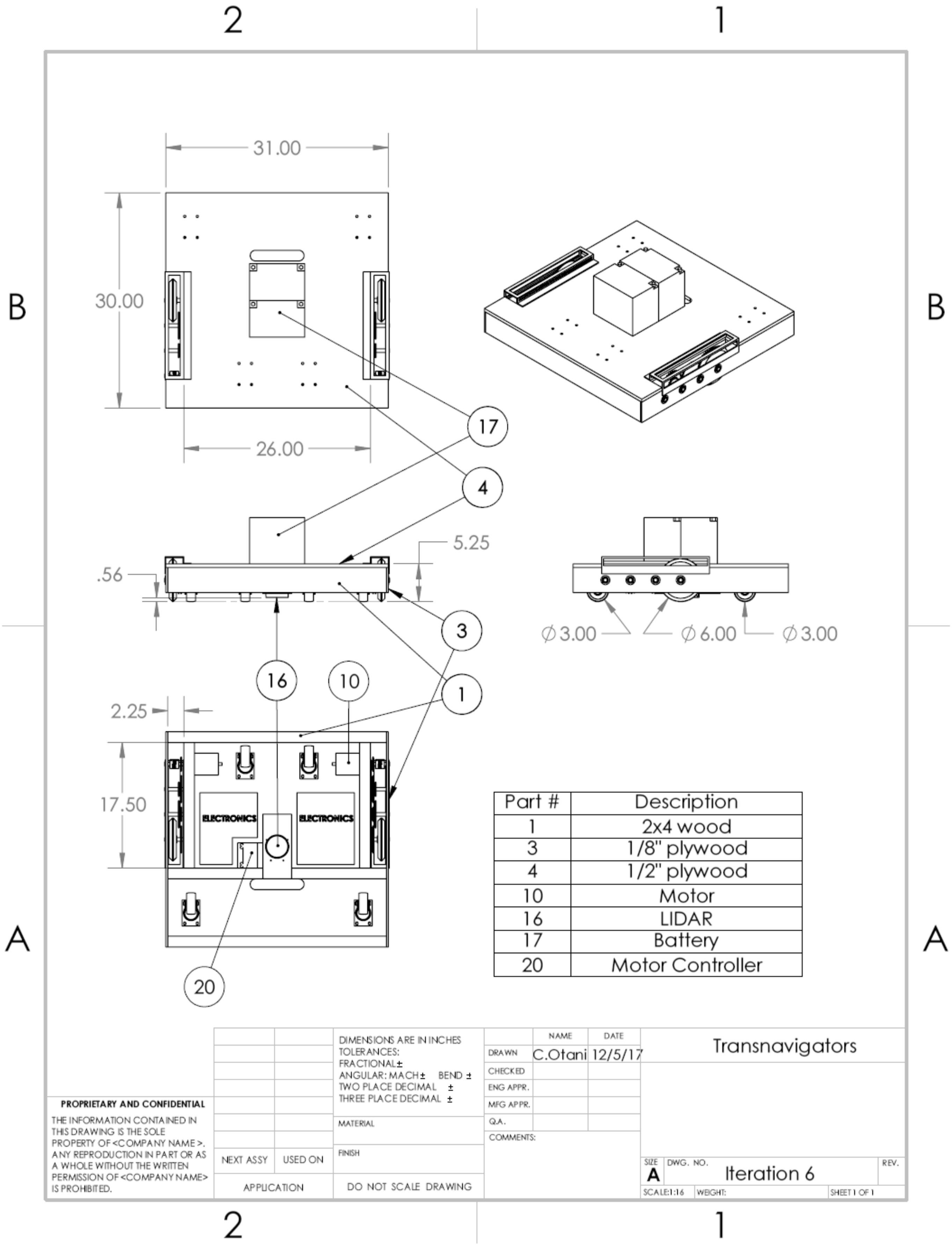


Appendix B-6: Fifth Iteration



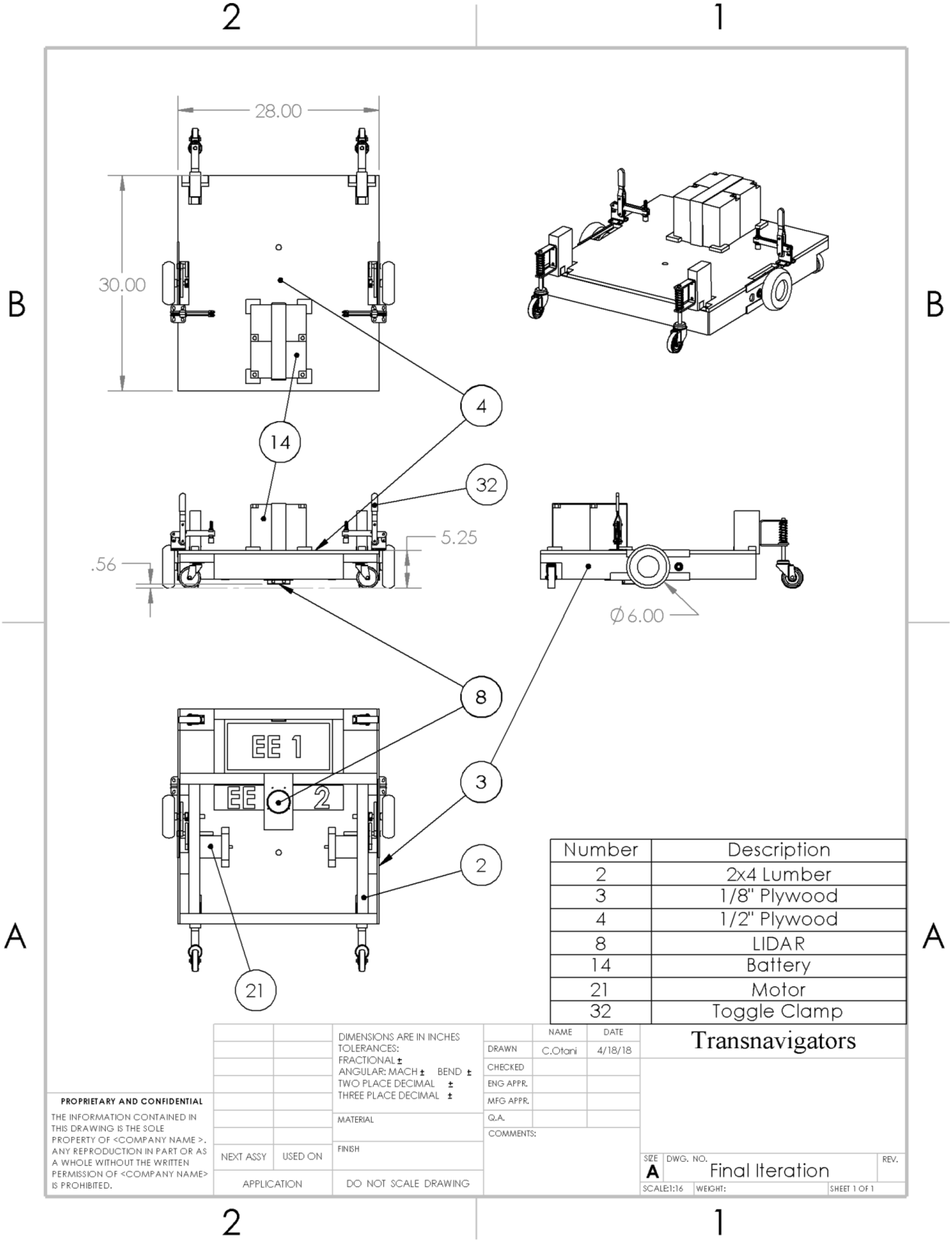
Part #	Description
2	1/4" Al: Sides, Bott
7	Lidar
8	1/2" Plywood

Appendix B-7: Iteration at the End of Fall Semester



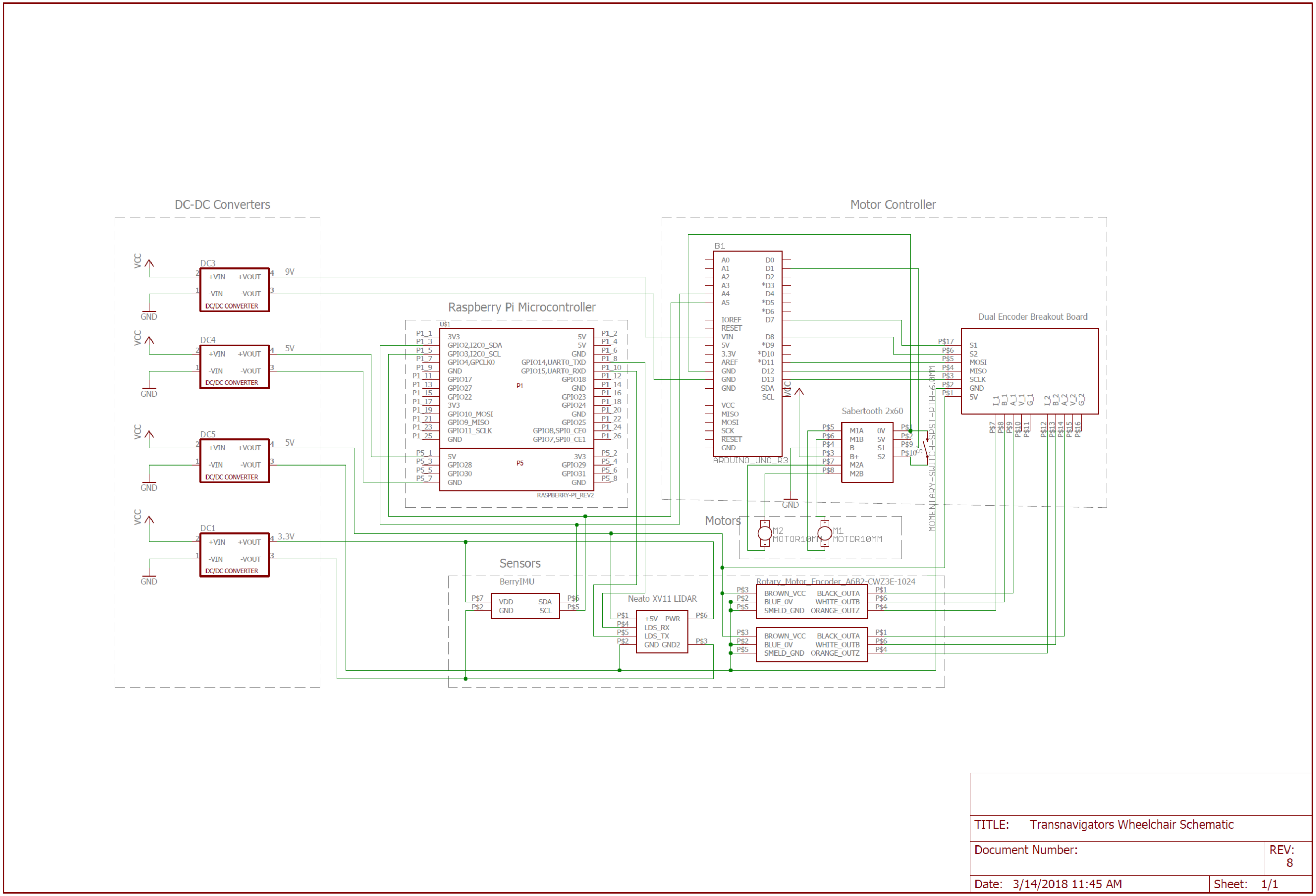
Part #	Description
1	2x4 wood
3	1/8" plywood
4	1/2" plywood
10	Motor
16	LIDAR
17	Battery
20	Motor Controller

Appendix B-8: Iteration at the End of Spring Semester



Number	Description
2	2x4 Lumber
3	1/8" Plywood
4	1/2" Plywood
8	LIDAR
14	Battery
21	Motor
32	Toggle Clamp

Appendix C: Schematic


DC-DC Converters
DC3
DC4
DC5
DC1
DC/DC CONVERTER
+VIN +VOUT
-VIN -VOUT
VCC
GND
9V
5V
5V
3.3V
Raspberry Pi Microcontroller
RASPBERRY-PI_REV2
Motor Controller
ARDUINO_UNO_R3
Sabertooth 2x60
Dual Encoder Breakout Board
MOMENTARY-SWITCH-SPST-PTH-6.0MM
Motors
M2 MOTOR10MM
M1 MOTOR10MM
Sensors
BerryIMU
Neato XV11 LIDAR
Rotary_Motor_Encoder_A6B2-CWZ3E-1024
TITLE: Transnavigators Wheelchair Schematic
Document Number:
REV: 8
Date: 3/14/2018 11:45 AM
Sheet: 1/1

Appendix D: Weekly Reports

Appendix D-1: Fall Semester Week 1

University of Portland

Weekly Report-Out

Name Matthew Yuen Team Wheelchair Team

Today's Date: 09/08/2017

1 What commitments have you completed since our last check-in?
(let others know you've kept your commitments, declare work "done" so it can be accepted)

Customer	Commitment/Hours Expended
Wheelchair Team	Found an ME advisor and set up weekly meetings / 1 hour
Wheelchair Team	Installed Whatsapp for group communication / 0.5 hour
Wheelchair Team	Designated project roles / 0.5 hour
Wheelchair Team	Updated A3 to incorporate Levi / 2 hours
Wheelchair Team	Contacted possible industry advisor / 0.5 hour

2 What work will you complete this week (by our next session)?
(let others know what they can depend on)

Customer	Commitment/Hours Anticipated
Wheelchair Team	Update budget / 3 hours
Wheelchair Team	Research Location Technology / 4 hours
Wheelchair Team	Update A3 to reflect new CS/EE advisor & new requirements / 1 hour
Wheelchair Team	Apply for Dean's funding / 1 hour
Wheelchair Team	Find hardware components to be used for project / 3 hours
Wheelchair Team	Find a client / 2 hours

3 What constraints are keeping you from getting your work done?
(ask for help, declare a breakdown, raise concerns...)

Concern, breakdown, or help you need	Resolution (Action by When)	Who's Responsible?
Enough money for sensors/motors	Talk to Dr. Jones 9/13/17	Jarren
How feasible is finding the user?	Research/Choose solution 10/31/17	CS/EE

4 Overall, are you still on track to meet your commitments to the project?

Yes

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Appendix D-2: Fall Semester Week 2

University of Portland

Weekly Report-Out

Name COURTNEY OTANI Team TRANSNAVIGATORS

Today's Date: 9/14/17

1 What commitments have you completed since our last check-in?
(let others know you've kept your commitments, declare work "done" so it can be accepted)

Customer	Commitment/Hours Expended
N/A	-INITIAL DESIGN CALCULATIONS / 1HR
↓	-CREATED/STARTED A SCHEDULE FOR MECHANICAL SIDE OF PROJECT / 1 HR
	-MET WITH INDUSTRY ADVISOR / 30 MIN
↓	-MET WITH BOTH FACULTY ADVISORS / 1 HR
NURSING DPT	-CONTACTED CLIENT (NURSING DEPT)
N/A	-CREATED/STARTED A SCHEDULE FOR CS/EE SIDE OF PROJECT
	-CREATED WEBSITE
↓	-RULED OUT GPS FOR INDOOR POSITIONING

2 What work will you complete this week (by our next session)?
(let others know what they can depend on)

Customer	Commitment/Hours Anticipated
N/A	-BEGIN RESEARCH W/ECHO DOT (CODING) / 4 HR
	-RESEARCH BEACON FOR INDOOR POSITIONING / 1 HR
↓	-WHEELCHAIR STORE / 1 HR
NURSING DPT	-FOLLOW UP W/NURSING DPT
N/A	-MEET W/BOTH FACULTY ADVISORS / 1HR
	-TALK TO LAB TECHNICIANS
↓	-RESEARCH OUTSIDE FUNDING / 2 HR

3 What constraints are keeping you from getting your work done?
(ask for help, declare a breakdown, raise concerns...)

Concern, breakdown, or help you need	Resolution (Action by When)	Who's Responsible?
LACK OF KNOWLEDGE	RESEARCH	
- INDOOR POSITIONING	for another	MATT, LEVI, ANTHONY
- MECHANICAL REQUIREMENTS	week or 2	COURTNEY & JARREN
	weeks	

4 Overall, are you still on track to meet your commitments to the project?

YES, IN PLANNING STAGE ON WAY TO CONCRETE 1ST ITERATION DESIGN

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Appendix D-3: Fall Semester Week 3

University of Portland

Weekly Report-Out

Name Anthony Donaldson Team Transnavigators

Today's Date: 9/22/17

1	What commitments have you completed since our last check-in? (let others know you've kept your commitments, declare work "done" so it can be accepted)	
	Customer	**Commitment/Hours Expended**
		Configured AWS interface to Pi / 8 hours
		Finalized Spring schedule / 1 hour
		Drew sketches of overall system design / 2 hours
		Measured wheelchair dimensions & specs / 30 mins
		Outlined budget / 4 hours
		Met with faculty advisors / 1 hour
		Attended safety training for lab access / 10 mins
		Researched motor controllers / 2 hours
		Updated A3 / 15 mins

2	What work will you complete this week (by our next session)? (let others know what they can depend on)	
	Customer	**Commitment/Hours Anticipated**
		Brainstorm mechanical designs / 6 hours
		Proof of concept for Proximi.io / 4 hours
		Update team member descriptions on the website / 1 hour
		Finalize budget / 6 hours

3	What constraints are keeping you from getting your work done? (ask for help, declare a breakdown, raise concerns…)		
	Concern, breakdown, or help you need	**Resolution (Action by When)**	**Who's Responsible?**
	Broaden design possibilities	Meeting with Symons on Tuesday (9/26)	Jorren / Courtney
	P-card delivery date	Speak with Lisa Bassett	Levi

4	Overall, are you still on track to meet your commitments to the project?
	Yes, we are on track.

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Appendix D-4: Fall Semester Week 4

University of Portland

Weekly Report-Out

Name Levi Banks Team Transnavigators Today's Date: 9/29/17

1 What commitments have you completed since our last check-in?
(let others know you've kept your commitments, declare work "done" so it can be accepted)

Customer	Commitment/Hours Expended
	Completed budget / 4 hrs
	Brainstormed new design options / 6 hrs
	↳ chose one of these new designs to work with
	Updated sketch for our new idea / 2 hrs
	Met with facilty advisors / 1 hr
	Researched DWM1000 chips as cheaper alternatives / 2 hr
	Decided on alternative to proxim.io (DWM1000)
	Looked at PolySync for simulation (received license) / 0.5 hr

2 What work will you complete this week (by our next session)?
(let others know what they can depend on)

Customer	Commitment/Hours Anticipated
	Update team bios on website / 1hr
	Work with simulation on 10/1 / 6 hrs
	~~Create~~ Begin work on schematic of system / 6 hrs
	Begin CAD model of new design / 3 hrs
	Mechanical calculations / 1 hr

3 What constraints are keeping you from getting your work done?
(ask for help, declare a breakdown, raise concerns…)

Concern, breakdown, or help you need	Resolution (Action by When)	Who's Responsible?
Money (specifically lack thereof)	Turning in budget on 9/29	Galati
Lack of knowledge / experience	More research! (by next week)	Us!

4 Overall, are you still on track to meet your commitments to the project?

Yes, we are still on track.

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Appendix D-5: Fall Semester Week 5

University of Portland

Weekly Report-Out

Name Jarren Takaki Team Transnavigators Today's Date: 10/6/17

1 What commitments have you completed since our last check-in?
(let others know you've kept your commitments, declare work "done" so it can be accepted)

Customer	Commitment/Hours Expended
	Met with faculty advisors / 1hr
	Met with industry advisor / 0.5 hr
	Mechanical Calculations / 1.5 hr
	Design matrix - Chassis / 5 min
	Worked on simulation / 8 hr
	Bios / 8 min

2 What work will you complete this week (by our next session)?
(let others know what they can depend on)

Customer	Commitment/Hours Anticipated
	Design Matrix - Battery / 2 hr
	Make Simulation Skeleton / 4hr
	Select a motor / 1.5hr
	Work on Bios / 0.5 hr
	Design Matrix - Motor / 1.5hr
	CAD (Iteration #1) / 5hr
	~~[illegible]~~ Schematic of Electrical Circuit / 5hr

3 What constraints are keeping you from getting your work done?
(ask for help, declare a breakdown, raise concerns...)

Concern, breakdown, or help you need	Resolution (Action by When)	Who's Responsible?
Lack of Knowledge	Research (Always)	All
Unsure about budget	Wait till we hear back	Galati

4 Overall, are you still on track to meet your commitments to the project?

Of Course!

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Appendix D-6: Fall Semester Week 6

University of Portland

Weekly Report-Out

Name Matthew Yuen Team Transnavigators

Today's Date: 10/12/2017

1 What commitments have you completed since our last check-in?
(let others know you've kept your commitments, declare work "done" so it can be accepted)

Customer	Commitment/Hours Expended
Project	Met with faculty advisors / 1 hour
Project	Completed iteration 1 CAD design / 6 hours
Project	Completed iteration 1 circuit schematic / 6 hours
Project	Calculated power requirements and picked a motor / 4 hours
Project	Made a battery matrix + select a battery / 2 hours
Project	Updated bios on website / 30 minutes
Project	Updated A3 / 30 minutes
Project	Finished simulation skeleton / 3 hours

2 What work will you complete this week (by our next session)?
(let others know what they can depend on)

Customer	Commitment/Hours Anticipated
Project	* Finish calculating power requirements / Matthew 1 hour
Project	Iteration II of CAD design / Courtney 6 hours
Project	Iteration II of schematic / EEs 3 hours
Project	* Pick a motor controller & Encoder / EEs 3 hours
Project	* Pick a battery / MEs + EEs
Project	Simulation data: Lidar / Anthony 12 hours +
Project	Simulation data: Localino, Berry IMU, Encoder, Alexa / Levi 12 hours
Project	Thread the simulation, wheelchair turning, simulation stopping / Matthew 12 hours
Project	* Calculations for wheelchair / Jiren 6 hours

Priority for meeting with Jeffers on Tuesday after break

3 What constraints are keeping you from getting your work done?
(ask for help, declare a breakdown, raise concerns...)

Concern, breakdown, or help you need	Resolution (Action by When)	Who's Responsible?
Lack of knowledge	Research	All

4 Overall, are you still on track to meet your commitments to the project?

Yes

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Appendix D-7: Fall Semester Week 7

University of Portland

Weekly Report-Out

Name COURTNEY OTANI Team TRANSNAVIGATORS Today's Date: 10/26/17

1 What commitments have you completed since our last check-in?
(let others know you've kept your commitments, declare work "done" so it can be accepted)

Customer	Commitment/Hours Expended
PROJECT	PICKED MOTOR CONTROLLER / 3HRS
↓	BATTERY SPECIFICATIONS DEFINED / 2 HRS
	THREADED SIMULATION / 1 HR
	COLLISION DETECTION, 1ST ITERATION / 1 HR
	PICKED ENCODER / 2 HR
	DRIVE + CHASSIS 2ND ITER. PAPER DRAWING / 2 HR
	WHEEL RESEARCH / 2 HR

2 What work will you complete this week (by our next session)?
(let others know what they can depend on)

Customer	Commitment/Hours Anticipated
PROJECT	GENERATE RAMP + MOUNTING IDEAS/JARREN/2 HR
↓	DRIVE + CHASSIS 3RD ITER. DESIGN/COURTNEY/3HR
	MOTOR CONTROLLER + ARDUINO INTERFACE/LEVI
	MATT, ANTHONY / 3 HR
	SIMULATION DATA: LIDAR / ANTHONY / 12 HR
	LOCATION. BERRY. IMU, ENCODER, ALEXA / LEVI / 12 HR
	UML DIAGRAM FOR SIMULATION / MATT / 3 HR

3 What constraints are keeping you from getting your work done?
(ask for help, declare a breakdown, raise concerns...)

Concern, breakdown, or help you need	Resolution (Action by When)	Who's Responsible?
BUDGET UNKNOWN	ASK GALATI ON	MATT
DATE BUDGET RECIEVED	FRI 10/27/17	
IS UNKNOWN		

4 Overall, are you still on track to meet your commitments to the project?

YES, BUT STRUGGLING TO STAY ON TRACK.

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Appendix D-8: Fall Semester Week 8

University of Portland

Weekly Report-Out

Name Anthony Donaldson Team Transnavigators Today's Date: 11/2/17

1 What commitments have you completed since our last check-in?
(let others know you've kept your commitments, declare work "done" so it can be accepted)

Customer	Commitment/Hours Expended
Project	Edited A3 / 30 mins
	Revised hardware interfaces in EE schematic / 5 hours
	Implemented Lidar in simulation / 3 hours
	Created UML diagram / 2 hours
	3rd iteration design CAD / 4 hours
	Battery research / 3 hours
	3rd iteration design sketches / 2 hours

2 What work will you complete this week (by our next session)?
(let others know what they can depend on)

Customer	Commitment/Hours Anticipated
Project	4th iteration CAD / 4 hours Courtney
	Ask for shop training and working space / 1 hour Jarren & Courtney
	Simulation data: Localino, BerryIMU, encoder, alexa / 12 hours Anthony & Matt
	Generate ramp & mounting ideas / 2 hours Jarren
	Research, design, and calculations for gear system / 2 hours Jarren
	EE Research / 3 hours Matt

3 What constraints are keeping you from getting your work done?
(ask for help, declare a breakdown, raise concerns…)

Concern, breakdown, or help you need	Resolution (Action by When)	Who's Responsible?
Budget approval	Next week	Lisa Bassett

4 Overall, are you still on track to meet your commitments to the project?

No, we are not on track. We need to know if our budget was approved.

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Appendix D-9: Fall Semester Week 9

University of Portland

Weekly Report-Out

Name Jarren Takaki Team Transnavigators Today's Date: 11/9/17

1	What commitments have you completed since our last check-in? (let others know you've kept your commitments, declare work "done" so it can be accepted)
Customer	**Commitment/Hours Expended**
Project	Chassis Design Iteration #4 / 2.5
↓	DC-DC Converter Research / 2.0
↓	Worked on simulation / 1.0
↓	Motor - Gearmotor - Wheel Research / 1.5
↓	Purchasing / 0.5
↓	Meeting with faculty advisors / 1.5

2	What work will you complete this week (by our next session)? (let others know what they can depend on)
Customer	**Commitment/Hours Anticipated**
Project	Purchasing / 0.5 - Jarren Takaki
↓	Gear Research / 1.5 - Jarren Takaki
↓	Chassis Design Iteration #5 / 3.0 - Courtney Otani
↓	Battery Research / 1.5 - Matt Yuen
↓	Talk to Allen / 0.5 - ME Members
↓	Test gezebo & ROS / 3.0 - Anthony

3 What constraints are keeping you from getting your work done? (ask for help, declare a breakdown, raise concerns…)

Concern, breakdown, or help you need	Resolution (Action by When)	Who's Responsible?
Ramp for vehicle	Build Non-ADA Ramp	ME Members

4 Overall, are you still on track to meet your commitments to the project?

Slightly Behind

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Appendix D-10: Fall Semester Week 10

University of Portland

Weekly Report-Out

Name_Matthew Yuen____ Team_Transnavigators______________ Today's Date:_11/16/2017_________

1	**What commitments have you completed since our last check-in?** *(let others know you've kept your commitments, declare work "done" so it can be accepted)*	
	Customer	Commitment/Hours Expended
	Project	CAD iteration 5 / 4 hours
	Project	Wheel research / 2 hours
	Project	ROS research / 6 hours
	Project	AGM Battery Batteries / 3 hours
	Project	DC/DC converter research / 2 hours
	Project	Bought hardware / 1 hours
	Project	Worked on Paper / 1 hour

2	**What work will you complete this week (by our next session)?** *(let others know what they can depend on)*	
	Customer	Commitment/Hours Anticipated
	Project	PosterPaper / 18 hours-All
	Project	CAD iteration 6 / 4 hours-Courtney
	Project	Testing the DC-DC Converter up to rating / 2 hours- EE
	Project	ROS Research / 10 hours-Anthony
	Project	Belt & Wheel Research / 3 hours-Jarren
	Project	Finalize Voice Interface / 2 hours-Matthew
	Project	Test LiDAR / 3 hours - EE
	Project	Localino Research / 2 hours-Matthew

3	**What constraints are keeping you from getting your work done?** *(ask for help, declare a breakdown, raise concerns…)*		
	Concern, breakdown, or help you need	Resolution (Action by When)	Who's Responsible?

4	**Overall, are you still on track to meet your commitments to the project?**
	We are still a week or two behind from getting the budget two weeks late

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Appendix D-11: Fall Semester Week 11

University of Portland

Weekly Report-Out

Name_Courtney Otani   Team_Transnavigators   Today's Date:__11/30/2017

1	**What commitments have you completed since our last check-in?** *(let others know you've kept your commitments, declare work "done" so it can be accepted)*	
	Customer	Commitment/Hours Expended
	Project	Wrote the first draft of report/60hrs
	Project	Created first draft of poster/7hrs
	Project	Began work on Final CAD for Chassis/Full System/3hrs
	Project`	Begin testing localino/8hrs

2	**What work will you complete this week (by our next session)?** *(let others know what they can depend on)*	
	Customer	Commitment/Hours Anticipated
	Project	Finish Final CAD for full system/6hrs/Courtney
	Project	3D Print prototype/3hrs/Courtney
	Project	Revise/Edit draft report/2hrs/Jarren
	Project	Revise/Edit poster/2hrs/All
	Project	Purchase Encoders/2hrs/Matthew, Anthony, Jarren
	Project	CAD Localino anchor holder/2hrs/Matthew
	Project	Look for wheels to buy/3hrs/Jarren
	Project	Purchase wood for chassis/2hrs/Courtney and Jarren

3	**What constraints are keeping you from getting your work done?** *(ask for help, declare a breakdown, raise concerns…)*		
	Concern, breakdown, or help you need	Resolution (Action by When)	Who's Responsible?

4	**Overall, are you still on track to meet your commitments to the project?**
	Not with respect to our original time line but we are on track with respect to current expectations of when we expect
	things to be finished so we are prepared to hit the ground running next semester.

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Appendix D-12: Fall Semester Week 12

University of Portland

Weekly Report-Out

Name: Anthony Donaldson Team: Transnavigators

Today's Date: 12/7/2017

1	**What commitments have you completed since our last check-in?** *(let others know you've kept your commitments, declare work "done" so it can be accepted)*	
	Customer	Commitment/Hours Expended
	Project	Edited paper and poster/30 hours
	Project	Bought encoder/1 hour
	Project	CAD development and render/10 hours
	Project	Motor, shaft, and wheel research/6 hours

2	**What work will you complete this week (by our next session)?** *(let others know what they can depend on)*	
	Customer	Commitment/Hours Anticipated
	Project	Decide gears vs sprockets/10 hours Jarren & Courtney
	Project	Finish design/30 hours Courtney & Jarren
	Project	Finish reading Robot Operating System book/50 hours Anthony & Matthew
	Project	Create updated 2nd semester timeline/4 hours All

3	**What constraints are keeping you from getting your work done?** *(ask for help, declare a breakdown, raise concerns…)*		
	Concern, breakdown, or help you need	Resolution (Action by When)	Who's Responsible?
	Gear vs Sprocket	Janurary 15th	Courtney and Jarren
	How to use Robot Operating System	January 15th	Anthony and Matthew

4	**Overall, are you still on track to meet your commitments to the project?**
	Yes

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Appendix D-13: Spring Semester Week 1

Project Title: Transnavigators: Voice Controlled Wheelchair

Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	Encoder was defective and machined gears are not usable.	9.5/10	We are on track to meet all the deadlines we have set.

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates) Target	PTD Results (Dates) Actual	Rating	Comments/Concerns	Next Steps
Bought parts	Shopped at Home Depot (2 Hours) Online shopping (10 Hours)	Jarren and Courtney Jarren	1/21 1/24	1/20 1/24	10/10	Bought lumber, plywood, back casters, nails, and shafts. Bought gears, wheels, bearings, and shaft collars.	We are curerntly scheduled to cut wood in the shop this Friday (1/26). These materials are expected to come in within the following week. Once obtained we will measure distances then cut lumber and machine shafts accordingly.
Test Electronics	Tested rotary encoder (1.5 Hours) Tested UBEC power supplies (1 Hour)	Anthony and Matthew	1/23	1/23	4/10	One of the two encoders were found to be defective out of the box; no signs of life from output A. One of the UBEC power supplies blew up during testing.	A complaint was submitted and the encoder was shipped back to the supplier as of 1/25. It is still unknown whether/when a replacement will be supplied. We have elected to do without it.
Made Gears	Obtained steel plate and cut gears with waterjet (5 hours)	Jarren and Courtney	1/2	1/2	5/10	This was a good learning expereince. We learned how a waterjet works and were able to get a good physical idea of how ordered gears would look. This attempt costed us $0 (Fail quick, fail cheap) as Jarren was able to get the steel plate for free from his Boyscout troop and Courtney was able to gain access to the waterjet at her highschool.	The gears are not usable. The type of steel used was unknown leading to maching problems. Also, overtime the gears have rusted on the faces revealded by the waterjet leaving a rough surface. We have ordered gears online to replace these.
Update CAD	Update for the new gear design (2 Hours)	Courtney	N/A	1/24	8/10	Still unsure about a cuple things, but the CAD is not very important as of now.	Will continue working on this as the project progresses.
Faculty Advisor Meetings	Met with Symons (1 Hour) Met with Albright (0.5 Hours) Met with Galati (0.5 Hours)	All	1/17;1/24 1/24 1/19	1/17;1/24 1/24 1/19	10/10 10/10 10/10	We were able to meet with all of our faculty advisors. We were having trouble scheduling a meeting time with Albright, but were able to set it up thanks to Chris's help. We shared what we did over the summer and the first week of college with regards to the project. We are currently shceduled to meet with Symons weekly and Albright semi-weekly.	We are scheduled to meet with Jefferis this Friday (1/26).
Updated Voice Interface	Updated Voice Interface	Matthew	1/11	1/11	7/10	Alexa confirms commands. Commands are recognized more accurately. However, unknown commands are recognized as "Move Forward."	Fix the unknown command problem

Appendix D-14: Spring Semester Week 2

Project Title: Transnavigators: Voice Controlled Wheelchair

Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	Drilled a hole too large for LIDAR so part needs to be recreated.	9.5/10	We are on track to meet all the deadlines we have set.

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates) Target	Actual	Rating	Comments/Concerns	Next Steps
Bought parts and received parts	Shopped at Home Depot (1 Hour)	Jarren and Courtney	1/28	1/28	10/10	Bought velcrove straps, L-brackets, and spring loaded castors. Received gears, bearings, and shaft collars.	Update the CAD to match these parts and mark out the lumber for cutting/drilling. We will measure distances then cut/drilll lumber and machine shafts accordingly.
Cut Wood	Sawed and drilled lumber and plywood with Jacob (1 hour)	Jarren and Matthew	1/26	1/26	9/10	The hole for the LIDAR was drilled too thicc for the attachemnt holes to be used.	Since we have the bearings, shafts, and gears, we will measure those and cut and drill through these pieces made.
Localino Trianguasltion Node and Arduino Node	Created these nodes in Robot Operating System (ROS) (6 hours)	Anthony	1/26	1/29	6/10	Since the network is not up right now the chip cannot be tested which means triangulation software cannot be tested.	Fix the network, test the chip, test the software. The network is expected to be fixed on Friday (2/2).
Battery and Wheelchair Attachment Ideas	Sketched designs for battery and wheelchair attachment (1 hour)	Courtney	1/25-2/15	1/26	8/10	Battery attachement idea led to purchasing of velcrove straps and creating designs for wheelchair attachment was good for reminding us of this feature.	Will consider more ideas over time but currently placing emphasis on getting the chassis and drive constructed.
Faculty Advisor Meetings	Met with Symons (1 Hour) Met with Jefferis (0.5 Hours)	All	1/31 1/26	1/31 1/26	10/10 10/10	Meeting with Symons was productive to identify priorities in mechanical progress. Focus will be on creating chassis and drive, attachements will be thought of in the background. Updated Jefferis on our progress over the break and though the first week.	Planning to meet with Albright and Symons on 2/7.
Research	Did research on electromagnets, shaft coupling for encoders, and ports (4 hour)	Jarren and Matthew	N/A	1/30	2/10 4/10	Didn't find much on electromagnets and shaft couplings. Unsure if research on ports is accurate.	Do more research on shaft couplings. Hold off on thinking about attachment methods (what the electromagnets were an idea for) until chassis and drive train are worked on. Test what was found in research on ports.

Appendix D-15: Spring Semester Week 3

Project Title: Transnavigators: Voice Controlled Wheelchair **Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen**

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	We need a new way to mount the casters (Front and Back). Symons suggests not mounting directly to plywood top.	9.5/10	We are on track to meet all the deadlines we have set.

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates) Target	Actual	Rating	Comments/Concerns	Next Steps
Cut Wood Holes	Cut the bearing holes in the 2x4 and ply wood pieces. Also cut the steel shaft into 6" pieces (4 hour)	Matthew and Jarren	2/1	2/6	10/10	Jacob is a beast in the shop. The bearing holes needed to be pretty precisely drilled and he was able to do that, no problem.	Sometime next week we are going to try and assmble the frame of the platform. We would need to cut wood to accommodate the caster desing beforehand. Finalizing this design to something we can feel good about is the next step.
Assemble and Test Dirve Train	Shim bearings into hole, put everything together, and test gear meshing (2 hours)	Jarren	2/6	2/6	10/10	It works. Its really cool being able to feel the torque difference needed to spin each individual shaft.	We need to figure out a way to mound the casters. Symons had an idea, but it would prevent us from rounding the corners.
Castor Attachment	Designed adjustments needed to be made to chassis for castor wheel attachment (1 hour)	Courtney	N/A	2/8	5/10	Amount of material needed to be cut away is larger than initially anticipated. This is ok though because it will result in a more sturdy and easy to manipulate design. Design only done for back castors.	Design attachment for front castors. Cut materil to the new design.
Updated Schematic	Schematic update (3 hours)	Matthew	2/8	2/6	9/10	"It's Beautiful" -Matt	Implementing the circuits and giving Dr. Albright a copy.
ROS Package, NAV Stack, and TF. Integrating Travis CI into repository	Created Packages and set up navigation stack (22 hours)	Anthony	2/5	2/5	8/10	Didn't have time to test everything.	Testing everything. Writing unit tests.
Faculty Advisor Meetings	Symons Meeting Albright Meeting	All (0.5 hours) All (0.5 Hours)	2/7 2/7	2/7 2/7	10/10	Symons really helped this week. We scared Dr. Albright with our motor :(	We need to figure out the caster situation before our next meetings. Scheduled to meet with Jefferis on 2/16

Appendix D-16: Spring Semester Week 4

Project Title: Transnavigators: Voice Controlled Wheelchair

Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	ROS Navigation stack is not working as expected	9.0/10	We are on track to meet all the deadlines we have set.

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates) Target	Actual	Rating	Comments/Concerns	Next Steps
Assemble Chassis	Attached casters to chassis and integrated it with the drive train	Matthew and Jarren	2/15	2/13	9/10	Currently, we have a platform that rolls smoothly with all the wheels in place. During our weekly meeting, Symons noticed that the wood was thin in one section, so we need to reinforce it wih 2x4s	Thiccen the chassis and test movement under load. Also find large indoor location for testing. Add bumpers.
ROS Unit Test	Set up unit test framework and wrote some unit tests	Anthony and Matthew	2/13	2/13	6/10	The framework is great but our unit tests failed. One concerns is the errors in the unit tests could be due to errors in our actual code or errors in the unit tests themselves, so debugging will take some time	Work more to fix errors in the code and the unit tests
Designed the stop button holder	Soldered button to wires. Took measurements, created CAD.	Courtney and Jarren and Matthew	2/8	2/6	9/10	We soldered a button to wires and designed an ergonomic case to hold it in. One concern for this component is that the tolerances for the CAD are tight right now. STL File was sent to Allen for printing.	Wait for button holder to be printed and check fit with button. Adjust CAD and reprint if needed.
ROS Integration Test	Tested the ROS navigation stack	Anthony and Matthew	2/13	2/13	2/10	After running all nodes, no output was produced for cmd_vel, so something is broken within either our set up or the nodes themselves	A lot more testing and research into the navigation stack is needed
Faculty Advisor Meetings	Symons Meeting	All (0.5 hours)	2/14	2/14	10/10	Symons noticed that we needed more supports on the Chassis around the rear wheels.	We will test our chassis and motor set up next week (need to find a good/safe indoor test space) Scheduled to meet with Jefferis on 2/16

Appendix D-17: Spring Semester Week 5

Project Title: Transnavigators: Voice Controlled Wheelchair

Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	ROS Navigation stack is not working as expected, encoders may not be functioning, and the gears undo themselves	8.5/10	We are on track to meet all the deadlines we have set.

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates)		Rating	Comments/Concerns	Next Steps
			Target	Actual			
Prototype 1 wheelchair	Reinforce chassis, mounted motors (10 hrs)	Jarren	2/22	2/21	5/10	The platform moves only an inch under load. The gear's set screws undo themselves when there is too much weight on the platform.	Lock-tight the gears.
Emergency Stop button holder	Designed and printed stop button (4 hr)	Courtney	2/22	2/21	10/10	The stop button holder looks nice and fits the button. Glued button to button holder and attached it to clamp. Courtney got maker space training so she work more on her own instead of relying on the shop for small jobs.	Design and print a red button cap
Continuous Integration testing	Wrote unit tests for several nodes and updated config filles (15 hrs)	Anthony and Matthew	2/22	2/18	9/10	Anthony fixed some config files for travis ci. We wrote test scripts for arduino control, arduino publisher and the alexa voice control.	Work on Navigation stack now that most of the tests are complete
i2c communication	Began writing new code for arduino and raspberry pi communication (4 hrs)	Matthew	2/22	2/22	8/10	We could not get serial communcation to work between the raspberry pi and arduino, probably because we were sharing serial lines with the motor controller. i2c seems like it works great but test our scripts more to ensure that it will consistantly give us reliable communication.	Test the protocol with the berry imu and integate test scripts into the arduino nodes
Faculty Advisor Meetings	Symons Meeting Albright Meeting Jefferis Meeting	All (1.5 hours)	2/14	2/14	10/10	Symons noticed that the left wheel is not parallel to the side of the chassis. Albright tried to debug encoders with us. They appeared to be working at the end of the meeting. "Stay motivated"	We will ask Jacob what to do and try shim the shaft Test encoders more and ensure they are functioning properly Schedule meetings for the rest of the semester

Appendix D-18: Spring Semester Week 6

Project Title: Transnavigators: Voice Controlled Wheelchair **Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen**

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	ROS Navigation stack is not working as expected. Six axis controller is buggy. Gears still aren't attaching to the shaft	8.0/10	We are on track to meet all the deadlines we have set.

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates) Target	PTD Results (Dates) Actual	Rating	Comments/Concerns	Next Steps
Wheelchair Upgrades	Lock Tighted the wheel. Rebraced the motor (2 hrs)	Jarren	3/1	2/27	6/10	This was alright. The set screws are digging into the shaft so locktighting won't work.	Test without loading the platform too heavy. If we need to we will need to tap the shaft for the set screws to skink
Emergency Stop button holder top	Design a button cap and sent STL to Allen for printing (.5 hrs)	Courtney	3/1	2/27	8/10	The design of the button looks great. Need to follow up with allen to see if it is printed or not.	Follow up with Allen. Attach to button
Drive calcuations	Differential drive calcuations (1 hr)	Courtney	3/1	2/28	9/10	Verifying differential drive calcuations	Double check code
i2c communication	Finished writing i2c commmunication (12 hrs)	Matthew and Anthony	3/1	2/23	9/10	i2c communication works reliably now. We integrated software and hardware but the sixaxis controller is sending spurious data to our arduino_motor node	Debug sixaxis controller. Mount electronics to chassis. Work on navigation stack. Checkout the diff drive node
Faculty Advisor Meetings	Symons Meeting	All (1.5 hours)	2/28	2/28	10/10	We need to think of attachment methods for the wheelchair. In addition Symons pointed out that we might not have identified all the problems that we will face when integrating everything together.	We will meet with Jefferis tomorrow and Dr. Albright & Dr. Symons next Wednesday

Appendix D-19: Spring Semester Week 7

Project Title: Transnavigators: Voice Controlled Wheelchair

Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	ROS Navigation stack is not working as expected. Six axis controller is buggy. Gears still aren't attaching to the shaft	8.1/10	Founders' Day is Really Soon…

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates) Target	PTD Results (Dates) Actual	Rating	Comments/Concerns	Next Steps
Drive Train and Chassis Changes Pro Forma	Flattened Shaft and Lock Tighted Gears Pro Forma	Jarren (3 hours) (2 hours)	3/9	3/8	?/10	Did this the same day we are writing the report-out so we are letting the glue set before testing.	Test tomorrow and react accordingly.
Documentation	Worte Down Equations and Other Math for Differential Drive	Courtney (2 hours)	3/2	N/A	9/10	It eliminated some discrepancies between some of the theoretical math we found and what is currently written in the code.	Farthur inverstigation is still needed to determine what needs to be changed in the code.
Integration	Mounted the Electronic onto the Chasis, Made Bigger Holes for Wires	All (4 hours)	2/28	3/2	10/10	Everything worked out well. The wires are too long, but we fixed the problem with tape. Flipping polarity of battery will destroy $150 chip.	DONE
Test Prototype	Run Platform, Tested Vouce Control	Matthew and Anthony (1 hours)	2/28	3/6	9/10	We tested in the thrid floor Shiley open space. Anthony was able to ride on top from the center to the lab. Matt dropped the ball and forgot to film this long-sought milestone smh. The gears popped off when the platform stopped and the wheels have "knocked knees" under heavy loads. Alexa works.	Fix the grears again to prevent high tourques from unlocking the setscrews.
Faculty Advisor Meetings	Symons Meeting	All (.5 hours)	3/7	3/7	10/10	We need to find a wheelchair still. Final prototype needs to be functional (Ramp + Attachment). Didn't meet with Albright because he was too busy.	Will meet with both faculty advisors after break Currently asking everyone on campus for a wheelchair (Jarren). Will finalize ramp and attachment design (Courtney).

Appendix D-20: Spring Semester Week 8

Project Title: Transnavigators: Voice Controlled Wheelchair **Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen**

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	Testing the Navigation stack. Localino chips still have unrealiable connections	8.1/10	Founders' Day is Really Soon…

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates) Target	PTD Results (Dates) Actual	Rating	Comments/Concerns	Next Steps
Documented code	Setup Sphinx, Doxygen, Breathe, and ReadtheDocs integration & wrote Transduino README (12 hours)	Anthony and Matthew	3/23	3/15	8/10	Sphinx was easy to setup, but it was difficult to get Breathe/Doxygen to work together. Breathe was especially annoying because its documentation lies and there is no alternative to import C code in Read the Docs.	Clean up old files from repos and make them presentable
Updated Schematic	Added i2c connecion and more dc-dc converters to the schematic to reflect the physical setup of our system (2 hrs)	Matthew	3/16	3/14	9/10	Schematic looks beautiful. It will look nice in our final report. The schematic repo is cleaned up and the files are now named appropriately	Keep the schematic up to date with any other future changes
Founders Day Presentation	Began populating slides with data about our project (1 hr)	All	3/16	3/15	7/10	The slides are far from complete but we still have a couple weeks to finish and polish them	Keep editing the slides
Wheelchair Search	Contacted a lot of people on campus looking to borrow a wheelchair (0.5 hours)	Jarren	3/19	3/15	10/10	The nursing department said that they have a wheelchair we can borrow until Founder' day.	Will contact Chris Blackhurst, MS, RN, CNL Director – Simulated Health Center on Monday with regards to picking it up.
Wheelchair attachments	Picked and purchased wheelchair attachments (1 hr)	All	3/9	3/8	8/10	The attachments we bought were delivered on 3/9. They do not lock closed so we will need to figure out a way to prevent them from opening when the platform tilts.	Go to the shop and ask Jacob for advice

Appendix D-21: Spring Semester Week 9

Project Title: Transnavigators: Voice Controlled Wheelchair **Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen**

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	ROS Navigation stack is not working as expected still. The bearings are falling out of the holes when there is weight on the platform.	8.1/10	Founders' Day is Really Soon…

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates) Target	PTD Results (Dates) Actual	Rating	Comments/Concerns	Next Steps
Fixing	Cut Velco holes Glued bearings Locktighted gears Pump wheels	Jarren (3 hours)	3/22	3/22	10/10	The bearing fell out of the holes and split the wood a little, so we glued them back inside. We don't think its going to work well.	Try more stuff to keep the bearings in the holes.
Begin Updating CAD	Took measurements	Courtney (2 hours)	3/22	3/22	9/10	Measurements went well	CAD will updated to match new measurements and design. A new design for ramp, battery attachment and wheelchair attachment will be added.
Update Powerpoint	Added slide Updated current slides Updated diagrams	Courtney and Matthew (4 hours)	3/21	4/2	10/10	Some slide need work	Update and complete more slides
Debugging Code	Debugged Arduino, ROS, Naviagation stack code	Anthony (15 hours)	3/20	3/22	9/10	Joystick works fine now but the navigation stack needs more work.	Work more the navigation stack
Faculty Advisor Meetings	Albright Meeting Symons Meeting	All (45 hours) All (45 mins)	3/20	3/20	10/10	The velocity control system sometimes oscillates when the gears get loose. Dr. Albright said that under load this shouldn't be problem under load since the weight will provide damping. Because the bearings are falling out, Symons recommended reinforcing the thin pieces of wood with sturdy metal.	Meet with Dr. Symons next week

Appendix D-22: Spring Semester Week 10

Project Title: Transnavigators: Voice Controlled Wheelchair

Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	The bearings are falling out of the holes when there is weight on the platform.	8.1/10	Founders' Day is Really Soon…

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates) Target	Actual	Rating	Comments/Concerns	Next Steps
Backup Master Node	Wrote the master node (7 hrs)	Matthew and Anthony	3/29	3/27	7/10	It is a good concept but we still need to work out a few bugs before we can say we have integrated the voice control into the system.	Find and Fix the bugs
Fix Gear Slip	Drilled and tapped holes in shaft for set screw to go through shaft and gear. (1 hr)	Courtney	3/29	3/27	9/10	The tap got stuck in one of the shafts but that just means that it will be sure not to slip from the gear. We may want to get a bolt for the one that has the set screw in it but it hasn't slipped so far so it is probably ok.	See how the shafts operate in testing, and if needed, buy the bolt for the shaft.
Update CAD	Updated CAD of platform to match new design (1.5 hr)	Courtney	3/29	3/29	7/10	Started to update CAD. Changes to chassis are more significant than expected. Some more measurements need to be taken.	Take other needed measurements, finish updating CAD, add design for ramp.
Fix Chassis and Add Mounts	Added metal plates to sides to stiffen wood (1 hr)	All	3/29	3/22	10/10	Wood no longer flexes. Bearings still come out of holes.	Add tape or other retention methods to hold the bearings in.
	Added corners for battery and created hole for velcro. Mounted toggle clamps for wheelchair mount. (1.5 hr)	Jarren and Matthew		3/26	10/10	Batteries fit in mount and wheelchair can be solidly mounted and roll through open mounts.	Add rubber or some kind of friction covering to the toggle clamps.
Faculty Advisor Meetings	Symmons Meeting (20 mins)	All	3/28	3/28	10/10	Deadlines set, wants the platform moving in response to voice commands and a ramp attached.	Meet with Albright and Symmons next week
Purchased Mechanical Parts	Purchased collars and ramp hinges from McMaster (30 mins)	Anthony and Jarren	3/29	3/29	10/10	Found what we needed, made sure dimensions of things were all correct.	Wait for them to come and use them to build ramp and fix shaft from moving side to side.

Appendix D-23: Spring Semester Week 11

Project Title: Transnavigators: Voice Controlled Wheelchair

Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	Time	9.0/10	Founders' Day is Tuesday

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates) Target	Actual	Rating	Comments/Concerns	Next Steps
Editted Navigation system software	Fixed the backup master node/broken nodes (23 hrs) Worked on navigation stack (9 hrs)	Matthew and Anthony	4/2	4/4	8/10	It is a good concept but we still need to work out a few bugs before we can say we have integrated the voice control into the system.	Find and Fix the bugs
Editting Presentation	Editted slides and added new ones (14 hrs)	All	3/29	3/27	9/10	The presentation has a lot of technical information right now. We need to cut it down to keep it in the time limit and make it accessable to a non technical audience.	Keep on editting, revising and practicing the presentation.
Fixed Drive Train	Tapping the small gears (30 mins)	Jarren	3/15	4/5	7/10	Tapping the shaft does not work. The gears that we locked in place last week are moving a little. Jacob said that the taps are brittle and could have broken.	Try not to use the hard stop to reduce the force on the gears
Platform testing and video taking	Tested the platform against metrics and took videos (3 hrs)	All	4/3	4/3	8/10	The platform was jerky during testing but we met the metrics specified in the A3 Document. We have updated navigation software that we can test now and video	Do more testing and video taking with the new navigation system
Faculty Advisor Meetings	Albright Meeting (20 mins) Symons Meeting (20 mins)	All	4/4	4/4	10/10	Demonstrated the platform moving with voice controls	Follow up meetings after founders day

Appendix D-24: Spring Semester Week 12

Project Title: Transnavigators: Voice Controlled Wheelchair

Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	None	9.0/10	Founders' Day has passed and we survived. Mrs. Shiley liked it.

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates) Target	PTD Results (Dates) Actual	Rating	Comments/Concerns	Next Steps
CAD	Created CAD for final wheelchair design	Courtney	4/10	4/8	10/10	The CAD matches the final prototype quite well	None
Edited Presentation and Videos	Editted slides as we presented and edited video (2 hours)	All	4/9	4/9	9/10	The presentation was refined for clarity and time and people liked it.	None
Practiced Presentation	We met and practiced (1.5 hours)	All	4/9/2018 4/6/2018	4/9	9/10	We found a lot of problems while practicing and fixed the presentation	None
Updated website and code	Uploaded documents to website, uploaded videos, fixed failing builds (2.5 hours)	Anthony	4/10	4/10	8/10	We fixed the failing build, so our Github page is green now	None
Founder's Day	We presented in Session I	All	4/10	4/10	10/10	It went well! All of our advisors and Mrs. Shiley gave positive feedback.	We need to write a final paper.

Appendix D-25: Spring Semester Week 13

Project Title: Transnavigators: Voice Controlled Wheelchair

Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	None	9.0/10	We just have to finish the paper now and gut the chassis of parts.

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates)		Rating	Comments/Concerns	Next Steps
			Target	Actual			
Final Paper Draft	Wrote paper (28 hours)	All	4/18	4/18	9/10	There are a few sections we still need to work on	We will compile the changed sections in the paper and send it to Symans for her to edit.
Met with Symons	Meeting (30 minutes)	All	4/18	4/18	10/10	Created plan for the rest of the year Received deadline for draft Symons will review Talked about disassembling chassis	We will meet with Symans and Albright next week.

Appendix D-26: Spring Semester Week 14

Project Title: Transnavigators: Voice Controlled Wheelchair **Team Members: Anthony Donaldson, Courtney Otani, Jarren Takaki, Matthew Yuen**

Project Definition	Project Goals	Progress Against Goals	Rating	Comments
The Transnavigators' Voice Controlled Wheelchair will increase people's independence by autonomously navigating them to their destination using voice commands. This platform will allow users to convert their existing wheelchair into an autonomous wheelchair. It is controlled by voice commands and can find the user or navigate to a destination. One possible application is for patients in a hospital setting. In situations where their wheelchair is far away, patients can simply ask Alexa, and a wheelchair will automatically navigate itself to their position. In addition, after they get on their wheelchair, the patient can use directional and destination commands to navigate to a desired location.	Voice controlled navigation Motorized wheelchair system Working prototype	None	10.0/10	None

Goal/Deliverable	Activities	Responsible Performer	PTD Results (Dates) Target	PTD Results (Dates) Actual	Rating	Comments/Concerns	Next Steps
Final Paper Draft	Wrote paper (36 hours)	All	4/26	4/26	10/10	Editting and formatting	None
Faculty Adviser Meeting	Meeting with Albright (15 minutes) Meeting with Symons (15 minutes	All	4/25	4/25	10/10	Closed up	None

Appendix E: Resumes

Appendix E-1: Anthony Donaldson's Resume

16740 NE Glisan St
Portland, OR
971-401-6115
donaldsa18@up.edu

Anthony Donaldson

Objective Full-time position where I can apply and further develop my knowledge in Computer Science and Electrical Engineering.
LinkedIn - https://www.linkedin.com/in/anthony-donaldson-216704b2/

Team Projects

Android Chess - https://github.com/PawnStars/Pawn-Stars-Chess-Game
Team developed a networked Chess app with Stockfish Chess AI engine.
Gained experience pair programming and collaborating with to architect the app

Credo Reference Survey Data Website - https://github.com/DinocoCo/DinoGraph
Team developed a data visualization website using Google Charts, Node.js, and Heroku cloud services.
Learned website optimization
Practiced Agile software development methodology

Active Directory Account Lockout Inspector - https://github.com/donaldsa18/ADALI
Created a Java EE web application to query a domain controller, Cisco ISE server, and Oracle database for account information as a resource for the UP Help Desk

PIC Microcontroller Keypad and Audio Player - https://www.youtube.com/watch?v=KFzrQo8IHg4
Programmed a PIC microcontroller to play songs with a keypad and LCD using PIC Assembly
Learned how to debug microcontrollers and interface with

Skills

GitHub Repository - https://github.com/donaldsa18/

Programming languages
- Android, Assembly, C, C++,, Java, Javascript, Lisp, Python, MATLAB, SQL

Software
- Computer Science: Bootstrap, JUnit, Node.js, Heroku, MSSQL, MySQL
- Electrical Engineering: B²Spice, Eagle, L-Edit, MPLAB, PSpice
- IDEs/Editors: Eclipse, Emacs, Netbeans, Notepad++, Visual Studio
- Adobe Creative Suite, Google Docs, LaTeX, Microsoft Office

Operating Systems
- Windows, Mac OS X, Linux (BSD, Debian, RHEL), Android

Soft skills
- Fast learner, collaborative, hardworking, innovative, self-motivated, organized, problem solver, team player

Education

University of Portland, Portland, OR — Expected May 2018
- B.S. Computer Science, Second Major in Electrical Engineering
- Member of the Tau Beta Pi Honor Society and Treasurer of the Association of Computing Machinery
- GPA: 3.90

Experience

Information Security Specialist, University of Portland — May 2017 – Present
- Implemented and managed a Splunk environment for machine data analytics

Computer Technician, University of Portland — May 2015 – May 2017
- Increased productivity by implementing SCCM and MDT to automate desktop imaging
- Created software packages for automated deployment with SCCM, Casper, and App-V
- Provided Tier 3 IT support by troubleshooting PC hardware and software

Computer Lab Aide, University of Portland — Sept 2014 – December 2015
- Provided desktop IT support

Appendix E-2: Courtney Otani's Resume

COURTNEY OTANI

5000 N. Willamette Blvd. Lund #214
Portland, Oregon 97203
(808) 206 -2937
otani18@up.edu

Mechanical engineering student excited to learn new skills and technical knowledge. Will demonstrate initiative, creative problem solving, conscientiousness, and interpersonal skills.

EDUCATION

UNIVERSITY OF PORTLAND: PORTLAND, OREGON *Expected Graduation: May 2018*

- 4th Year Student, Senior credit standing — Current GPA: 3.805
- Major: Mechanical Engineering
- Minor: Entrepreneurship and Innovation Management

UNIVERSITY OF PORTLAND: SALZBURG, AUSTRIA *Spring 2016 Engineers Program*

TECHNICAL SKILLS

Trained in:

- Software: CAD (Solidworks), MATLAB
- Tools: Basic power tools and hand tools: chop saw, drill press, hand drill, Laser cutter (Epilog Laser)

Some experience with:

- Software: Arduino Uno, Lab View, AutoCAD, FME, GeoMedia, Global Mapper
- Tools: CNC milling machine, waterjet cutter

RELATED EXPERIENCE

MAKAI OCEAN ENGINEERING: WAIMINALO, HAWAII

Internship *May – August 2016 and 2017*

- Updated and expanded documentation for their submarine cable software training to a level where interested customers could follow the tutorial-style documentation as a self-taught course
- Performed SWAC (Sea Water Air Conditioning) modeling with AutoCAD drawings and company's software created using MATLAB to yield estimates for a client interested in installing a SWAC system
- Conducted extensive search of bathymetry data and electronic navigational charts for the development of a broader database to provide with the submarine cable software
- Assembled rigging for and performed tests on an integral component of a prototype

UNIVERSITY OF PORTLAND: PORTLAND, OREGON

President of Global Engineering Initiative Club *Fall 2015 – Present*

- Advise structure of the club and its future endeavors such as continued work with Global Brigades
- Manage, motivate, and collaborate with other club leaders (ex. Vice President, Project Advisor, etc.)

'IOLANI SCHOOL: HONOLULU, HAWAII

Internship *May – August 2015*

- Redesigned robotics spaces in Sullivan Center for Innovation and Leadership for better functionality and greater storage capacity for the engineering courses and two afterschool robotics programs
- Coordinated closely with Headmaster, faculty, and staff whose spaces I was redesigning
- Purchased, assembled, and installed furniture and equipment such as work benches and storage systems

Teacher's Aide for 4th Grade Robotics Class *Summer 2013 and 2014*

- Designed and created robotics challenges for students to solve by creation of attachments and code
- Assembled student teams and answered students' questions in class for optimal student involvement

ACTIVITIES

- Corresponding Secretary of University of Portland Chapter of Tau Beta Pi Engineering Honor Society
- Research: Numerical Model of Oscillating Water Column Wave Energy Converter, presented at NCUR 2018

Appendix E-3: Jarren Takaki's Resume

3480 Kupaa Drive Honolulu, HI 96816•(808)782-4101•takaki18@up.edu

Jarren Takaki

Education

University of Portland	B.S Mechanical Engineering	Estimated Grad: May 2018
Portland, OR	Double Major in Chemistry	Current GPA: 3.90

Related Experience

Organic Chemistry Workshop Leader — **8/16 - Current**
University of Portland – Portland, OR

- Leads a workshop to help students currently taking organic chemistry
- Communicates organic chemistry concepts in both a presentation and one on one manner
- Adapts and problem solves to resolve unforeseen issues in the workshop

Student Concessions Cashier & Runner — **8/15 - Current**
University of Portland – Portland, OR

- Works well and remains composed in hectic and crowded work spaces
- Deals with unsatisfied customers in a professional manner
- Efficiently works to ensure setup and clean up finish as quickly as possible

Summer Student Research Program — **6/17 to 8/17**
Hawai'i Pacific Health (HPH) – Honolulu, HI

- Retrospective chart review of the diagnosis and management of lung cancer treatment in Hawai'i
- Interacted with and received advice from a plethora of physicians and administration
- Shadowed several specialties including radiology, neurology, general surgery, and more
- Toured all the HPH facilities along with outside affiliated companies
- Gave a research presentation to 200+ people

Shadowed a Physician – Queen's Medical Hospital – Honolulu, HI — **12/16 to 1/17**

- Interacted with and learned how to communicate effectively with patients
- Observed how a physician deals with delivering bad news and consulting difficult patients
- Sat-in on numerous GI track procedures: Mostly Upper endoscopies, Colonoscopies, and ERCP

Engineering Internship – AECOM – Honolulu, HI — **5/15 - 8/15 & 5/16 - 8/16**

- Interned summer 2015 in the water department and summer 2016 in the wastewater department
- Shadowed engineers both in the office and out at the field
- Focused and remained productive for 40-hour work weeks

Engineering Student Advisory Council – President – Portland, OR — **8/16 - Current**

- Communicates between the students and dean of the engineering school to improve quality of life
- Leads meetings and maintains contact with the members

Engineering Group Project – University of Portland — **Spring '17**
Machine Design – Portland, OR

- Collaborated with peers to make a small LEGO agriculture vehicle that would transport a mass as quickly as possible while remaining within the set restrictions
- Maintained a schedule of deadlines before the final project presentation

Member of Tau Beta Pi – Oregon Gamma Chapter — **Fall '16 - Current**

- Engineering Honor Society

Eagle Scout / Senior Patrol Leader – Boy Scouts of America — **Summer '14**

- Organized a project to construct eight rolling whiteboards for Nu'uanu Elementary School
- Collaborated with professionals to develop a design and procedure

Appendix E-4: Matthew Yuen's Resume

Matthew Yuen

yuenm18@up.edu | (808)-542-2492

5000 N Willamette Blvd
Tyson Hall Room #211C
Portland, OR 97203

Permanent Address:
1144 Kaluanui Road
Honolulu, HI 96825

EDUCATION

University of Portland, Portland, OR — Expected May 2018
Dual degree: B.S. Computer Science & B.S. Electrical Engineering — GPA: 3.91
Minor: Mathematics

- Tau Beta Pi

TECHNICAL SKILLS

Programming Languages: Java, C, Python, MATLAB, Javascript, Bash, SQL, PIC Assembly
Operating Systems: Windows, Mac OS, Linux
Applications: Microsoft Office, B2Spice, PSpice, MPLab, Eclipse, BlueJ, Android Studio, Git

REVELANT EXPERIENCE

Student Web Developer — Fall 2017 – Spring 2018
University of Portland, Portland, OR

- Developing Java Liferay Portlets which will be used internally by the University
- Built a portlet to replace the Academic Resource Center's sign-in sheet to reduce data entry errors
- Currently porting old forms over to Liferay

Computer Science Fellow — Fall 2017 – Spring 2018
University of Portland, Portland, OR

- Tutoring sophomore level students in Intro to CS, Data Structures and OO Design
- Debugging code and explaining programming concepts to students

Software Developer Intern — Summer 2017
Pacific Disaster Center, Kihei, HI

- Built a dashboard which monitors and locates failures in PDC's disaster monitoring platform
- Created a REST Service with Jersey & Hibernate and a web application with AngularJS & Bootstrap
- Made system failure information readily accessible to both technical and non-technical people

Teaching Assistant — Spring 2017
University of Portland, Portland, OR

- Helped students understand programming concepts and use the MATLAB language

Engineering Research Assistant — Fall 2016 – Spring 2017
University of Portland, Portland, OR

- Tested the susceptibility of different GFCI units to Electrical Fast Transients
- Presented a paper at ISPCE 2017 and at an Oregon IEEE EMC society chapter meeting
- Showed that various GFCIs perform differently in the presence of fast transients

EXTRACURRICULAR ACTIVITIES

Volunteer, Habitat for Humanity — 2016 – 2018
Volunteer, Relay for Life — 2017
Volunteer, Stem Camp — 2016

PUBLICATIONS

M. S. Yuen, J. P. Kirby, P. E. Perkins, A. S. Inan, and H. W. Benitez, "Why Do GFCIs Keep Tripping?," *2017 IEEE Symposium on Product Compliance Engineering (ISPCE 2017) Proceedings*, pp. 15-19, San Jose, CA, May 8-10, 2017.