Biometric Autonomous Droid (BAD-2024) Safety Plan

Hunter Angst,[†] Angela Busheska,[‡] William Cassidy,[‡] Lindsey Huppin,[†] Seyha Khom,[‡] Robbie Leslie,[‡] Alex Ojeda,[‡] Renee Pascoe,[†] Owen Pazera,[‡] Laxman Poudel,[‡] Eren Tekbas,[‡] Nam Vu,[‡] and Yih-Choung Yu[*,‡,†]

†*Integrative Engineering Program, Lafayette College, Easton, PA 18042*

‡*Department of Electrical and Computer Engineering, Lafayette College, Easton, PA 18042*

E-mail: yuy@lafayette.edu

1 Abstract

Lafayette College's Engineering Division has requested that our 2024-2025 Senior Design team design a Biometric Autonomous Droid (BAD-2024) system for deployment on the fourth floor of the Acopian Engineering Center. The main objective of the proposed system is to create an autonomous wheelchair that is capable of navigating a single-floor indoor setting. The wheelchair will contain all of the items necessary for self-containment and autonomous operation for a finite time and over a limited range. This system is composed

of a physical wheelchair, a joystick for navigation, a 24V battery, two motors and motor controllers, a comprehensive sensor system, biometric technology, self-driving capability, and an interactive interface. The proposed system is intended for indoor use only.

2 Design Problem Overview

In clinical settings, patient mobility is crucial for well-being. For the elderly population, and for those who live with disabilities such as Multiple Sclerosis (MS) or chronic conditions that impair mobility, navigating hospital floors poses a challenge. Traditional wheelchairs require patients to use their strength to move about the floor or to rely on a nurse or aide to assist them with transportation. The need for constant assistance places strain on staff resources and availability, and calls for an innovative, personalized solution: an autonomous wheelchair. At the intersection of mobile robotics and patient care, our senior design project envisions a biometric, autonomous droid in the form of a power wheelchair capable of safely transporting patients through single-floor, indoor environments such as hospitals or assisted living facilities. Our proposed technology aims to improve patient self-sufficiency while addressing and improving healthcare staff efficiency, allowing for personalized patient care management.

3 Prototype Specifications

3.1 Dimensions

The dimensions of the entire chair will not exceed one meter in the horizontal plane, excluding the passenger. The height measured from the floor to the top of the chair will not exceed 65 inches. For the chair to be used as a seat for the wheelchair, the dimensions of the chair alone (excluding chair legs) are: 19.7" W x 20" D x 26.8-31.5" H due to the adjustable headrest. The dimensions of the aluminum base plate are 24" x 24," and the dimensions of the footrest plate are 24" L x 6" W. The dimensions of the 80/20 box are 18" L x 18" W x 12" H.

3.2 Wheel Support

- To support the wheels, solid 80/20 T-Slotted, triple rail, silver, 3" H x 1" W aluminum was used, which was wider than the standard 80/20 used throughout the rest of the design, as the swivel plate for the front caster wheels necessitated a greater width of 80/20.

- The plate for the base and for the footrest was a multipurpose 6061 aluminum sheet, 1/8" thick, 24" x 24", and 6" x 24," respectively.

3.3 Materials

- To construct the frame of the chair, including the box, the area under the box, and frame for under the chair, 80/20 T-Slotted, 1" H x 1" W aluminum was used. Pieces were put together using screws, hole inserts, and brackets to secure the 80/20.

- All materials were purchased from the McMasterMcCarr website, with the exception of the 80/20 T-Slotted, 1" H x 1" W aluminum, screws, and hole inserts, which were provided by the machine shop.

3.4 Color

- The color of the wheelchair seat was chosen to be black in order to provide a minimally distracting appearance to bystanders and to hide stains in case of any accidental spills. The base and frame of the wheelchair is a gray/silver color due to the use of the 80/20 aluminum. This is another neutral color choice. However, the color of the warning light was chosen to be a red color, to draw bystanders' attention to the top of the wheelchair when it is in use.

3.5 Weight

The total weight of the wheelchair and occupant should not exceed 400 pounds in total, and the weight of the entire wheelchair system, excluding an occupant, should not exceed 200 pounds. As the wheelchair is constructed, the physical subgroup will ensure that the entire system does not exceed the predetermined weight capacity. The components of the wheelchair system which hold the most significant weight are the motors and the battery. Together, the motors weigh 31.4 pounds. The battery weighs 27.5 pounds. Weight estimations and calculations may be made for the 80/20 pieces, and for the base plate and footrest, as such information is not provided for those pieces on McMaster-Carr.

3.6 Patient

The total weight of the wheelchair and occupant should not exceed 400 pounds in total, and the weight of the entire wheelchair system, excluding an occupant, should not exceed 200 pounds. As the wheelchair is constructed, the physical subgroup will ensure that the entire system does not exceed the predetermined weight capacity. The components of the wheelchair system which hold the most significant weight are the motors and the battery. Together, the motors weigh 31.4 pounds. The battery weighs 27.5 pounds. Weight estimations and calculations may be made for the 80/20 pieces, and for the base plate and footrest, as such information is not provided for those pieces on McMaster-Carr.

3.7 Wheels

In order to select the wheels for the device, there were a few criteria that were set in place. The most important of these criteria was the capability of the wheels to bear the weight of the design. The front wheels had to be 8-10 inches wide and swivel in order to allow for easier turning for the wheelchair. The drive wheels needed to be 12 inches or more, along with needing to be able to fit on the motor. For the first set of drive wheels ordered, research was done before the motor was officially found and picked. However, there were unforeseen issues, and the chosen wheels did not end up fitting onto the motor, necessitating further study. The drive wheels selected were 12 inches tall and 2.75 inches wide, but they contained ball bearings. While the team was able to remove those, the hub diameter was too big to attach the wheel directly, yet too small to create a sturdy axle to fit it onto the motor. For these reasons, the wheels had to be shipped back to the manufacturer. Because we had the motors to set the hub size of the drive wheels, along with the possible method of using a key to hold the wheel in place with the motor, we decided to find a wheel similar to our last, but with a keyed hub instead of bearings on the inside. The search was tough, as there were not many vendors that sold wheels that fulfilled the criteria. So we asked Marvin from the Engineering Machine Shop to assist in our search for the right wheels. With his help, the team found wheels that met our criteria and were reasonably priced. With that, we ordered new wheels. The new wheels are 12.992 inches tall, with a keyed hub that fits properly on the motor.

3.8 Use

The wheelchair is only to be used indoors, and is only to travel on a single floor. It should not be used or directed to transport a patient on stairs. Measures will be implemented to ensure that the wheelchair stays on the proper path, avoiding obstacles and staircases.

3.9 Converters

Currently, we have a 24V battery with 60 amp hour power output to feed all of the electronic components. The motor systems do not require a voltage regulator as the controllers are connected directly to the battery which in turn power the motors. This circuitry does not require a voltage change as the products are selected to be directly connected.

Listed below are the components that require a voltage regulator:

- 19V: Jetson Nano, the mini-computer that will be used primarily to calculate data from the Lidar and receive/send signals to various components in the design. Below are components that can be powered by the Jetson Nano:
  - 5V: Raspberry Pi Pico x 2, Alarm x1
  - 3.3V: Ultrasonic Sensor x 6, PIR Sensor x4, IMU Sensor x 4
- 12V: Fan x 4, Screen x 1, ASG light x 1, LiDAR x1 Through the components listed above, it is determined that we need 2 types of voltage regulators: a 24V to 19V at 3A and 24V to 12V at 1.8A.

3.10 Self-Driving Subsystem

The system shall be autonomous, moving under its own control, power, and guidance, perpetually patrolling a hallway setting, navigating and avoiding obstacles. In the later mentioned text, autonomous vehicles will be referred to as self-driving systems.

The robot should be in autonomous operation in the designated area. For that honour, our end goal is to design a level 4 autonomous vehicle that is fully self-driving under certain conditions.

This system is responsible for ensuring that the patient is safe while the wheelchair is in use.

3.11 Sensors Subsystem

The wheelchair must avoid obstacles. We need to detect dynamic obstacles like people walking and static obstacles like tables and chairs. It also needs to be able to detect stairs to ensure that it does not fall.

By using the sensors it can detect obstacles while moving at a high speed so the chair doesn't need to come to an abrupt stop. By having multiple sensor types, we can collect more accurate data on the surrounding environment to ensure the passenger's safety.

In addition to obstacle avoidance, the wheelchair must be able to autonomously navigate a specified area. This means that it needs to recognize where it is spatially located in the specified area, which in this case is either the 4th floor of AEC. This specification meant that we needed a more powerful sensor that allows the chair to locate itself in relation to the surrounding area.

4 Design

4.1 Physical Design

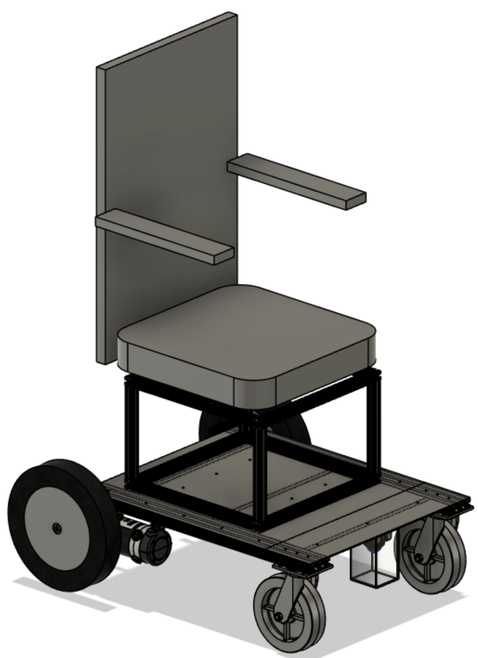

Figure 1: Final Proposed Wheelchair Design. Drawing created in Autodesk Fusion.

4.2 Box Design

For the design of the box enclosure, which contains all components essential for the functionality of the wheelchair, there are several components. The largest component is the battery, which is placed towards the front of the box to balance out the weight of the motors, which

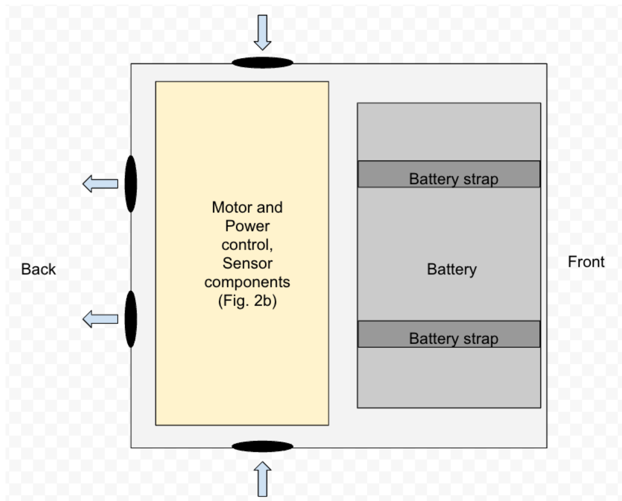

Figure 2: Box Organization, including battery, motor, and sensor components; top view (not to scale). Black ellipses represent fan placements. Arrows represent the direction of airflow.

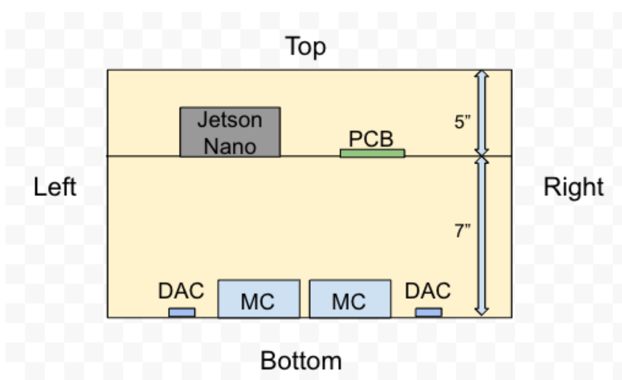

Figure 3: Two level organization of sensors and motor control components; side view (not to scale). PCB stands for printed circuit board, MC stands for motor controller, DAC stands for Digital-to-Analog

are towards the back of the chair (Fig. 2b). In addition, there will be two level organization of the sensor and motor components, to maximize space. This shelf design will be constructed of 1/8 inch PVC.

Fans are another component of the box design (Fig. 2a). It was decided that the optimal fan to use would be standard 140mm 12V PC case fans. These were chosen because they are cheap and provide significant airflow to ensure that the components in the box enclosure do not overheat. These fans use the standard Intel PWM fan design, and have a 5V PWM signal to control the fan speed and a tachometer, which can either be at 5V or 3.3V, depending on a pull-up resistor. Since the PWM signal is at 5V and the Pico pins supply 3.3V, we are using an opto-isolator to convert the signal from 3.3V to 5V and isolate it so that the signal will not damage the GPIO pins on the Pico.

4.3 Computing Design

The central unit of the system is NVIDIA Jetson Nano Orin, which is connected to the Motor and the Sensors microcontroller. Additionally, it is connected to the screen, speakers and the LiDAR sensor

The machines in the machine shop are simple yet very professional pieces of equipment. It is most likely that the machine shop staff will be the ones using these to create your item, but in the rare off chance the student uses these, this is what should be followed. You must understand how to use the equipment you desire to use, and if not, you may ask the instructor for help in using the machine to create the part you wish to. To work with machines as well, you must have a drawing of the part with you to work with the machines and make the edits that you need to the drawing.

4.3.1 Sensors System

For this project, we are using LiDAR, ultrasonic, PIR, IMU and Joystick sensors. All of these sensors are connected to a Raspberry Pi Pico microcontroller. Sensors like the ADCs

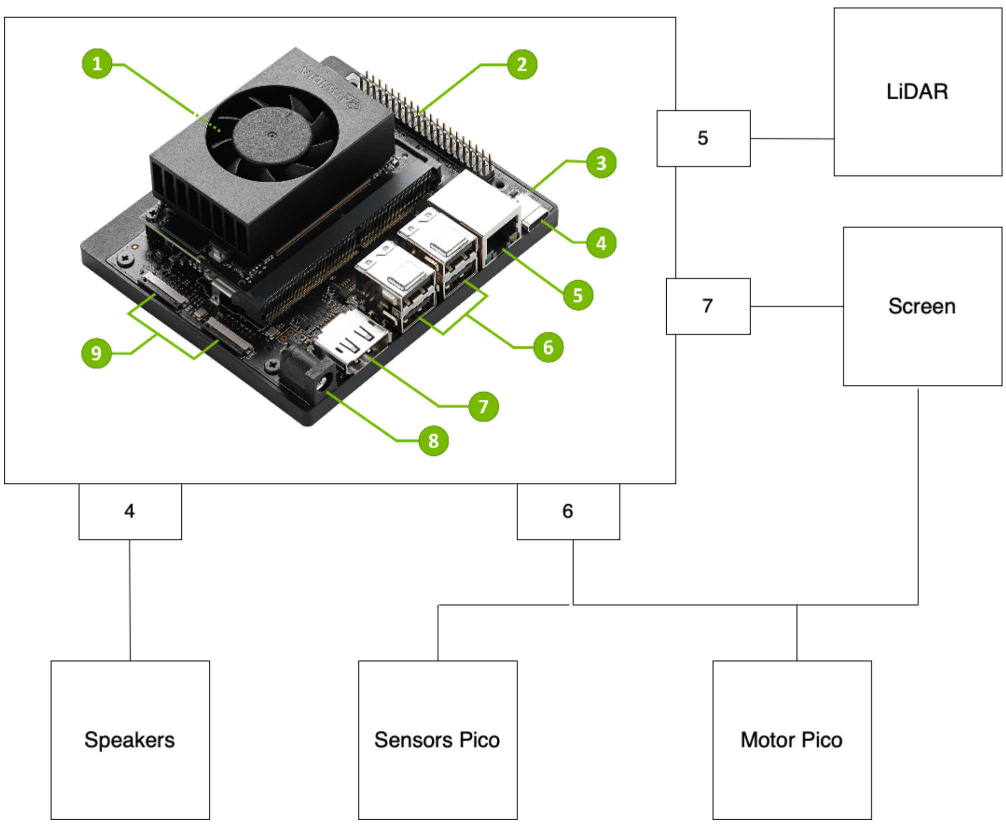

Figure 4: Computing Design

and IMU are connected to I2C because it simplifies communication with those sensors and reduces the number of pins on the microcontroller. They can all be connected to the same two pins. The fingerprint reader uses UART communication, so it has two pins. The fan control pins are connected to specific pins to avoid overlap on the Pico's PWM channels, and we need 4 PWM pins and 4 tachometer pins. The Pico will communicate with the Jetson Nano Orin over USB using a Serial connection. It can use MicroROS to communicate directly with other ROS2 devices (like the LiDAR) and software. This will simplify communication and how we read the data from the sensors. Figure 5 shows the data path for all the sensors.

- **LiDAR**: LiDAR sensor affords high-resolution data by sending out thousands of laser signals. These lasers bounce off objects, returning to the sensor where we can then determine how far away objects are by timing how long it takes for the signal to return. We are using it as our main obstacle detection sensor because it is both higher resolution and field of view then ultrasonic sensors, and is more accurate at giving the correct distance to an object compared to a camera. LiDAR sensors can also be used for mapping navigation, which will be discussed later.

- **LiDAR Data Description:** LiDAR data is described as a "point cloud." It is a collection of thousands of different points with an X, Y, and Z position relative to the origin (the sensor) and the intensity of reflection at that point. The ROS2 pointcloud documentation provides a specific description of the point cloud data.

- **Ultrasonic sensors**: These sensors utilize high-frequency sound waves - typically above 20KHz which is beyond the hearing range for humans (hence the term ultrasound) - to detect objects and possibly measure distances. These low-cost and power-efficient devices emit ultrasonic pulses in a set direction - if there is an obstacle, the sensor's receiver will detect the reflected sound wave. The flight time of the sound wave can thus be used to approximate the distance to the obstacle. These are useful in detecting transparent objects (where optical sensors suffer) 5 regardless of color or lighting conditions at a distance ranging from a few centimeters to meters, depending on the model. On the BAD, these would aid the patients in navigating narrow spaces, sensing crowded environments, and complement other sensors well. It is, however, to be noted that these sensors could be blocked by certain clothing materials that absorb ultrasonic waves and that one single sensor has a relatively low field of view. They can also have a short range, depending on the specific sensor.

- **PIR**: Ultrasonic sensors utilize high-frequency sound waves - typically above 20KHz which is beyond the hearing range for humans (hence the term ultrasound) - to detect objects and possibly measure distances. These low-cost and power-efficient devices emit ultrasonic pulses in a set direction - if there is an obstacle, the sensor's receiver will detect the reflected sound wave. The flight time of the sound wave can thus be used to approximate the distance to the obstacle. These are useful in detecting transparent objects (where optical sensors suffer) 5 regardless of color or lighting conditions at a distance ranging from a few centimeters to meters, depending on the model. On the BAD, these would aid the patients in navigating narrow spaces, sensing crowded environments, and complement other sensors well. It is, however, to be noted that these sensors could be blocked by certain clothing materials that absorb ultrasonic waves and that one single sensor has a relatively low field of view. They can also have a short range, depending on the specific sensor.

- **IMU**: An IMU (inertial measurement unit) is a sensor that can read acceleration and gyroscopic data. These are referred to as 6-axis IMUs. Some IMUs (called 9-axis IMUs) can also read their heading using a magnetometer. We are using a 9-axis IMU because it will give us information about the wheelchair's acceleration, and we can use the magnetometer to figure out which direction the wheelchair is moving. The direction of movement is the most important for self-driving, so we picked a 9-axis IMU. However, the acceleration will also ensure the patient is comfortable. If it detects any abnormal acceleration, such as gravity not facing down, we can tell that something is wrong with the wheelchair and notify a caretaker.

- **Joystick**: The joystick we picked is small and should be easy to move for someone even if they don't have fine motor controls of their fingers. Electrically, the joystick has two potentiometers representing the X and Y axes. To determine the stick's position, we need to read the voltage on each of the middle pins and then combine them in software. To do this, we use a 16-bit ADC to make the reading precise. One challenge with our joystick is that the resistance on the two potentiometers is different, so our software needs to be calibrated to compensate.

- **Biometric**: Mainly used for biometric authentication systems, capacitive fingerprint sensors can verify authorized hospital staff / personnel to make changes or set destinations for the BAD based on unique patterns in each person's fingerprint features. These cost-effective, easy-to-integrate sensors are durable even under heavy use from varying skin moisture levels. Apart from user authentication, these optical fingerprint sensors can: (i) leverage personalized settings as different patients might need adjustably different physical wheelchair configurations; (ii) ease the hospital staff (physicians, nurses, caregivers...) in securely accessing appropriate medical data (health records, care instructions...); and (iii) make the BAD more user-friendly.

4.3.2 Self-Driving System

- **Map Design**: To design the map, we combine the odometry and sensor data, to create a map of the area while estimating the location of the wheelchair in it. It will help us to navigate the wheelchair to specific locations in the presented map autonomously. For that purpose, a node first takes the map computed before (which is also updated constantly) and creates another one, presenting how risky or safe it is to traverse a specific area in the form of a cost function. Then, a planner node takes that cost

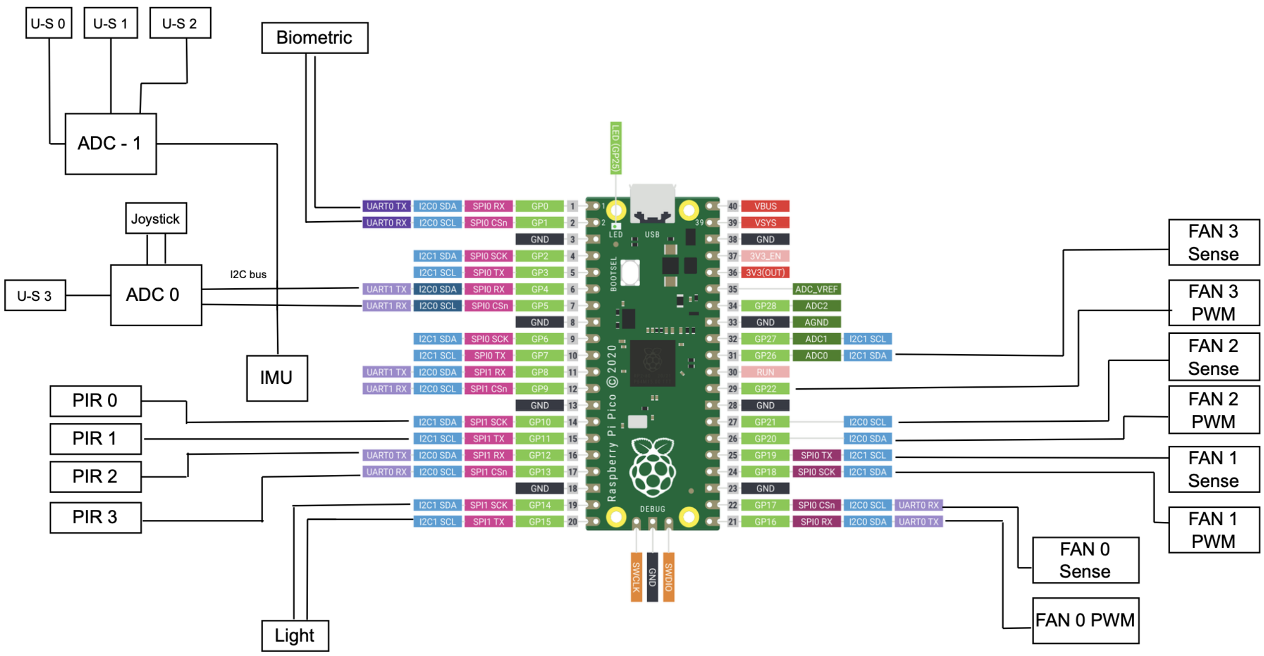

Figure 5: Computing Design

function and computes the most efficient path to get to the goal, and a controller node takes that path and converts it to instructions for the robot, in terms of the velocity commands. We can create various backup nodes to make the wheelchair recover from an uncertain/risky situation. All the nodes are updated each time a new map & location is computed.

- **Obstacle Detection**:
  - **Filtering**: To process raw LiDAR data, we first apply a filtering step to remove irrelevant or noisy information. The data points are converted into voxels of a specific dimension, which will help us structure the information for efficient processing. Points falling outside our defined spatial limits will be excluded from the dataset. Additionally, any roof points captured by the sensor are identified and removed using height thresholds or geometric filtering methods.
  - **Segmentation**: Following the filtering process, we segment the data to distinguish roads from other objects in the environment.

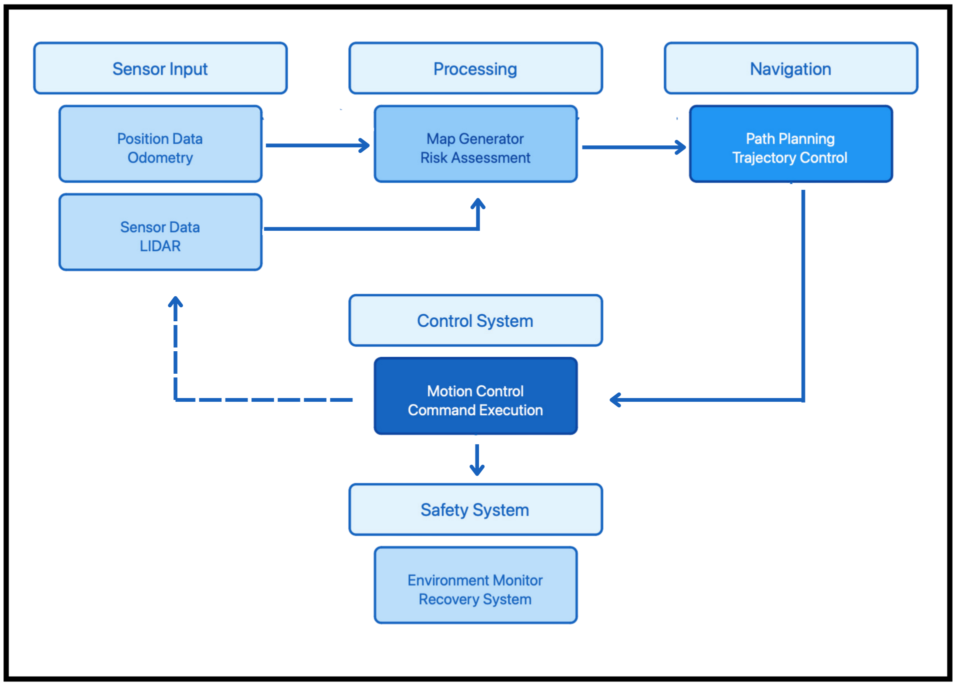

Figure 6: System architecture for autonomous navigation

- **Clustering**: Once objects are identified, clustering techniques will be employed to group points into meaningful clusters. For each identified cluster, a bounding box is generated to encapsulate the spatial extent of the object.
- **Visualization**: Finally, the processed data is rendered for visualization. Roads and objects are displayed using a rendering library, with distinct colors or markers

4.4 Electrical System

- **Connections**: The LiDAR sensor uses an RJ45 Ethernet port to connect to a computer. It has its own SDK from which to read data, but we are using ROS2 Humble instead because it is easier to work with, and most software for processing LiDAR data is written for ROS. The LiDAR can accept 9-27V DC, although the manufacturer recommends using 12V, which is what we are using to power it. It consumes 18 watts for around 6 seconds before dropping down 6.5 watts for as long as it is running.

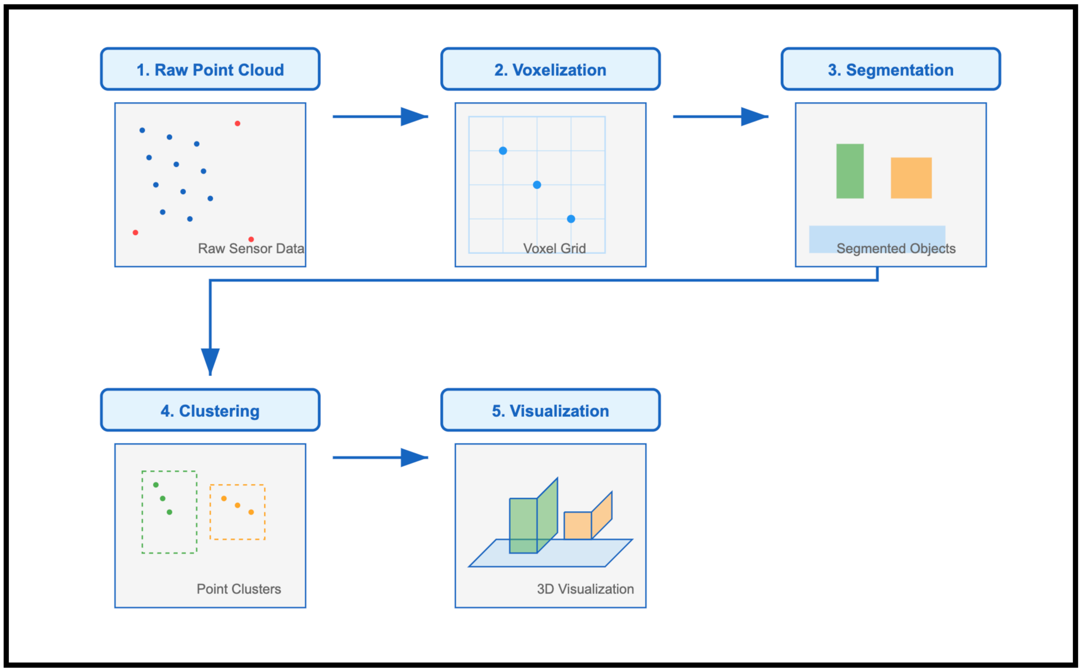

Figure 7: Point cloud processing pipeline: from raw data to voxelization, segmentation, clustering, and 3D visualization

- **Screen & Frontend**: The front end that the user will interact with will be a touch-screen. The screen will be mounted to the baseplate and be positioned near the right arm of the wheelchair. The screen will display relevant information to the users while allowing the user to control certain functions of the wheelchair. The screen we will be using is the Waveshare 13.3" HDMI Touch Display. The screen has an overall size of about 337 mm or 13.3" (Diagonal). The screen is powered by a 12 V / 1 A source using 12 W of power. The voltage regulators will provide the 12 V. In addition to the power supply connection, the screen will have two connections to the Jetson Nano. First, there will be a display port for an HDMI cable connection, and second, a USB-A to USB-micro connection for touchscreen capability. The screen will run an application using the Electron Framework. Electron is a framework that is used to build desktop applications on various operating systems using JavaScript, HTML, and CSS. The application will be a touch-based application that will be easy to interact with.

The application will show specific user profiles and prefaces based on who is using the wheelchair, this will be locked behind login information tied to our biometric sensor. Necessary information that the user must be shown will include speed, battery charge, user status (who is logged in), and position (a simple visual map). The user will have control over most importantly a brake button. Additionally, the user will be able to select what mode the light operates in (steady or operating) and what alert audio the speakers play/ volume level. Finally, the application will not require internet connection, the Electron Framework supports creating offline applications. This will allow the frontend of the wheelchair to function even if the Jetson Nano is not connected to the internet. Side Note: The touchscreen has a 3.5 mm jack that we might use for the speaker connection, this will be further discussed in the speaker section.

- **Warning Light**: The light we will be using is the Menics ASG, shown in Figure 8. The light uses 12 V / 0.67 A and 8 W. The voltage regulators will provide the 12 V. The light features two modes, steady and rotating. Our design will allow the user to control these modes from the frontend application.

  The light will be physically mounted on a support beam above the headrest. The dimensions of the light are 86 x 143 mm (3.4 x 5.3"), shown in Figure 9. To digitally control the light we will use the Raspberry Pi Pico along with a transistor setup to act as a relay. As shown in Figure 9 we can control the light mode by switching on and off the 12 V supply to the Red & Blue wires. The other two wires are the 12 V supply and GND. We will use two pins from the pico and drive them to optocouplers which will then drive the gate of the transistors. The source to drain gates will drive the switched on/ off 12 V. We will use optocouplers to ensure the pico is safe and remains operational, as the pico cannot take 12 V.

- **Speaker**: The speakers we will use are the Creative Pebbles V2, shown in Figure 11. These are a pair of speakers that will be mounted to the left and right sides of the

Figure 8: Menics ASG Beacon Light

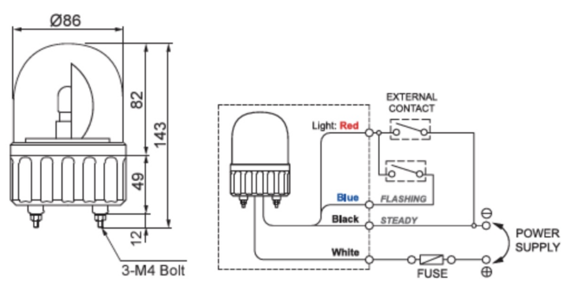

Figure 9: ASG Light Dimensions & Wiring

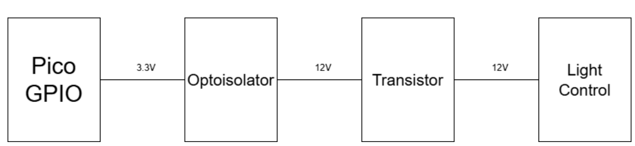

Figure 10: Controlling the light with Pico

base plate. These speakers use 8 W of power from a USB-C supply. There are two wired connections the speakers will need to operate. First is the USB-C as previously mentioned. This will be a direct connection from the Jetson Nano. Second is a 3.5 mm audio jack. There are two ways we can connect the audio jack; first is from the screen, so the data flow would be Jetson Nano → Touch Screen → Speakers. Our second option is to purchase an adapter and connect the audio jack directly to the Jetson Nano. This decision will be made after we test the Screen to Speaker with the Jetson Nano. Audio will be played while the wheelchair is in operation. Furthermore, from the frontend users will be able to select audio options/ preferred moving sounds and control volume level.

Figure 11: Creative Pebbles V2 Speakers

- **Database**: The proposed database structure is a NoSQL database. NoSQL databases are efficient at storing large amounts of data and feature quick reads and writes. Apache Cassandra is an open source NoSQL distributed database. While Cassandra is usually used alongside networks to create distributed database structures, we can use it as a single local database, so we will not require internet connection or cloud storage. Our current local data storage is a 64 GB Micro SD Card, more storage can be purchased if required.

  There will be two main use cases for using a NoSQL database in conjunction with our design. The first use case is to use the database to store simple data which will include user information (biometric data & user profiles) and audio files (audio option for specific users). This will allow the application to be more customized for each user.

The second user case is storing mapping information from LiDAR. Depending on how efficiently we read data from the LiDAR and process that data to perform self driving we will want to consider storing data in a NoSQL database to improve operational efficiency. Mapping information that might be stored would include the global map and the current instance of the local map being sensed. Currently this is a backup idea to improve efficiency if necessary, the algorithms and computations we plan to perform might already be able to handle the LiDAR data efficiently. So this part of the database will be determined in the future via testing.

4.5 Motor Design

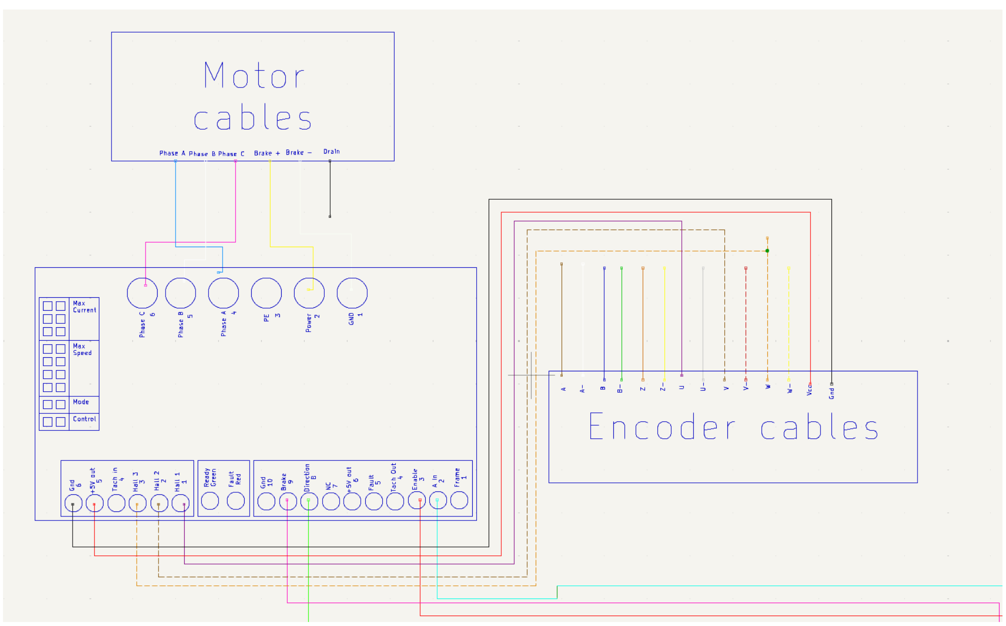

Figure 12: Motor design wiring diagram for the motor and controller.

The motor requires the phase and hall sensors to be connected to be able to safely operate and for controllers to be able to work (Fig. 12) . The brakes will be connected to power and to ground to release the brakes, allowing the motor to turn. When not connected to power, the brake lock prevents the motor from moving, acting as an emergency brake or parking brake for our wheelchair.

For the controller to calculate and control the speed of the wheelchair, the controller reads the Hall sensors from the motor which are signals U, V, and W. The rest of the signals will be left floating to reduce the signal's noise. Additionally, some of the controller inputs will be coming from the microcontroller that will control brake direction speed and allows the motor to start turning.

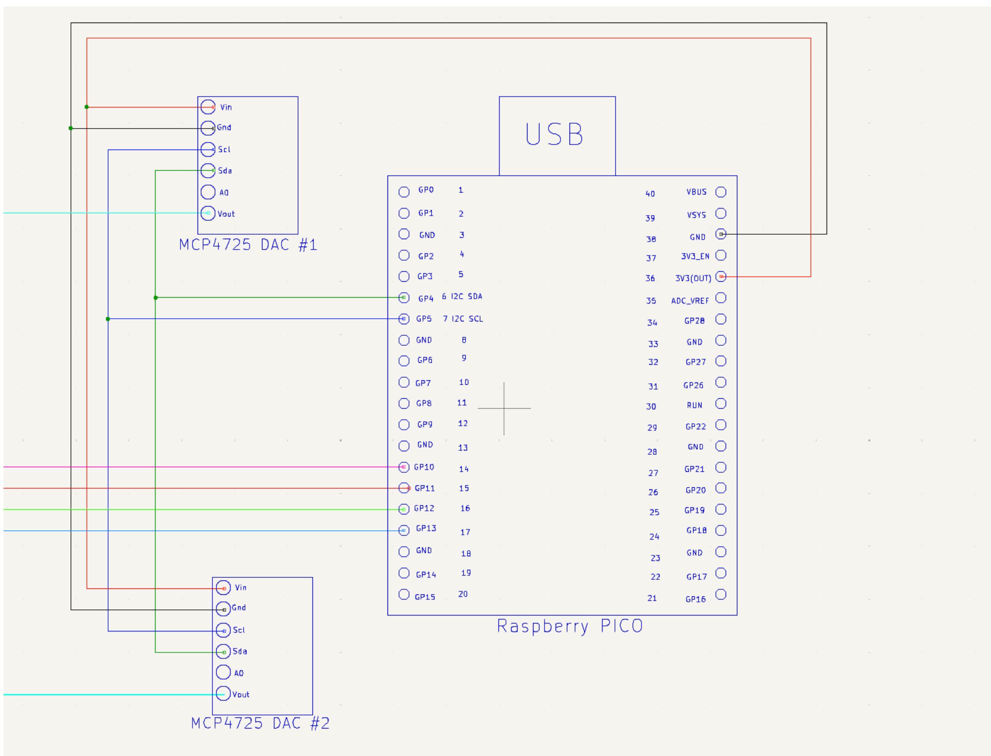

Figure 13: Wiring diagram for using the motor controller via a microcontroller

The wiring diagram in Fig 13 includes the two DACs and Pico that are responsible for controlling the motor operation by sending signals to the controller which includes direction speed enable and brakes. Our controller requires an analog signal to tell the motor what speed to operate at but our Pico only sends out a PWM signal so to convert the signal from digital to analog we connect the GPIO pins to a DAC that converts our digital signal to analog lastly we need to add amplifier that boasts the voltage from the Pico from 3.3 volts to 9.9volts which will work for our controller range of 0-10 volts. The rest of the signals that we need for our controller need a digital signal that does not require any conversion so they can be directly connected right to the controller from the pico. Lastly, our Pico will receive signals from Jetson Nano for what operations the motors need.

5 Schedule

Figure 14: Schedule for next semester

6 Deliverables this Semester

6.1 Physical Wheelchair

6.1.1 Previous Design

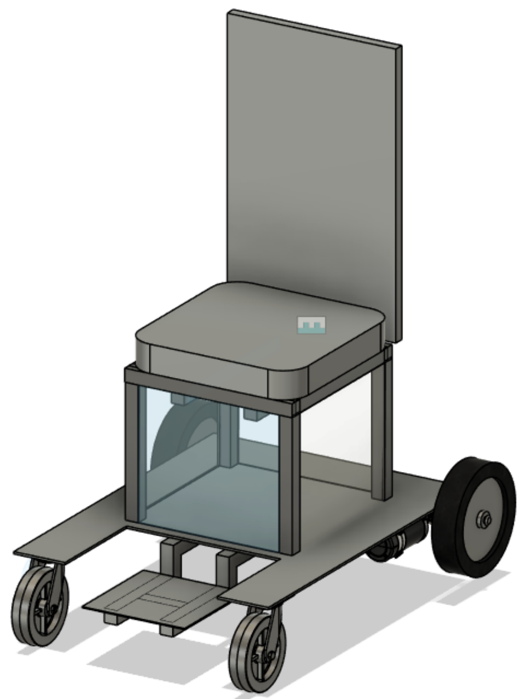

Figure 15: Earliest design of the wheelchair. Drawing created in Autodesk Fusion.

The design above was inspired by multiple research into different types of wheelchairs on the market and one currently sitting in our advisor's lab. This preliminary design drew upon different requirements we created but were not coherent together. Multiple improvements were needed as the first iteration did meet some of our requirements but was not practical in building a real model. The first and foremost problem to address was that the motor and wheels are going to be directly connected to the base plate which in normal circumstances are great implementation but in this design, the base plate only measures up to a 1/8 inch thick, with the weight of close to 200lb requirements the base plate will suffer a significant bending problem. Another problem that was connected to the base plate as well was the base frame as you can see above, there are only four points of contact between the base frame and the base plate. This will allow the base frame to deform. The last most important problem was the footrest. In the above figure, the footrest was seen too close to the ground with which the will be a big obstruction when installing the Lidar sensor. Another issue was that the size of the footrest was either too small or expanding it would obstruct the free-turning front wheel. With these problems in mind, we went to seek help from experts in the field of mechanical engineering for some advice namely, Professor Scott Hummel from the Mechanical Engineering department and Marvin Snyder from the Machine Shop at Lafayette College. Professor Hummel was a huge help in guiding the calculations of the various elements in the design that would prevent bending and fracture problems in the wheelchair while Mr. Snyder was very helpful in verifying the practicality of the new solutions. Numerous consultations resulted as below, the ways we tackle these problems.

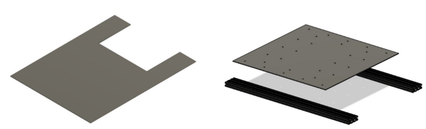

Figure 16: The figure above shows the side-to-side comparison of the before and after of the base plate. To stabilize the base plate and provide a strong foundation for mounting the motor and caster wheel. We concluded the use of the 1 by 3 inch thick 80/20 aluminum, will provide more than enough solid support for the 200lb load requirement in our design.

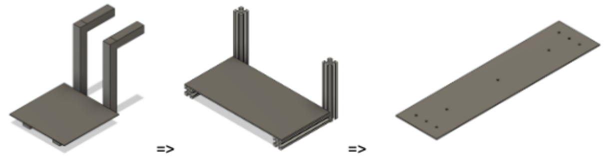

Figure 17: The figure above depicts the different stages of improvement to the footrest design. The final solution to the footrest problem is to raise the footrest to the height of the base plate as there will be no more obstruction to the front free turning caster wheel and it will provide ample space for installation of various other sensors if needed beside the LiDAR.

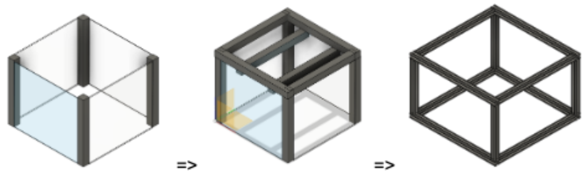

Figure 18: The figure above shows the improvements in the base frame. The base frame is arguably the most important structure in the design as it houses all the important electrical components and power supply. By the rule of safety first, it should be the most secure structure in the design above to withstand more than just the load but also protect the important assets inside. The final design went back to the most primitive structure that provide the most secure connection and resistance to deformation.

6.1.2 Final Design

The final design is a fully realized design that is built for the most stability and durability. The base frame and base plate are connected using the 8020 aluminum unique structure with adjustable screw placement. The iron plate below the chair will be connected directly to the three 8020 aluminum which will be securely placed on the base frame. The base plate and footrest are connected in a way that is most secure to the 1 by 3 inch 8020 aluminum by using 3 18 inch long 1 by 1 in 8020 aluminum. This will secure the base's most powerful connections, resistant to bending, and provide a placeholder for sensors to be connected in the future. The motor and the caster wheel will be connected directly to the 1 by 3 inch 8020 aluminum resulting in the strongest foundation for the wheelchair. All joints in this design will be reinforced with corner brackets and T-brackets which will further provide strength and durability to the design.

From the final design, we have worked with the Machine Shop to craft different components required for building the frame and the base. We have put the base, the frame and the chair together now waiting for the rest of the group the finalize their components, design and where everything would be mounted on the wheelchair to further the construction of the whole wheelchair. Below are drawings submitted to the Machine shop for crafting the components:

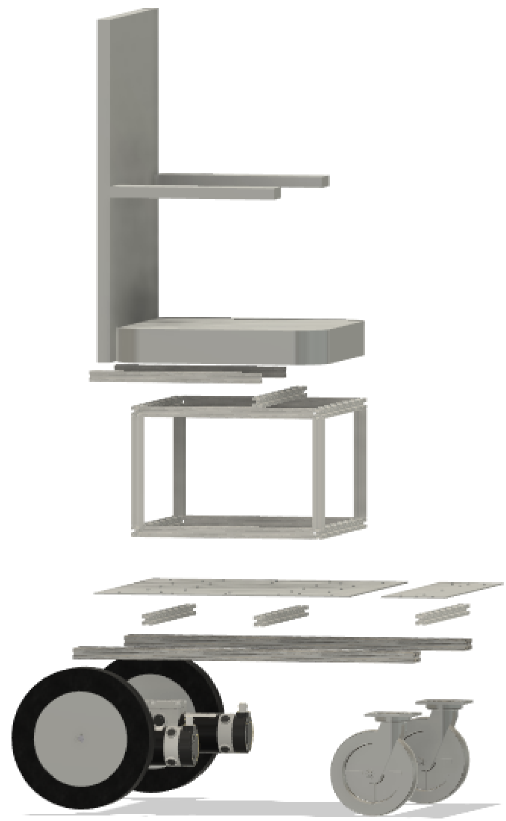

Figure 19: This is a layout view of how the final design structures are connected.

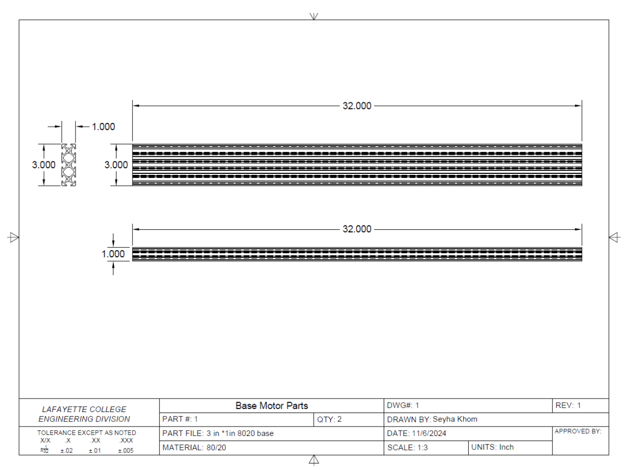

Figure 20: This is a drawing sent to the machine shop. This drawing is requesting from the machine shop to cut 80/20 that is 3 inches by 1 inch in size. There are two pieces cut both at 32 inches long. These pieces are used underneath the aluminum plate of the wheelchair to properly hold the motors and the front wheels.

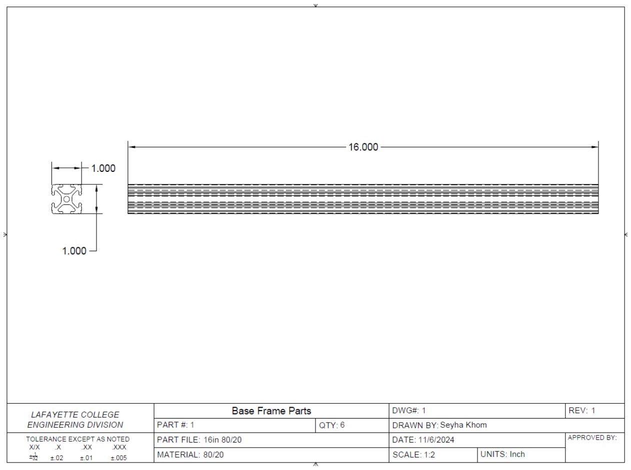

Figure 21: This is a drawing sent to the machine shop. This drawing is requesting from the machine shop to cut 80/20 that is 1 inch by 1 inch in size. There are six pieces cut at 16 inches long. These pieces are used for the left and right of the box containing the electronics.

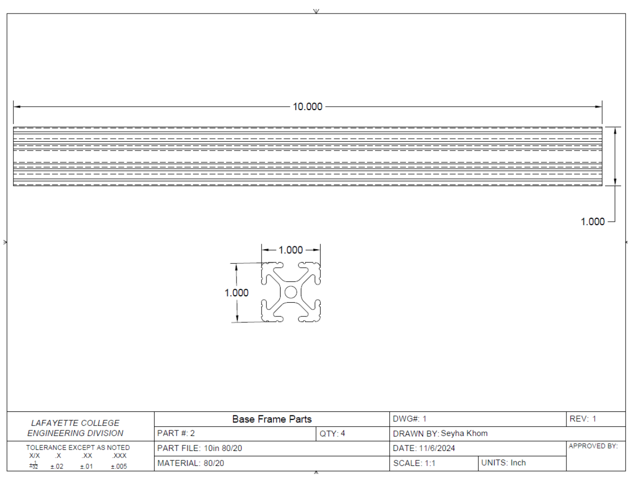

Figure 22: This is a drawing sent to the machine shop. This drawing is requesting from the machine shop to cut 80/20 that is 1 inch by 1 inch in size. There are four pieces cut at 10 inches long. These pieces are used for the corners of the box containing the electronics. These pieces are placed vertically.

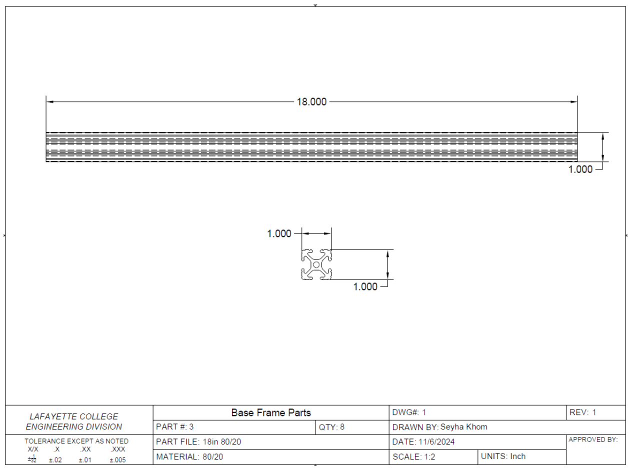

Figure 23: This is a drawing sent to the machine shop. This drawing is requesting from the machine shop to cut 80/20 that is 1 inch by 1 inch in size. There are eight pieces cut at 18 inches long. These pieces are used for the front and back of the box containing the electronics.

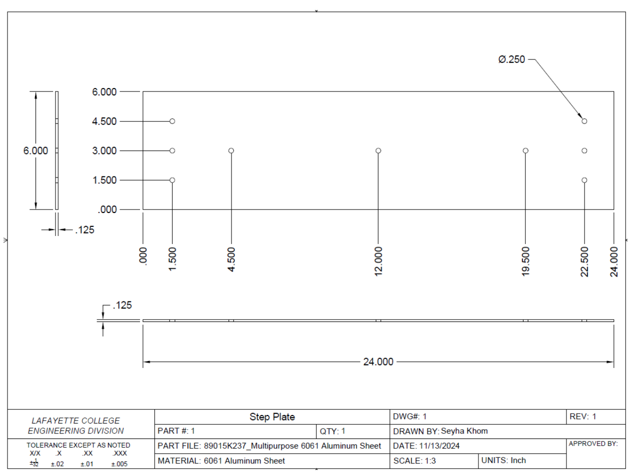

Figure 24: This is a drawing sent to the machine shop. This drawing is requesting from the machine shop to drill holes into the aluminum sheet. This drawing specified how many inches each hole should be drilled from the corner as well as specifying the diameter of the holes. These holes are necessary for placing screws through the aluminum to connect the 80/20 to the aluminum.

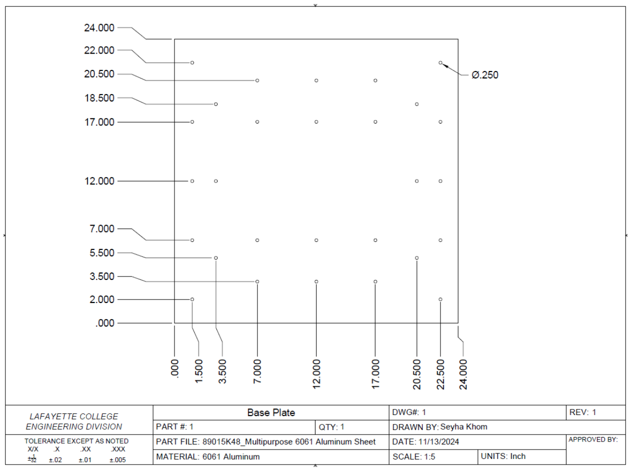

Figure 25: This is a drawing sent to the machine shop. This drawing is requesting from the machine shop to drill holes into the aluminum sheet. This drawing specified how many inches each hole should be drilled from the corner as well as specifying the diameter of the holes. These holes are necessary for placing screws through the aluminum to connect the 80/20 to the aluminum.

6.1.3 Box Design

This semester, we have determined many parts that need to be placed inside the box that is underneath the wheelchair. The box is structurally supported by 80/20 pieces and will be covered by PVC to enclose the box.

Fans are required to cool down the pieces contained inside the box. The fans chosen are the Arctic P14 fans after looking at multiple different options. These fans are 140mm by 140mm. This semester, we researched the connections that standard 140mm PC case fans use so that we could control them with the Raspberry Pi Pico. We designed a circuit that should be able to power the fans and read the signal back. The fans will be placed to optimize the air flow to ensure the electronics are properly cooled. The back wall will contain two fans to pull the air out and the sides will contain two fans to pull the air in. They will be attached by screwing them into the PVC pieces.

The battery will be placed towards the front of the box. This is to disperse the weight across the wheelchair. The dimensions of the battery are 6.93 inches by 13.07 inches with a height of 8.66 inches. There will be two shelves within the box as well. The shelf will be

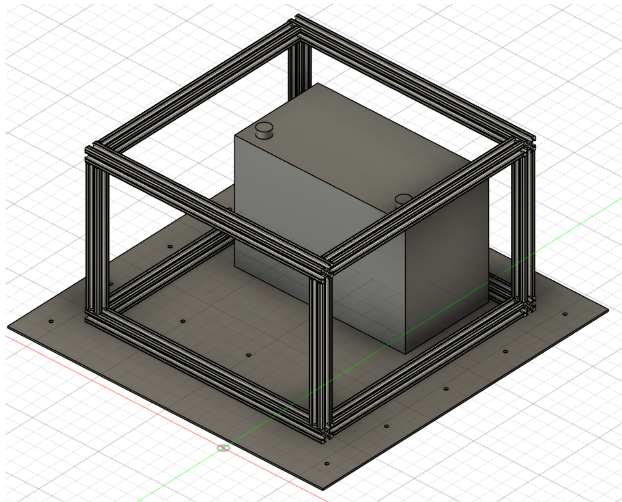

Figure 26: The placement of the battery inside the box. As shown, the battery is placed towards the front of the box, which leaves enough space for the rest of the parts.

made of 1/8 in PVC.

On the top shelf will be the Jetson Nano Orin with the dimensions of 100mm by 79 mm by 20 mm. The Jetson Nano will be placed towards the back of the box to avoid getting too overheated from the battery as well as allowing it to be cooled well. The microcontroller PCB will also be placed on the top shelf. The Microcontroller PCB and Jetson Nano need to be close together since they will have cables running between them. Both of them will need to have cables that can run to other parts of the wheelchair for various sensors. This will be done by drilling holes into the PVC or aluminum plate to run wires through.

The bottom shelf will contain the two motor controllers, two DACs, one Raspberry Pi Pico, and one power distribution board. The motor controllers will be placed closer to the back so they are as close as possible to the motors. The motor controllers are 3.1 in by 3.2 in by 1.15 in. The Raspberry Pi Pico will be placed near the motor controllers to ensure there are short cable connections to each other.

Throughout the process of designing and building this wheelchair, our group has sought guidance and assistance from the Engineering Machine Shop. Marvin Snyder was instrumental in helping the team bring this project from conceptual designs to a constructed chair. Through numerous conversations with Marvin, the physical subgroup worked to iterate the design of the physical wheelchair, including the base plate, box, and frame components. The physical subgroup worked to create a wheelchair design which evolved over the course of the semester, with input from other group members, Marvin, and Professor Yu. Once the Autodesk Fusion 360 designs were approved by Marvin, the group sought approval from Professor Yu. From there, the team was able to submit the drawings to the Machine Shop and order the appropriate materials.

The Machine Shop assisted the group by providing 80/20 aluminum to construct the box that supports the chair, and the accessories needed to attach pieces. The Machine Shop was also able to help the group drill holes in the appropriate places of the 80/20 and the aluminum base plate, in order to help team members attach the pieces themselves.

6.2 Motor control

A compatible Motor and motor controller were purchased from the manufacturer. In testing motor controller, we have had issues with the motor and the controller. To solve this the group met with manufacturers to get the motor working After 2 weeks after getting the motor, the motor is running as expected, and plan to work on controlling the inputs for the controller We also plan to control input signals.

6.3 Screen and Frontend

We tested the touchscreen with the Raspberry Pi and confirmed the screen is operational. Furthermore, we ordered the cables required to connect the screen to the Jetson Nano. Regarding the frontend application, some basic prototyping and experimentation with the Electron Framework has been done, but no big developments regarding a live demo. Physical design for the screen mounting arm will still need to be finalized.

6.4 Database

Mainly considered the primary use cases for a NoSQL database. Further development will occur once live LiDAR data is able to be accessed along with the Jetson Nano.

6.5 Light and Speakers

Both the lights and speakers we plan to use were determined, and a purchase request will be put in next semester. Furthemore, I did research into how to safely control the light using optocouplers and transistors. How the lights and speaks will be attached still needs to be finalized.

6.6 Voltage Regulators

After extensive research and evaluation of various voltage regulator options, we concluded that the LM2596 DC-DC Buck Converter Step-Down Module Power Supply was the optimal choice for our project. This decision was based on its balance of performance, efficiency, and affordability compared to other solutions. The module's specifications include an input voltage range of DC 3.2V to 35V, with the condition that the input voltage must be at least 1.5V higher than the desired output voltage, as it does not support boosting. The output voltage is continuously adjustable between 1.25V to 30V, with a maximum output current of 3A and high efficiency.

6.7 Sensors

6.7.1 LiDAR

We bought the Livox Mid-360 sensor because it has good 3D LiDAR capabilities while not being as expensive as other options, which cost thousands of dollars. We connected the LiDAR sensor to a Raspberry Pi and an Ubuntu desktop computer. This allowed us to read data from the LiDAR using ROS2 Humble and use a visualizer to see what the LiDAR "sees." This allowed us to make a more informed decision about utilizing the sensor. We also tested a few libraries, like Glim, with the sensor but did not create the map of the floor.

6.7.2 Ultrasonic and PIR

We propose using the URM09 Analog Ultrasonic Distance Sensors, the signals of which can be converted to digital via the ADC board and having different I2C addresses which will be used by the Pico. As for the passive infrared sensor, we will be using the Panasonic EKMC1605113 horizontally wide PIR detection sensor so that we only need one PIR and one ultrasonic sensor in each direction (forward, backward, left, and right) of the wheelchair. This will allow detection of up to 5 meters with field of view up to 122 degrees.

6.7.3 Joystick

This semester, we got a prototype of the joystick working to verify the design and improve it. As discussed above, the joystick uses two potentiometers to determine the stick's location. This means that we just need to power the joystick and read the middle pins' voltage to figure out which way the user is pushing the stick. To do this, we are using the Texas Instruments ADS1115, a 16-bit analog-to-digital converter. The ADS1115 has four channels to read an analog signal, which allows us to read the two pins for the joystick and have two pins left for other sensors. The ADS1115 uses I2C to communicate with a Raspberry Pi Pico microcontroller, which processes the signal into a signal for each wheel. In this case, that signal is the wheel's speed as a percentage of the maximum speed and a direction using positive and negative numbers. Because the potentiometers on the joystick have different values, some signal processing needs to be done to ensure that the chair behaves intuitively. The wheelchair has two types of special zones. A dead zone is applied when the stick is in its natural position to ensure the wheelchair doesn't move when the joystick isn't pressed due to analog errors. A zone is also applied when the user presses directly forward and backward to set the wheel's speeds to the same manually so the chair doesn't drift. A diagram of those zones is pictured below.

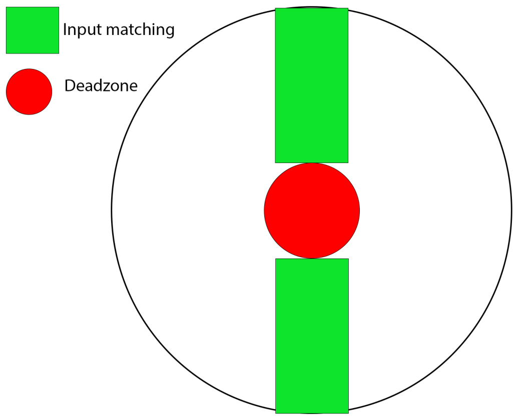

Figure 27: Deadzones for the Joystick Prototype

We bought demo boards from Adafruit containing the ADC to prototype the joystick. This allowed us to breadboard the circuit and write the code to verify it worked. However, putting those boards on the final wheelchair would take up much space and require lots of unnecessary wiring. To reduce the size of the joystick circuit, we started designing a custom PCB into which we would plug the joystick module, and then it would connect to the microcontroller at the center of the chair. Pictured below is the schematic and design for the PCB.

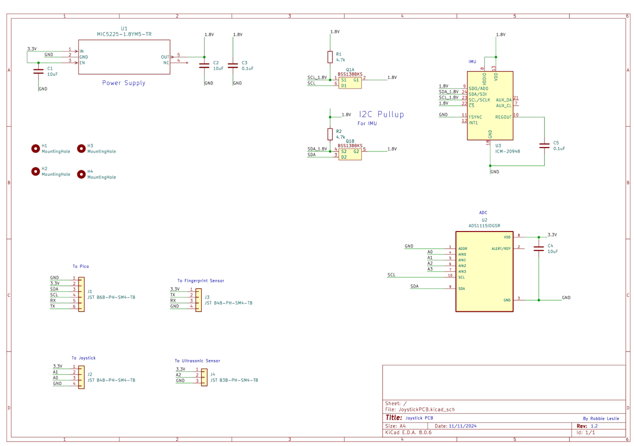

Figure 28: Schematic for the Joystick

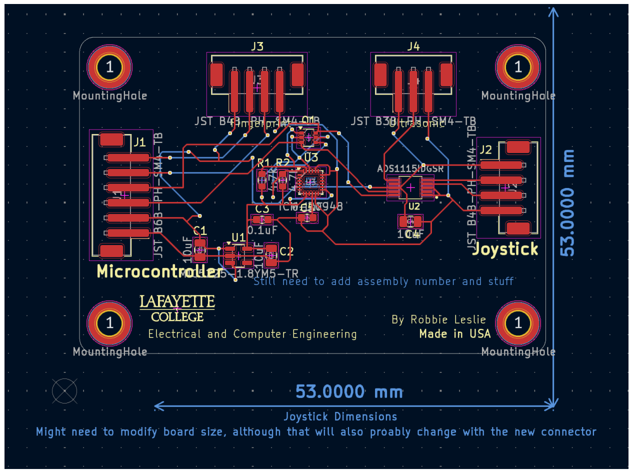

Figure 29: PCB Layout for Joystick

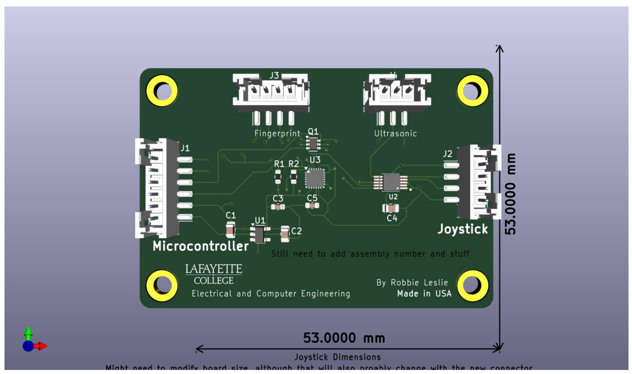

Figure 30: 3D View of the Joystick PCB

Finally, a housing for the joystick needs to be designed. This housing will hold the joystick module, PCB, and an ultrasonic sensor. However, there is no 3D model of our joystick that we can download to reference during the creation of the box. As a result, we started modeling the joystick in Fusion 360 so that we can use it as a reference. Below is the initial version of that 3D model.

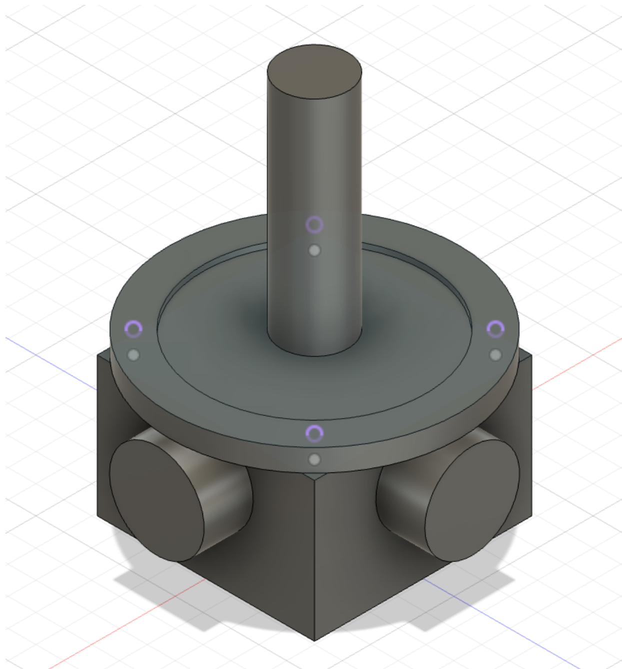

Figure 31: 3D Model of Joystick

6.7.4 Overall Design

We started a KiCAD drawing for the PCB for the Raspberry Pi Pico which reads all the data from the sensors. It has connectors for all the different sensors on the wheelchair, and connects the data to the specific GPIO we selected. Right now it is missing a few parts for connecting the light and the PWM for the fans.

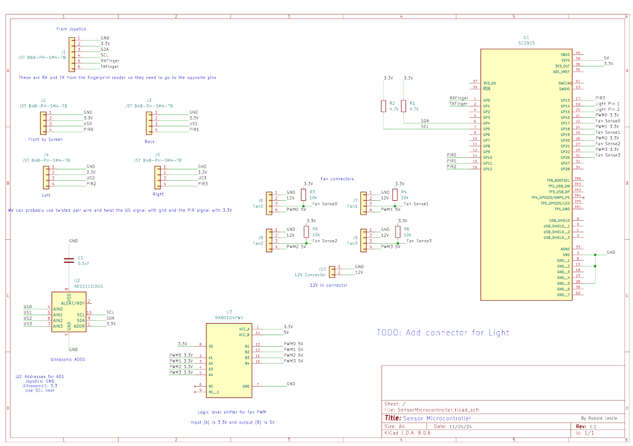

Figure 32: Schematic for the Pico PCB board

6.8 Networking

Initially, we had planned on using a computer not physically on the wheelchair, to process the LiDAR data because that is a computationally heavy task. This would allow us to use a lower-power computer on the wheelchair, saving power. We had a few meetings with ITS where they helped set up a network we could use to test ROS2 over WiFi, and then they helped us determine that we could use a Raspberry Pi as a ROS discovery server on the main Eduroam network to simplify things. However, we ultimately decided that relying on a computer over the network for something as critical as obstacle detection could have latency problems or, worse, wouldn't work if the network went down. So, we decided against the idea of using the network to process data and switched to the more powerful Jetson Nano Orin for processing.

7 Deliverables Next Semester

7.1 Wheelchair

If unable to be implemented by the end of this semester, then next semester, the wheels and motor should be attached to the chair. In addition, the associated components for the screen, joystick and support, LiDAR, biometric system, lighting, and audio will be attached to the physical wheelchair where appropriate. The screen, joystick, and biometrics will be attached to the armrests. The lighting system, which will consist of a single red warning light, will be attached to the top of the chair. The audio system, in the form of two small speakers, will be attached to the left and right sides of the base plate of the chair. The sensors must also be attached to the wheelchair. Regarding the box, it must be covered on all sides. Assistance will likely be needed from the Engineering Machine Shop to drill holes in the aluminum to run wires through the box walls. In addition, fans must be added to the current design as a form of air circulation. All components of the box must be organized and implemented next semester before testing is to be conducted. Then, testing will be conducted to ensure that the wheelchair can support the weight it must carry. These tests include static and dynamic stability tests; then, other tests to confirm the functionality of components may be run.

7.2 Motor Control

If can not be achieved this semester, we will finish implementing the microcontroller with the motor controller, as well as interfacing the joystick control with the motor control system.

7.3 Joystick

Next semester, we need to integrate the joystick with motors. This will involve sending our speed signals to the motor's microcontroller and then testing driving the chair to see how it behaves. We will need to tune the processing to ensure the joystick moves the wheelchair smoothly and intuitively. We also need to finalize the PCB design for the joystick electrical components, order them, and assemble them. We also need to design and print the housing for the joystick and accompanying components (like an Ultrasonic sensor and the fingerprint reader).

7.4 Converters

Next semester, we will focus on the Test and Implementation phase, ensuring the selected voltage regulators, including the LM2596 modules, meet the system's power requirements. Key components include the Jetson Nano (19V), two Raspberry Pi Pico boards and an alarm (5V), six ultrasonic sensors, four PIR sensors, and four IMU sensors (3.3V), as well as four fans, one screen, one ASG light, and one LiDAR sensor (12V). To support these, we identified the need for two additional voltage regulators: one to step down from 24V to 19V and another from 24V to 12V. We will test and integrate the regulators with all components, ensuring efficient power distribution and system stability. Testing will include validating connections, monitoring performance under various conditions, and verifying that the power network operates reliably to meet project requirements.

7.5 Sensors

We plan to finish implementing and integrating the different sensors next semester. This means we need to connect the ultrasonic and PIR sensors, read their data, and start processing that data and sending it to our self-driving algorithm. We also need to finish the PCB designs for some sensor boards and order and assemble them. We must also design the joystick housing and housing for the other sensors to prevent damage.

7.6 Self-Driving

- Train and fine-tune models for real-time obstacle detection using sensor data
- Design and implement map visualization capabilities using the SLAM (Simultaneous Localization and Mapping) algorithm.
- Develop code to process data from multiple sensors simultaneously.
- Write the core "operating system" logic to control wheelchair movement
  - Define actions based on sensor inputs or combinations hitting predefined thresholds.

8 Qualification Test Plan For Systems

Refer to the Safety Plan and Review for a detailed description of general and specific safety procedures which will be adhered to by all team members who are involved in the testing process.

8.1 Wheelchair

8.1.1 Static stability

To test static stability, we will follow the procedures outlined in the ISO 7176-1 "General test procedure" section. The forward test setup is as follows:

- Adjust chair to be in the least stable configuration for forward stability.
- Then set the chair on a zero degree platform to face down the slope itself.
- Orient all wheels to be set forward and set the wheelchair to run down the slope.

The rearward test setup is as follows:

- Adjust the chair to be in the least stable configuration for rearward stability.
- Then set the chair on a zero degree platform to face up the slope itself.
- Orient all wheels to face the slope.
- Set up rear wheels to be unlocked

The testing process begins with the slope of the platform starting at zero. Increase the slope at 0.3 degrees per second until it reaches the tipping angle, which should be around 3 degrees. Ensure that the floor will not inadvertently affect the test in any possible way. Reassure the position of the test dummy and ensure that the chair does not move in any way.

8.1.2 Dynamic stability

- For dynamic stability testing, set the wheelchair to least stable configuration. Begin testing at lower wheelchair speeds, and gradually increase speed with every repeated test.

- For forward movement, position the wheelchair on the horizontal plane, and accelerate the device forward and observe the response. Then repeat the process on inclines of 3 degrees, 6 degrees, and 10 degrees.

- For braking when moving forward, position the wheelchair on the horizontal plane, and accelerate the device forward at maximum speed, then apply retardation to the acceleration device. Then repeat the test, but turning the chair off as it moves. Then, repeat the test on a 3 degree, 6 degree, and 10 degree plane.

- To test uphill braking, position the wheelchair on the horizontal plane, and accelerate the device forward at maximum speed up the hill, then apply retardation to the acceleration device. Then repeat the test, but turning the chair off as it moves. Then, repeat the test on a 3 degree, 6 degree, and 10 degree plane.

- To test downhill braking, position the wheelchair on the horizontal plane, and accelerate the device forward at maximum speed down the hill, then apply retardation to the acceleration device. Then repeat the test, but turning the chair off as it moves. Then, repeat the test on a 3 degree, 6 degree, and 10 degree plane.

- For turning the wheelchair, begin by positioning the wheelchair on the horizontal plane, and accelerate the device left with minimum turn radius for the device until it has made a full 180 degree turn. Then, repeat the test on a 3 degree, 6 degree, and 10 degree plane.

8.1.3 Temperature testing

Temperature testing should be conducted inside of the box enclosure once all necessary components are covered and in place.

8.2 Power Systems

8.2.1 Battery

- Provides correct 24-voltage
- Able to charge the battery to full capacity using an external charger and has a switch to control charging without removing the battery out of the wheelchair.
- Able to see the battery status while in operation using the LCD Display
- Able to power all electronics on the wheelchair with no issues
- Charge the battery using an external charger and include a safety switch for added protection.

8.2.2 Motor

- Test with no load to see if the motor operates safely at the correct voltages and current.
- Test with max load to see if motor can safely with correct voltage and current and make sure no overheating occurs when operating at max load.
- While these test check make sure no short circuits and no noise signals coming from the motor.

8.3 Sensors and Mapping

- Test the SLAM algorithm's ability to generate accurate maps of a predefined test environment.
- Test the ultrasonic sensors' ability to detect obstacles at their rated range between 4cm and 5m.
- Test the PIR sensor's ability to detect a person's presence from all sides of the wheelchair.

- Test the LiDAR's ability to detect a single object in front of the wheelchair.
- Test the LiDAR's ability to detect multiple obstacles in front of the wheelchair.
- Test how the joystick controls the motors to make sure that the wheelchair moves in a fluid motion based on the user's input.
- Test the wheelchair's ability to respond to an obstacle in its way by either avoiding it or stopping.

9 Safety

9.1 Schedule

Drawings for the machine shop should be detailed heavily and approved by them to be used. Failure to get their approval of the detailed drawings will require needing to go back into the drawing and update it overall. The template for the drawings and a set of previously detailed drawings have been provided in the Google Drive folder for the project.

9.2 Safety Instructions for Electrical Equipment

- All participants will follow the detailed safety instructions provided for each type of electrical equipment.
- Have a fire extinguisher near the workstation, and ensure everyone knows its location and operation.
- Avoid working with high-voltage components alone; adhere to the buddy system for battery and motor handling.
- De-energize electrical parts before working on electrical circuitry. Remember to turn off the power supply terminals while debugging and only turn them on for testing.

Make sure all electrical parts (power supply, wave generator, etc) are shut off before leaving the room.

- Keep the bench area dry.
- If you smell anything burning, immediately de-energize the circuit (shut off the power supply) and check the circuit for possible shorts.

9.3 Labeling Wires and Components

- Apply clear and durable labels on all wiring, including voltage indications and warnings for high-risk areas.
- Use warning stickers for critical components:
  - **Battery:** High-temperature and high-voltage warnings.
  - **Circuitry:** Electric shock hazard warning, and authorized personnel-only warnings.
- Label any components left in shared spaces with part numbers and contact information for responsible team members.

9.4 Soldering Lab Safety

Some components, including through-hole and surface-mount device soldering, will need to be soldered during the assembly of our projects. We will need to use the soldering lab to assemble those components. However, the soldering lab contains equipment that can injure users if improperly used. To avoid personal injury, we must follow the soldering lab's guidelines and rules and learn how to use the equipment properly. This includes wearing safety glasses while in the lab and securing long hair and loose clothing. There are signs in the lab with instructions, as well as phone numbers for people to contact in case of an emergency. Extra soldering waste needs to go in the barrel labeled "Soldering waste." Team members were encouraged to attend the IEEE soldering workshop to learn how to solder and use the lab properly. Members are also responsible for cleaning up after themselves to ensure the lab remains clean and safe.

9.4.1 Soldering Iron

The soldering iron is used for through-hole and some surface mount soldering. Because it gets very hot to melt solder, users must exercise caution while using it. They should only hold it by the grip and never touch the tip once the iron has been turned on. When a user is not actively using the soldering iron, it must be placed in its holder so that it doesn't touch anything and burn it. Use the brass wool to clean the tip of the soldering iron. Soldering irons must be turned off while not in use and should never be left unattended.

9.4.2 Boards and Components

Components being soldered will become hot, so team members should only touch recently soldered components once they have had time to cool down. Some elements are also polarized, so team members should understand the markings on the components so they solder them correctly. Soldering components, especially electrolytic capacitors, the wrong way can lead to injury.

9.4.3 Fume Extractor

Solder is made of various metals. When it is heated, it releases fumes that can be harmful if inhaled. The soldering lab has fume extractors that filter the fumes so the harmful materials don't end up in the air. Therefore, whenever users are soldering, they should run the fume extractors and solder near the extractor. When done soldering, turn the fume extractor off.

9.4.4 PCB Oven

For surface mount soldering, the lab has a PCB oven to melt solder paste on a PCB. However, Adam Smith must train users before using the oven, and team members must only use it once they have received training. After users have received training, they must be aware that the boards will be hot when they come out of the oven, so users should not touch the boards until they have had time to cool. Once users are done with the oven, they should put it away correctly to ensure the lab stays clean and the oven isn't damaged.

9.5 24V Battery Protocol

- Cover battery terminals to prevent accidental shorts, and connect them to a switch and power distribution board with fuses.
- If a fuse blows, immediately turn off the power supply/disconnect the battery and identify the current overload.
- Keep battery storage isolated from the system frame and have a universal spill kit ready for any accidental acid or alkaline spills.
- A warning light will indicate battery testing or system operation, ensuring all team members are aware.
- Wear appropriate clothing including insulated gloves and no metal jewelry.
- Use proper insulated tools when working on electrical circuitry.
- Avoid shorting the positive and negative terminals of the battery and de-energize the circuit by disconnecting the battery when not in use.
- Remove excess moisture from the skin by wiping hands before working on the battery and cables

9.6 Voltage Regulators

- Follow all protocols highlighted in section 10 regarding working with high-voltage.
- Before connecting regulators with the battery the validity of the design must be tested.
- The design will be tested with a separate voltage source, additionally, voltage measurement must be taken to ensure the design is correct.
- Ensure proper safety standards when testing including correct wear, emergency shut-off, and use of proper tools for measurements.

9.7 Motor Safety Protocol

- The motor operates on 24 V which can produce a high amount of torque. Securely mount the motor to prevent movement or disconnection during testing.
- Wear safety glasses and appropriate clothing (rubber-soled shoes, no loose clothing, and hair secured) when working near the motor or rotating parts.
- Turn off all power if working on the motor and cables.
- Ground yourself before working on the to prevent any shock or damage.
- Check fuses to see if the circuit is protected.
- Avoid touching the motor after extended use in case the motor temperature is hot.

9.8 Wheel Safety

- The wheels on all ends are supporting the rest of the wheelchair as well. Do not lift the wheels with your hands in any situation to operate on them.
- Wear appropriate safety gear (no loose clothing) when working with wheels as well.

- Turn off all power if working with the wheels.
- If the wheels need to be modified in any possible way, carefully detach the wheels from the assembly and ensure the rest of the wheelchair is positioned properly to ensure nothing is damaged while the wheels are detached.

9.9 Sensors

- **Temperature Warnings:** The LiDAR sensor and the Jetson Nano Orin may heat up during long periods of operation, especially in poorly ventilated areas. Avoid touching the interior of these devices immediately after extended use to prevent damage. Use protective cases where applicable.
- **Cooling System:** Use fan systems/heat sinks wherever possible to maintain an optimal temperature building.
- **High-Frequency Output:** Ultrasonic sensors can emit high-frequency sound waves that can interfere with hearing aids and other devices.

9.10 In case of Accidents

All incidents should be reported to the team and Professor Yu as soon as possible. In case of an emergency, call Public Safety at the emergency number: (610) 330-4444. If there is a non-emergent matter that requires attention from campus officials, call Public Safety at their non-emergency phone number: (610) 330-5330.

A Budget Proposal

Core Sensing & Computing ($1,120.34)

Item	Cost ($)
Livox Mid-360 lidar	820.00
NVIDIA Jetson Orin Nano Developer Kit	299.95
Display Port to HDMI cable	8.54

Drive System ($2,093.81)

Item	Cost ($)
MP24 Right Hand BLDC Motor	604.00
MP24 Left Hand BLDC Motor	604.00
EZ DRIVE FOR BRUSHLESS DC MOTORS (2)	370.00
POWER CONNECTOR KIT (2)	34.00
UNIVERSAL DRIVE I/O HARNESS KIT (2)	90.00
Drive Wheels (2)	82.78
Rubber Caster Wheels (2)	49.68
24V 60Ah LiFePO4 Battery	259.35

Structural Components ($341.21)

Item	Cost ($)
Aluminum Sheet 6” x 24”	29.01
Aluminum Sheet 24” x 24”	82.05
T-Slotted Framing	83.33
Polycarbonate Sheet x4	31.96
Marsail Office Chair	99.97
Wheelchair Seat Belt	14.89

Sensors & Interfaces ($273.26)

Item	Cost ($)
Raspberry Pi Pico (5)	20.00
Joystick	19.95
PIR Sensors (6)	60.30
Ultrasonic Sensors (6)	47.40
IMU	14.95
IMU Chips (3)	24.09
ADC1115 Converter	14.95
Geekworm PD Power Supply	12.90
Arctic P14 Fan Pack	34.00
Fan Molex Connectors (12)	7.08
128GB MicroSD card	17.64

Electronic Components ($174.00)

Item	Cost ($)
I2C to Male cable	1.50
I2C to I2C Cable	1.90
I2C breakout cable	0.95
6 Pin connectors (6)	5.04
4 Pin JST connectors (18)	12.24
2 Pin JST connectors (3)	1.98
3 Pin JST connectors (3)	2.22
PCB Boards	40.00
Various cables and connectors	20.00
0.1uF capacitors (9)	1.35
4.7k Resistors (12)	1.20
10k Resistors (12)	1.20
Optoisolators (18)	36.00
Transistors (6)	12.00
Logic level shifter transistors (3)	0.84
Voltage regulators (3)	1.59
10uF capacitors (9)	7.65
ADS for Ultrasonic Sensors (6)	26.34

Total Project Cost: $4,101.26

B Justifications for the Project Budget

1. **Livox Mid-360 lidar Minimal Detection Range Original**

- Selected for cost-effectiveness compared to industry alternatives
- Provides reliable data for self-driving capabilities
- Comes from a reputable manufacturer
- Internal spinning mechanism avoids passenger distraction

2. **128GB MicroSD card**
   - Originally purchased for recycled Raspberry Pi hardware
   - Compatible with current Jetson Nano setup
3. **Marsail Office Chair Black**
   - Accommodates various patient heights
   - Weight capacity up to 200 pounds
4. **Motor Control System Components**
   - DEESPAEK 24V 60Ah LiFePO4 Battery
   - EZ DRIVE FOR BRUSHLESS DC MOTORS
   - POWER CONNECTOR KIT
   - UNIVERSAL DRIVE I/O HARNESS KIT
   - RIGHT/LEFT HAND OUTPUT SHAFT (21 GEAR RATIO)
5. **Geekworm PD 27W Power Supply**
   - Supplementary power supply for Raspberry Pi 4B testing
6. **NEPPT Wheelchair Seat Belt Restraints**
   - Adjustable safety restraint system
   - Easy integration with existing design

7. **Polycarbonate Clear Plastic Sheet**
    - Environmental protection for LiDAR sensor
    - Guards against dust and debris
8. **12.5 Inch Drive Wheels**
    - Essential for basic wheelchair operation
9. **TI ADC1115 Converter**
    - Enables joystick value reading and processing
    - Facilitates motor testing integration
10. **Joystick**
    - Cost-effective dual-potentiometer design
    - Suitable for users with limited motor function
11. **Raspberry Pi Pico**
    - Affordable microcontroller solution
    - Abundant GPIO capabilities
    - Team familiarity from previous coursework
12. **IMU**
    - I2C bus compatibility verification
    - Integrated joystick prototyping capability
13. **Connection Cables**
    - I2C to Male: Prototype board connections
    - I2C to I2C: Additional connectivity solutions

14. **Aluminum Sheet (6" x 24")**
    - Adjustable footrest implementation
    - Accommodates varying patient heights
15. **Aluminum Sheet (24" x 24")**
    - Primary base plate
    - Foundation for enclosure and wheelchair structure
16. **T-Slotted Framing**
    - Triple-wide 80/20 configuration
    - Required for swivel plate compatibility
17. **Jetson Nano Orin**
    - Provides necessary computational power
    - Handles sensor and motor processing requirements

C Influence of Published Codes and Standards

C.1 ISO 7176-1: Determination of static stability

Upon completion of the physical wheelchair assembly, the group must ensure that a wheelchair loaded with a person sitting on it has static stability in accordance with ISO 7176-1. A loaded wheelchair is deemed to be statically stable as long as the gravity force line from the center of mass is inside the area on the ground that is confined by the outline of the contact points of its wheels. However, since the location of the center of mass of the wheelchair is not precisely known, it is not possible to measure the tipping angle of the chair directly. Therefore, static stability can be determined with the wheelchair on an adjustable slope test platform.

A test platform may be built to conduct this testing in the designated work space. From testing, the angle of the slope on which the wheelchair starts to tip can be measured, where the angle of the test platform represents the tipping angle.

C.2 ISO 7176-2: Determination of dynamic stability of electrically powered wheelchairs

Once the motor and joystick are functioning and properly connected onto the wheelchair, the motion of the wheelchair will be tested in accordance with ISO 7176-2. Using these tests will help determine the dynamic stability of the wheelchair. The tipping scoring system will be used to ensure that the wheelchair will not fall over when moving. When testing occurs, all parts of the wheelchair will be in the most unstable position as stated in ISO 7176-2, which includes testing with the headrest extended. When testing, the wheels must all be touching the ground at all times.

C.3 ISO 7176-3: Determination of effectiveness of brakes

- We can determine the effectiveness of the brakes by testing in different scenarios.
- We will test the brakes first by seeing the distance it takes for the wheelchair to stop on a flat surface at normal operating speed of 4 mph. We will repeat this process with different operating speeds to ensure it can safely come to stop. We can further test safe operating conditions by testing braking operation on sloped surfaces.
- We can determine the effectiveness of the brakes by testing if wheelchair will not move if put on a sloped surface or easily pushed when in parked situation

C.4 ISO 7176-6: Determination of maximum speed of electrically powered wheelchairs

The maximum speed of the wheelchair will be set internally by the motor controller. The maximum motor speed is planned to be set to 3000 RPM with a gear ratio of 21.33:1. The maximum output speed would then be calculated to be 3000/21.33 = 140.647 RPM. With a wheel diameter of 12.5," the maximum speed of the wheelchair will be 5.23 miles per hour.

C.5 ISO 7176-9: Climatic tests for electric wheelchairs

Climatic tests for electric wheelchairs are beyond the scope of this project, as the wheelchair system is intended for indoor use only. The wheelchair is not to be used for transportation outdoors, and should only be powered on when indoors.

C.6 ISO 7176-10: Determination of obstacle-climbing ability of electrically powered wheelchairs

Our team can determine the wheelchair's climbing ability by testing it on the slope of the fifth floor of AEC to see if it can handle climbing up a slope. We can also see if it can clear the gap in the elevator to see if it can fully traverse the building without issues.

C.7 ISO 7176-14: Power and control systems for electrically powered wheelchairs and scooters

- Requirements: power the chair
- Converters to manage power within the wheelchairs
- Assessing the heating issue ensures it operates within safe temperature limits.
- Converters ensure operational safety by indicating faults through LED blinking.

C.8 ISO 7176-25: Batteries and chargers for powered wheelchairs