Introduction to Engineering Design with Professional Development 1

Final Report for
ALA: The Automatic Luggage Assistant

Team: Zeta Group
Section 6
Instructors: Glen Gross, Rahmi Ozisik

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Prepared by

Saaif Ahmed	2022	Computer Science and Computer Systems Engineering
Hanyin Yuan	2022	Mechanical Engineering
Zhan Shu	2022	Computer Systems Engineering
Jose Canales	2022	Civil Engineering
Ganqi Xu	2022	Electrical Engineering

Rensselaer Polytechnic Institute

Executive Summary

In Summer 2020, the Zeta Group designed and tested the Automatic Luggage Assistant, an automatically following luggage carrier in the airport which can track and follow the location of customers by connecting their mobile device with Bluetooth service.

The report below contains detailed information about how the team came up with the idea, how the project was constructed and designed based on a variety of design considerations and unexpected challenges. The model and strength analysis were done using NX12. The circuit was built using Tinkercad. The main driver code, as well as position tracking simulation, were tested and debugged in Visual Studio Code and later combined with the circuit built in Tinkercad. Simulation, testing and analysis were done by changing the position of the user and observing the change in speed and direction output by the device. The team also did a large amount of research to find out the best solution to each subsystem.

The final project met all set customer requirements through results measured through simulation. The device has a minimal deformation under a load of 200 lbs and thus is expected to carry even more making the model very durable and the material choice a good one. The screw choice and assembly choices were able to withstand the stress of the unit under normal operation with a factor 8 for safety. The main circuit is able to operate for a desirable amount of time and work to 100% functionality for that duration. The sensors are able to work together to get the ALA device within 0.3 meters or 1 foot of the user and are able to maintain that distance at safe speed. The turning angles of the servo motors are wide enough to cover every aspect of the general use case and the ALA unit can go up to 5 mph to catch up with users. With a final cost of $578 per unit and rent cost of $7 the ALA unit is a reliable way to combine ease of travel with increased comfort without breaking the bank.

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1 Introduction

Traveling is a difficult task to accommodate. Flights are no exception to this scenario and are arguably the most difficult form of long distance traveling to accommodate with comfort. The typical traveler already spends a significant amount of money on purchasing flight tickets alone not to mention food, checked baggage, and sometimes even seat preference. With this truth in mind, flight passengers are almost always inclined to find ways to save even more money. What many people turn to is traveling lighter, or cutting out easy costs.

Travelers are looking for flights with included carry-ons, carrying heavy backpacks themselves, or traveling with others to transport more belongings. To travel cheap is becoming an increasingly physical task. There is a huge sacrifice of comfort in order to perform our flying needs. With this ever increasing physical demand there is a larger barrier formed for elderly people, those with physical challenges, and even flyers with small children. These are just a few examples of potential flyers who have to cut comfort from their budget in order to make a flight, yet end up placing more burden on their already hectic travel plans.

Traveling should be a time of relaxation, there should not be a hurdle to overcome to begin feeling relaxed. For airline, and airport administrations, this is an issue that should be addressed as it disincentivizes potential travelers from making the decision to fly. Our solution, which we call ALA, the Automatic Luggage Assistant, will address the problem of users finding great struggle with carrying multiple backpacks and carry-ons with them in airports. Other than resolving this issue, we expect many more benefits with our design. Primarily is the lack of the need to purchase new baggage. The ALA device will be compatible with carry-on sized luggage and personal items that most travelers already have. In addition, we envision the unit being rented out at the airports. This means that flyers will be able to easily afford the ALA units and airports/airlines are able to make a profit off of them as well. Furthermore we expect this to incentivize travelers to explore the airports themselves and visit shops and restaurants more frequently.

With ALA removing the challenge of carrying luggage for long walks across the airport, we anticipate travelers being open to seeing what other luxuries an airport has to offer such as lounges and restaurants.

2 Project Objectives & Scope

In the time allotted for the project, The Zeta Group has worked to design, build, and simulate a representational demonstration for ALA, a device that carries the users luggage and bags in an airport and follows the user around through the airport at a close distance. The device will consist of a polypropylene base with aluminum side panels that holds the luggage to be carried. Steel screws will be used to join the parts and ensure the durability of the device. The device uses Bluetooth modules and Ultrasonic sensors to determine its distance from the user. A 36V battery is used to power the main circuit where a microcontroller interfaces with the sensors and the motors used to drive the device. The microcontroller will be responsible for calculating the speed and turning angle of the device as well as receiving input from the sensors and output to motors. Users will connect their phones to the ALA unit through Bluetooth.

Outside of the virtual environment the prototype of the product will have additional characteristics. The circuit would be soldered onto a protoboard for demonstration and manufactured with a printed circuit board.

2.1 Mission Statement

Table 2.1 : Mission statement

Project Description	To create a device that will automatically follow the user around and will carry their luggage for them. Furthermore the device should remove the hassle of carrying around the luggage for the user.
Benefits	ALA improves comfort for customers like elders, frequent flyers, parents of young children, and those with physical challenges during travel, avoid them from getting hurt.
Goals	● Finding a balance between ease of travel, and saving money. ● ALA can bear 220 lb load ● The materials can be recycled ● Battery can be charged ● ALA should fully implement the auto-follow function ● Safety
Primary Market	● Airports ○ Elderly Travelers ○ Physically Challenged Individuals ○ Parents with Young Children
Secondary Market	● Frequent Flyers
Assumptions	● Must be lightweight and durable ● Environmental friendly ● Can be used in all airports
Stakeholders	● IED Zeta Group ● RPI School of Engineering

2.2 *Customer Requirements & Technical Specifications*

Although ALA devices are helpful for all types of airport travelers they are particularly helpful for travelers with physical disabilities who have a more difficult time carrying around heavy luggage. Parents traveling with children would also find ALA helpful, as well as elderly travelers. Specified below is a table listing requirements and specification for both airports and travelers.

Table 2.2.1: Customer Requirements

Customer Needs	Technical Specification		
	Metric	**Target Value / Range of Values**	**Actual Value / Range of Values**
Affordable	Rent Price	\$5 - \$7	\$6.50
	Unit Sale Price	\$650.00 - \$800.00	\$750.00
Safety	Speed	4 - 5 mph	5 mph
	Distance from Traveler	1 - 2 ft	1 ft
Efficient	Capacity	150 - 250 lb.	230 lb.
Storable	Folded Dimensions	3.5 ft x 2.33 ft x 0.75 ft	3.5 ft x 2.33 ft x 0.75 ft

3 Assessment of Relevant Existing Technologies

Table 3.1 Competitive Benchmarking

Competitive Product	Title / Description	Relation to this project
Cowarobot Auto-follow Smart luggage (Cowarobot Auto-follow Smart Luggage, 2020)	A suitcase that is able to follow the user around. Battery supports the user to travel a maximum distance of 12 miles.	The device provides the team with a basic idea of auto-follow, but the price is too high for most people to afford it.
FLEET Autonomous Baggage Robot (Curley, 2019)	A robot owned by airports to aid travellers checking in luggage. The service is offered free but can only follow a fixed routine.	The device is very efficient, but it does not implement the auto-follow function.
SITA's Baggage Robot (SITA's baggage robot lends passengers a hand at Geneva Airport | SITA, 2016)	A robot owned by airports to aid checking in and transporting luggage onto the correct flight. It has the function to detect the surrounding environment and automatically respond to obstacles and emergency conditions.	The device has the functions of detectring surrounding environment and automatically responding to it. When it comes to auto-follow, the device must be able to do that.

There are two major kinds of automatic luggage assistant in the market. The team did some research on three of them.

The first kind of product in the market aims at private use. These products are improved from normal suitcases. An automatic-follow feature is added to the suitcase allowing it to follow the customers around wherever they go.

Cowarobot developed one of such suitcases, called Auto-follow Smart Luggage (Figure 3.2). It costs 700 dollars, which is a lot more expensive than a normal suitcase. It knows where the customers are and sends an alert when the customers are 6 feet away. It comes with a 92Wh battery which allows the product to travel a maximum distance of 12 miles. Furthermore, customers can charge their phones using the product while it follows the customers around.

Figure 3.2: Cowarobot Auto-follow Smart luggage

The second kind of product in the market aims at public use. These products are mainly owned by airports. These products do not fully implement the auto-follow feature, but instead follow a fixed routine.

FLEET Autonomous Baggage Robot (Figure 3.3) aims at aiding travellers checking in luggage. Travellers can use a touch screen to identify their airline and the robot will transport the luggage to the corresponding baggage belt. It can handle about 450 bags per hour.

Figure 3.3: FLEET Autonomous Baggage Robot

SITA’s Baggage Robot (Figure 3.4) is similar to FLEET but has some more functions. It can carry up to 2 luggage with a maximum load of 32 kg. It can also help to check-in and transport the luggage onto the correct flight. However, SITA’s robot is able to work in all areas of the airport, so it is capable of detecting the surrounding environment and avoiding colliding with other people or objects.

Figure 3.4: SITA’s Baggage Robot

Compared to a normal mid-tier suitcase which costs around 100 dollars, an auto-follow smart suitcase costs about 7 times the price of a normal one, which means most of the customers are not able to afford such a suitcase. Furthermore, the battery inside the smart suitcase utilizes a lot of space and also limits the capacity of the suitcase. The FLEET robot has a suitable capacity and is free to use as an airport facility, however, has limited features. It can only follow a fixed routine for check-in from the specific service counter to the baggage load area. The SITA’s Baggage Robot is similar to the FLEET robot but is more developed. SITA’s robot is able to work in all areas of the airport due to the auto-drive function. But the function device also limits its capacity and the size that is too large to work in the busy area after security check. And like FLEET, the SITA’s robot also has the crucial problem that it’s only used for baggage check-in.If customers still have a lot of belongings after security check or they need assistance for baggage claim, they are not able to use the product.

The team plans to improve the above two designs and develop an automatic luggage assistant which is owned by the airport and is capable of following the customers around.

Table 3.2 - Patent Research for Related Technologies

Patent Number	Title / Description	Relation to this project
US20170220040A1 (Loudon, 2017)	Smart luggage systems	The smart luggage system includes processors that are able to determine the position of the user and is able to move the luggage bag based on the location of the user and the location of the luggage bag. The system gives the basic idea of position tracking.
US8874300B2 (Allard, Wienhold, Norris and Catalfano, 2005)	Systems and methods for obstacle avoidance	The obstacle avoidance system is basically used on a robotically controlled vehicle. With the system, vehicles are able to detect the obstacles and avoid the obstacles.

The team did some research on 2 patents as shown above in table 3.2.

For US20170220040A1, it is a smart luggage system that uses several processors, memory modules and wheel actuators. The system is able to determine the position of the user and move the luggage bag based on the location of the user and the luggage bag. The system gives the team a basic idea of position tracking. However, after thorough discussion on this problem, the team decided to use a mix of Ultrasonic sensors and Bluetooth to achieve the goal of position tracking, which is more accurate in measuring and easier to implement.

US2499349A is Systems and methods for obstacle avoidance. It is used on a robotically controlled vehicle which follows an obstacle map. The vehicle is able to detect those obstacles and avoid them. This system gives the team a basic idea of obstacle avoidance.

4 Professional and Societal Considerations

Table 4.1 - Engineering Solutions Impact

Area of Impact	Impact	Description of Impact
Public Health and Safety	Y	**Positive:** The device aims to increase customer comfort during their travels. They no longer have to carry lots of luggage or heavy baggage for long distances or long stretches of time in the airport. **Negative:** The device should have the ability to avoid other people or obstacles. However, under emergency or complex situations, it may not operate well and crash into another person.
Global	Y	**Positive:** Airports equipped with our product may attract more people, thus speed up the development of tourism in those areas. **Negative:**Travel laws and restrictions vary from country to country. The same holds true for airports rules and regulations as these change from location to location. Our product may not be able to be featured in airports whose guidelines prevent our product from operating.
Cultural	Y	**Positive:** The design that is currently developed features a spot for advertisements on the side of the device. For international airports especially, it is critical to consider how advertisements are chosen for the devices featured at these locations. This can be a substantial way to make profit for airports that choose to feature our device. **Negative:** In some cultures, people enjoy high social welfare. They believe those public services should be free.

		The product can be seen as rude by these people.
Societal	Y	**Positive:** The ALA device is meant to increase comfort for those with physical challenges, those traveling with small children, and frequent flyers who want to better their travel experience. **Negative:**The device may break TSA guidelines and restrictions meaning the device would need additional design iterations to fully comply. Furthermore the device, without any precautions, leaves the personal belongings of the customer open to theft. Our device should not increase safety in airports.
Environmental	Y	**Positive:** The main material should be environmentally protected that can be recycled when the device is damaged or no need to use. **Negative:** According to Forbes, certain battery types can have the effect of environmental contamination if not recycled properly. Factories producing our product can produce wastes, which is harmful to the environment.
Economic	Y	**Positive:** With our product, people are willing to travel more often because they do not have to worry about carrying heavy luggage. As a result, both airports and airlines can earn more money. **Negative:** An economic factor we must consider is the rapid growth of technology. Our circuits, batteries, and sensors are technologies that are rapidly advancing. At a point, the design we chose will become obsolete and airports would lose money on renting out our product. If the design isn't made to be updated, it will decrease the life cycle of our product.

5 System Concept Development and Selection

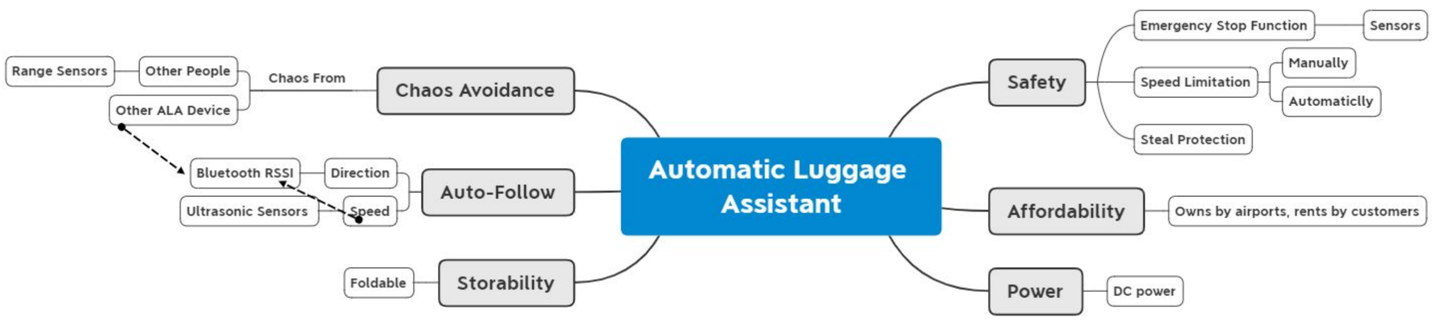


Figure 5.1 Mind Map

The team considered six aspects which are crucial to the design of our product as discussed below

1. The ALA device should fully implement the auto-follow function, which means it should be able to determine the direction and speed by itself.
2. Private suitcases which have auto-follow functions are expensive for customers, so the team aims at selling the products to the airports and airports can rent the service to customers.
3. Airports are usually crowded. The ALA device should not add more pressure to the heavy traffic at the airport. A speed limit is set to ensure the product is controllable. Under emergency situations such as getting into a huge crowd of people, the ALA device should be able to stop automatically or manually. While other people are getting too close to the device, a caution warning should be shown to notice others are getting too close and warn them from being hurt.
4. Situations in airports can be very complex. The ALA device may collide with an obstacle, other people or other ALA devices. Because of that, ALA should be able automatically avoid these cases.
5. Spaces in airports are limited. Normal luggage carts can be stored easily and take very little space. ALA should also satisfy this requirement. It can be folded when not in use.
6. Power supply is crucial to electrical products like ALA. Moving with heavy suitcases carried costs a lot of energy and the product should not suddenly run out of battery halfway. A sustainable, rechargeable and safe battery should be

used on ALA so it can support all of the operations as well as be friendly to the environment.

6. Subsystem Analysis and Design

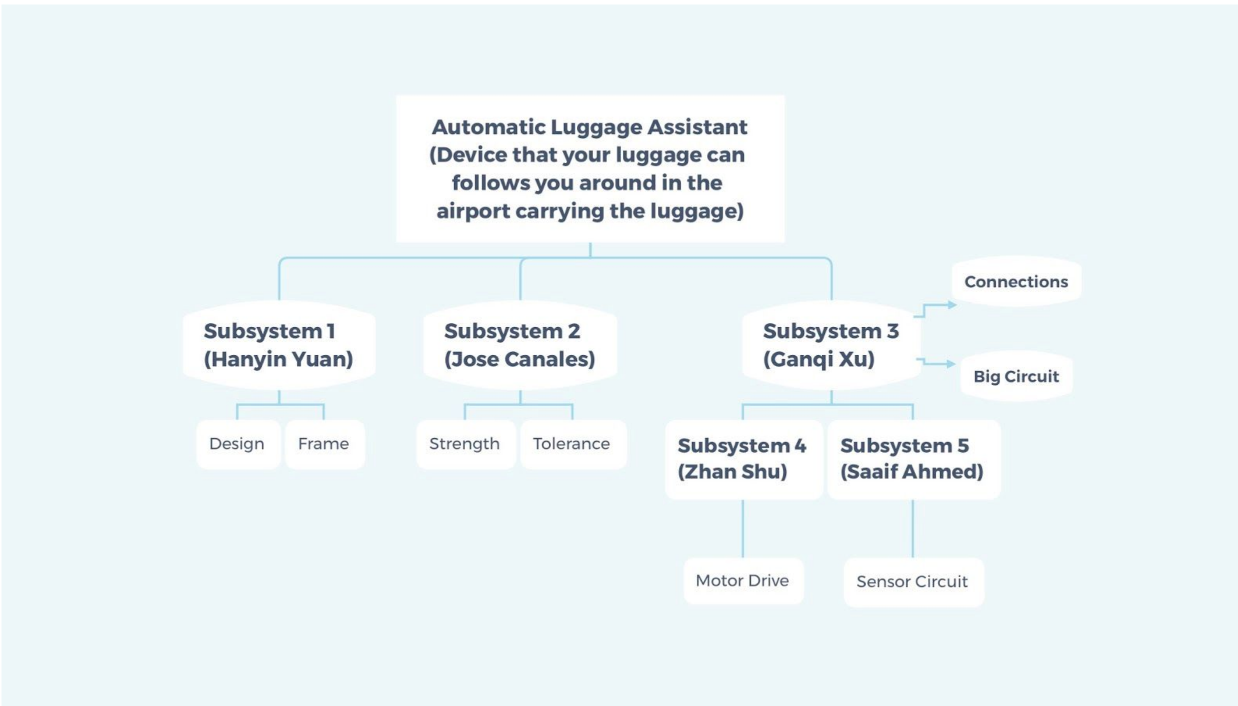


Figure 6: Subsystem Hierarchy Diagram

6.1 Model and Simulation

Initial Design:

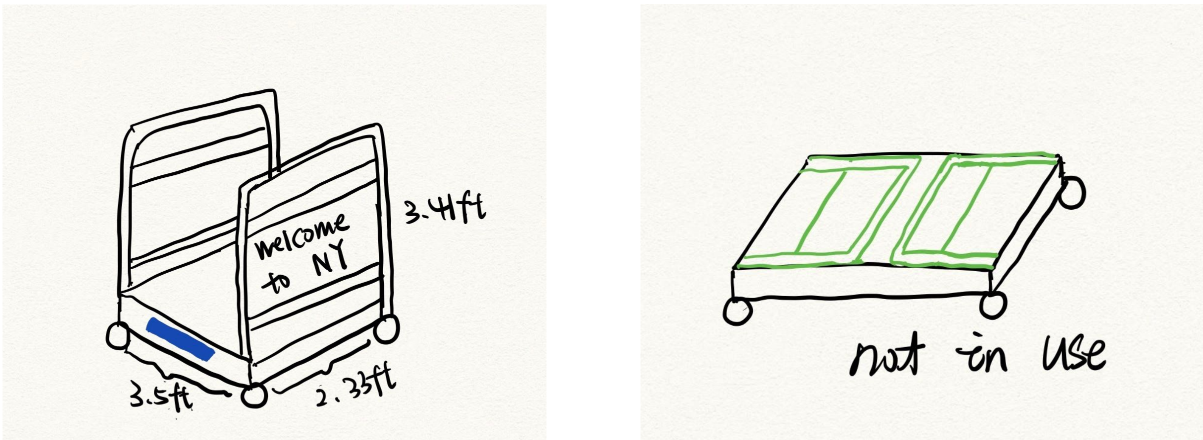


Figure 6.1.1: Initial design for ALA

The initial idea for the design is the device should not occupy too much space and it can easily move. The luggage assistant should be open from two sides to slide the luggage inside and should have some space for advertising. The sensors should be placed on both sides which are the blue part below. The initial length, width, and height of the automatic luggage assistant is 3.5 ft (43 inches)*2.33 ft (28 inches)*3.41 ft (41 inches).

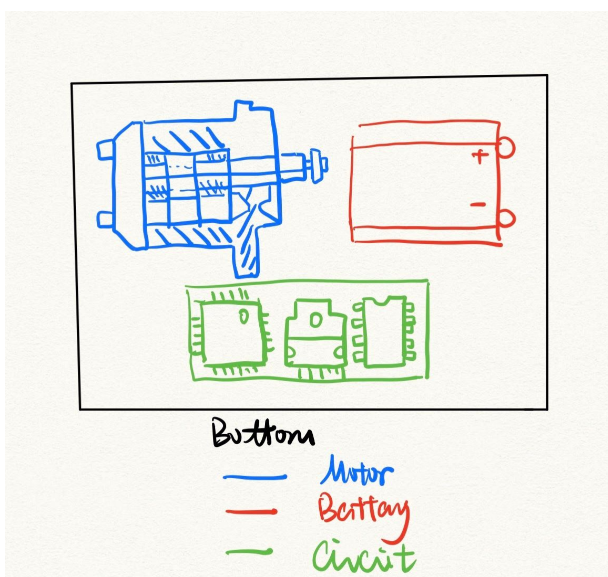


Figure 6.1.2: Inside of the bottom of the ALA

The above diagram is roughly drawing about the motor, battery, and the circuit. These three parts will be inside the bottom of the carts.

Considering the structure and load of the base part. The team changes the position of the battery and puts it in the center of the base. In addition, the motors should be placed beside the four wheels. The new design of the device is shown below.

<u>Model:</u>

Three-View Drawing of Automatic Luggage Assistant:

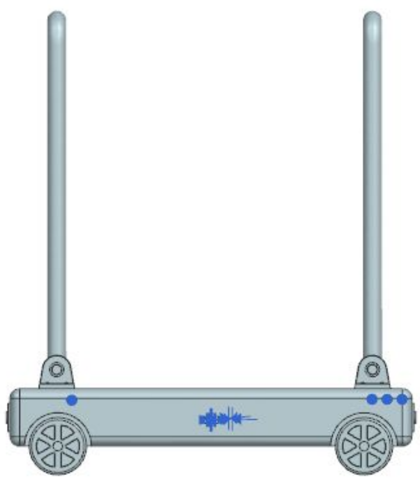


Figure 6.1.3: Front view

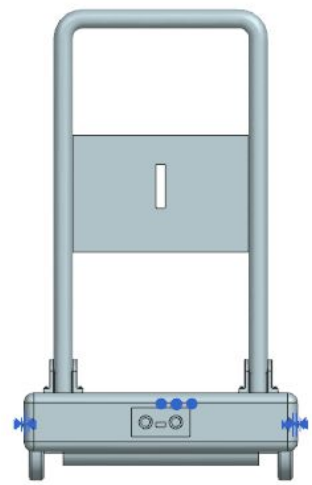


Figure 6.1.4: End view

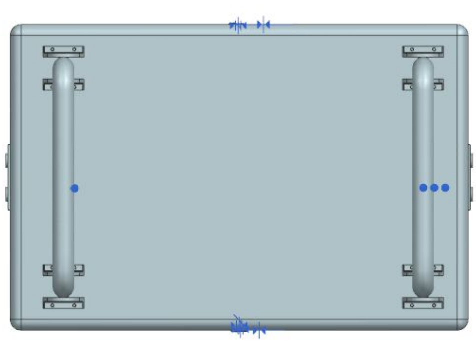


Figure 6.1.5 Vertical view

Figure 6.1.6 Overall Design

The overall design of the luggage cart looks like a figure 6.1.6. The total dimensions of the luggage cart are 3.5 ft*2.33 ft*4.33 ft(L*W*H). The total weight of the luggage cart is 354 lb. The product has two panels and the holes on the panels can attach billboards and advertisements. The material of the base is polypropylene and the material for panels is aluminium. The nylon wheel is most suitable for the product. The capacity range for the cart is from 150 lb to 220 lb.

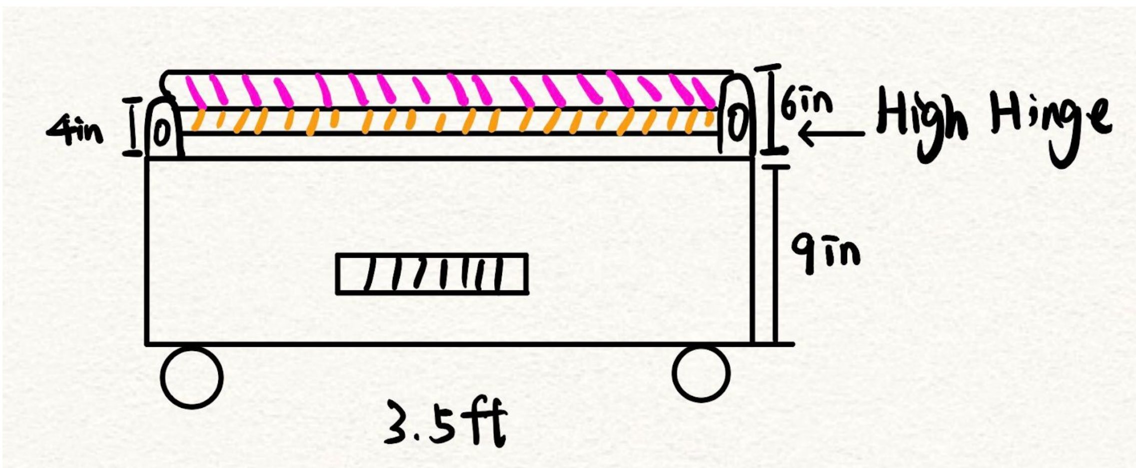


Figure 6.1.7: Panels are folded in

The panels can fold in when not in use. One panel is higher than the other one so that the hinge is higher and it can fold over the other (figure 6.1.7).

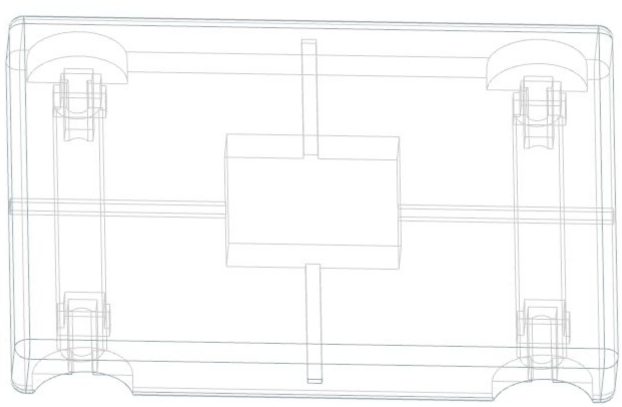
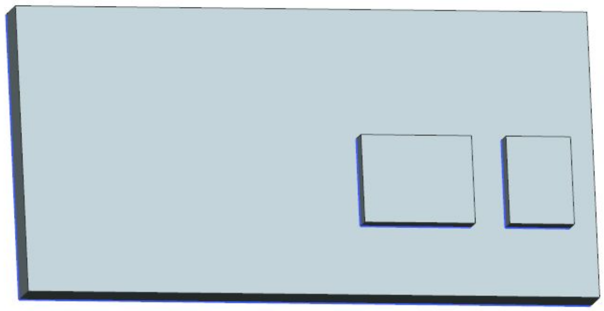


Figure 6.1.8: Perspective view of base



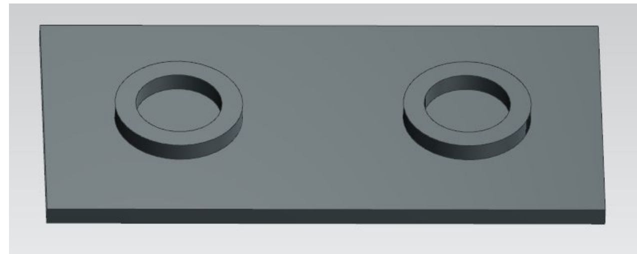


Figure 6.1.9: Bluetooth Sensor **Figure 6.1.10: Ultrasonic Sensor**

For the base part (figure 6.1.8), the two Bluetooth（figure 6.1.9）are attached to the right and left side, and one of the Ultrasonic (figure 6.1.10) is placed in the front of the base whereas the other one is placed on the back of the base. The battery is at the center of the base and it connects to the circuit part. The internal frame for the base is flange cruciform structure (figure 6.1.11). Flanged cruciform members are used in high-load applications as compression members. Typical applications include column and lateral bracing members for orthogonal moment frames with large bending moments about both local axes. So the base can load bearing. In addition, the plastic battery cover can prevent any damage from loading. The four motors are placed at each corner. Two servo motors are placed at the front wheel and speed motors are placed at the rear wheel. The luggage cart is a rear wheel drive cart.

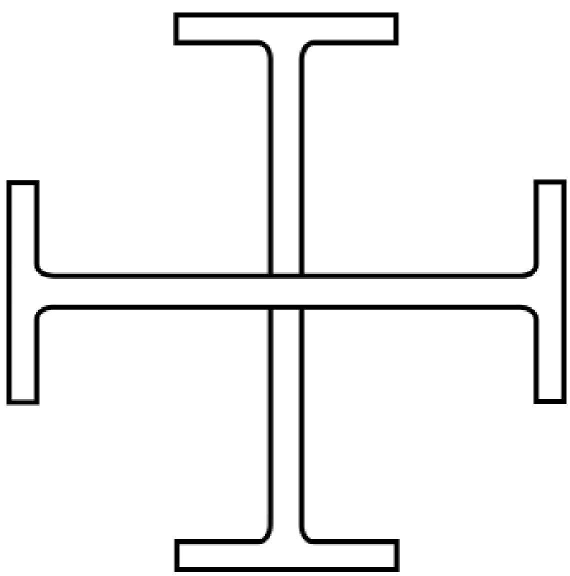


Figure 6.1.11: Cruciform Structure

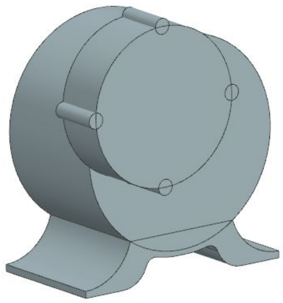


Figure 6.1.12: **Speed Motor**

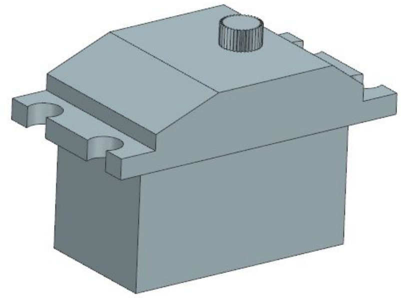


Figure 6.1.13: **Servo Motor**

Deformation for Polypropylene:

Polypropylene will act with elasticity over a certain range of delation, but it will also experience plastic deformation early in the deformation process. Polypropylene is a tough material, making it hard to crack. The Young's modulus of polypropylene is between 1300 and 1800 N/mm². The young's modulus measures the stiffness of a solid material. It defines the relationship between stress in a material in the linear elasticity regime of a uniaxial deformation.The young's modulus is large which means that the deformation of the material is small when the material is stretched and compressed. This allows polypropylene to be used as an engineering plastic.

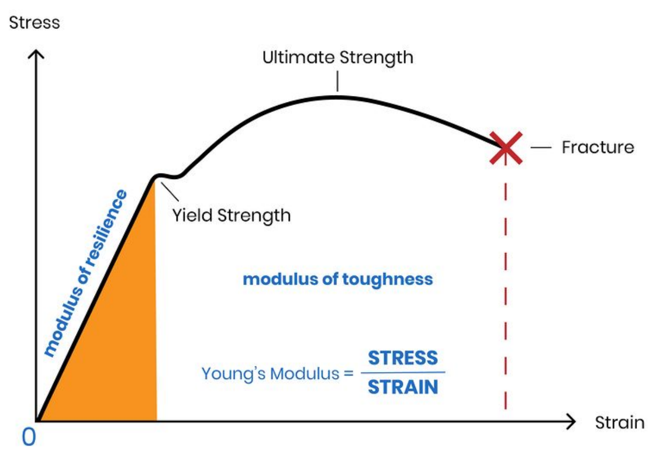


Figure 6.1.14: **Young's modulus**

6.2 Material, Assembly, and Stress Analysis

When designing a product every detail counts and influences the performance of the product. A design is not complete without considering multiple aspects including materials, assembly, and the different components that go into it. My subsystem is meant to consider the multiple aspects that go into completing and effectively designing a product, more specifically the material choice and connection choices. Afterwards, calculating the strength of the design based on material and connection choices.

Material Choice:

The most important things to consider when choosing a material for our design is having a material that is strong enough to carry heavy luggage, however the material should be more than just strong it must also be light enough to be carried by the wheels and motors with relative ease as well as being machinable in order to be shaped and assembled. Our material must be well suited to our device and what we want it to do, however it must also be affordable and available in order to produce and manufacture on a large scale. Apart from technical and price consideration on our material it is also important to consider the overall appearance of a material and how well it fits our device.

Our first consideration was having a metal base, two materials that came to mind were stainless steel and aluminum. Aluminum was ultimately ruled out due to its much higher price when compared to other suitable options. Our team's first concept featured a stainless steel base because of its strength, cost, and aesthetic. However once drawing our design on NX 12 and analyzing it using stainless steel we concluded it was too heavy for the motors and wheels as well as for transportation and manufacturing purposes. The first stainless steel concept came out to a weight of 1926 lbm.

3306.6738	in^2
6809.6350	in^3
Point(0.0, 0.0, 3.0331)	in
1926.0380	lbm
1926.0380	lbf
{ 143937.8388, 300205.4721, 397251.6895}	$lbm \cdot in^2$
{ 8.6448, 12.4847, 14.3615}	in
Vector(0.0, 0.0, 1.0000)	
Vector(1.3866e-07, 1.0000, 0.0)	
Vector(-1.0000, 1.3866e-07, 0.0)	
{ 397251.6895, 282486.8596, 126219.2263}	$lbm \cdot in^2$

Figure 6.2.1: Data for first trial

After concluding that metals would either be too expensive or too heavy our team decided to look into other material options such as strong plastics. We narrowed it down to two choices: polycarbonate and polypropylene. Polycarbonate is a very strong thermoplastic that is easy to shape and mold, it mostly stands out for having a transparent appearance making it commonly used for roofs. Polypropylene is also a thermoplastic meaning it's also easy to mold and shape, however it is a cheaper and weaker option. Polypropylene also doesn't have a transparent appearance and is commonly used for materials and industrial equipment. Below is a comparison of cost, weight, and tensile strength between the plastics.

Table 6.2.1: Plastic Options

Material	Polycarbonate	Polypropylene
		
Cost	\$1.70 /lb	\$0.12 /lb
Weight	75 lb/ft^3	60 lb/ft^3
Tensile Strength	9500 psi	4700 psi

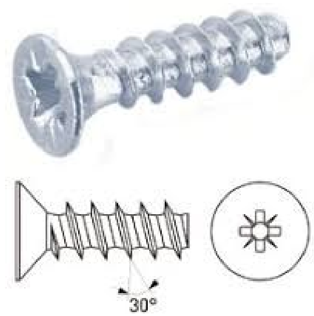
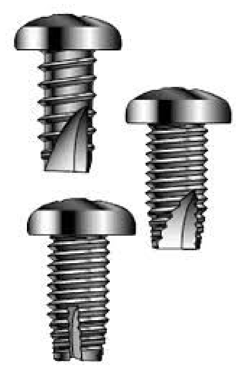
After analyzing both options, our team decided on polypropylene because of its cheaper cost, weight, and appearance. While polycarbonate would certainly be a strong enough option it has a much higher price. The transparency of polycarbonate is also not the appearance our team wanted for the base. Polycarbonates appearance can be changed with fillers however this alters the plastics properties and only increases the price. Polypropylene offers an option that is very cheap, accessible, and machinable. As well as a strong enough material for the task of carrying baggage.

Assembly

After deciding on a material it is important to choose the proper way of assembling the device itself depending on the materials properties, cost, and what the device will do. Proper assembly will result in an effective product but will also save time and money.

Screws would be the preferred fastener for the connections and attachment of our device. Screws are usually preferred for plastics and are also better options for joints where force would be experienced from multiple directions. This is ideal for our case where the connections will mostly experience vertical loads but may also be prone to horizontal loads if the device collides with an object. Choosing the correct screw type for plastic is crucial in maximizing performance and minimizing cost. The correct screw type means having higher strip out torque values, higher resistance to loosening and higher pull out values. Screw selection has an impact on cost effectiveness as well, choosing the correct screw reduces material usage and cycling times as well as eliminates the need for inserts and adhesives. Below are two options for screws, thread forming, and thread tapping screws.

Table 6.2.2: Comparison of Thread Forming and Thread Cutting Screws

	Thread Forming Screws	Thread Cutting Screws
		
Cost	1	0
Fit	1	1
Waste	1	0
Stress	0	1
Total	3	2

Thread cutting screws are a kind of self tapping screw that creates threads in holes within a material by cutting the material, it is usually used in hard materials such as metals and wood. While thread forming screws are screws that form their own threads in a material by pushing the material to form its thread, this causes more stress in the material but reduces waste because no material is shaved off. Based on the analysis of thread forming and cutting screws, the group has decided on using thread forming screws because of its lower cost and minimal waste generation.

Fastener design is crucial when choosing a screw for plastics. Regular screw fasteners have a wider thread profile of about 60°. Fasteners for plastic have a thinner profile ranging between 30° to 48°. Having a thinner profile reduces radial stress and expansion which helps the screws performance. Screws meant for plastic also have a larger axial shear area which in turn makes the screws more resistant to pull-out Radial force in screws creates outwards stress and thus can damage the material around it. Hence, the less radial stress created the better. Thread profiles of 60° and 30° displace the same amount of material, however a 30° thread profile generates about half of the radial force as the 60° thread profile of a regular screw.

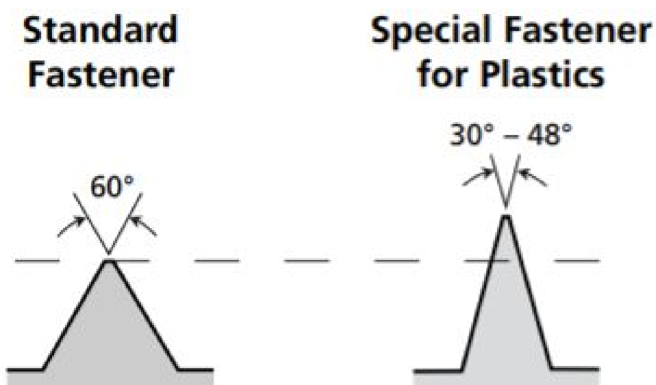


Figure 6.2.2: Screw fastener comparison **Fig 6.2.3: Radial Force Comparison**

Properties of Plastic to Consider:
Factors that affect fastening performance:
- Stiffness of material
- Amount of filler content such as glass
- Thermal expansion rate
- Creep rate

Stiffness or flexural modulus of a material is the most important property to consider when predicting how a plastic will respond to a fastener. Plastics with lower stiffness allow the formation of threads while plastics with higher stiffness require thread-cutting fasteners as opposed to thread-forming fasteners. Creep rate is another important property to focus on for our design, creep is the deformation created under a load. Increasing the head diameter of the screw can reduce the effects of creep on a joint. Polypropylene has a

Drive to strip ratio is another consideration, drive to strip ratio is the ratio of torque to form thread to the maximum torque that would damage the screw and material.

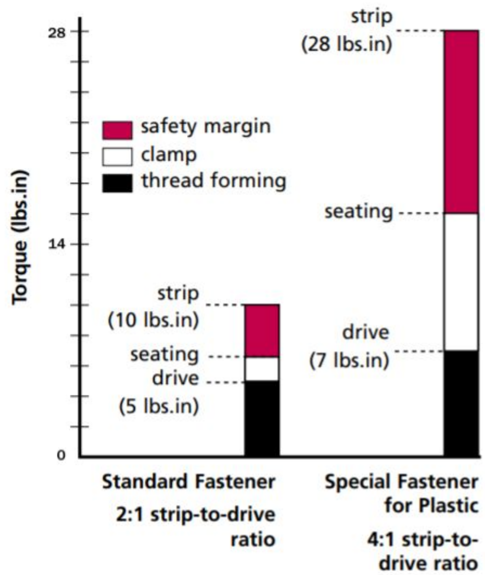


Figure 6.2.4: Strip to drive ratio comparison

As shown above, the safety margin between enough torque and too much torque is much larger for screws designed for plastic; this means the chance of damaging the screws or material during installation is much less.

Our team decided to go with the PT Thread Forming screws shown below because of its thread profile which makes it suitable for plastics with a lower flexural modulus such as polypropylene which has a flexural modulus of 200,000 psi. The screw designs increased thread engagement also increases load carrying capacity.

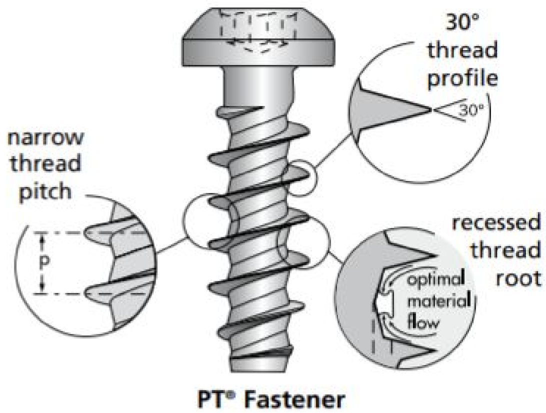


Figure 6.2.5: PT Fastener Design

Picking a Screw Head:

Figure 6.2.6: Rounded Head **Figure 6.2.7: Flat Head**

Above are two standard types of screw heads: rounded and flat. Both are perfectly suitable options for fastening plastic. However because of its better fit and lower cost, our team will use a flat head screw for fastening the plastic.

Picking the Screw Drive

When it comes to screw drives there are many options however our team narrowed it down to choosing between the phillips and knox drives.

Figure 6.2.8: Philips Screw

Figure 6.2.9: Torx Screw

Phillips drives were created to help machines use them and make manufacturing easier, however since then the design has been improved in the form of the Torx drive, the geometric design of this drive allows for more torque to be generated making fastening the screw require less force and thus easier for machinery and manufacturers. Our team will thus use a Torx drive because it requires less force from machinery to install.

Screw Choice

Based on the considerations and choices made, as well as price. Our team has decided to go with a size 1/4 for the base flat head thread forming screw with a torx drive.

Figure 6.2.10

Price: $0.30/screw
Material: Stainless Steel
Drive Style: Torx Six Lobe
Head Style: Flat Head
Head Diameter: 0.4 in
Length: 1 in

Hole Design for Polypropylene:

Hole Diameter	Boss Diameter	Length of Engagement
0.70 x d	2.00 x d	2.00 x d

Frame Production
Our polypropylene base will be manufactured using injection molding. Injection molding is a manufacturing technique used to produce parts by injecting a molten material such as plastic into a mold and letting it cool. Advantages of using injection molding include: detail, cheaper manufacturing cost, and higher strength. Injection molding is completely compatible with CAD drawings in order to create an accurate mold. Our material choice, polypropylene, is easy to mold and its low mold viscosity allows it to fill molds quickly and speed up the manufacturing process.

Panel Production
Our panels will be made from lightweight aluminum, to create the outer part of the panel our manufacturers will bend pre prepared aluminum tubing into the desired shape. Our panel will then be completed by welding an aluminum sheet to the aluminum tube.

Stress Analysis of Screws and Connections

After finalizing the choices for material, connection, and screw types we could now analyze the strength of the device at its connections. We start by calculating the tensile stress area (A_t) of the screw based on its dimensions, the tensile area is the cross section of the screw that will experience stress under the vertical load. The formula for tensile stress area is dependent on the ultimate stress of the screw itself. Materials with an ultimate tensile strength less than 100,000 psi yields the following formula:

$$A_t = 0.7854\left(D - \frac{0.9743}{n}\right)^2$$

A_t= Tensile stress area
D = Bolt shank diameter
n = Number of threads per inch

Our screw material is stainless steel which has a tensile strength of 73,200 psi which means it falls well within the range. Once we've calculated the tensile stress area our team can calculate tensile stress by dividing the applied load by the tensile stress area. In order to make sure our connections are suitable and acceptable, the calculations must be done taking a factor of safety of 8.5, according to the table below.

Equipment	Factor of Safety (FoS)
Aircraft components	1.5 - 2.5
Bolts	8.5
Cast-iron wheels	20
Engine components	6 - 8
Heavy duty shafting	10 - 12
Lifting equipment - hooks ..	8 - 9
Turbine components - static	6 - 8
Turbine components - rotating	2 - 3
Spring, large heavy-duty	4.5
Structural steelwork in buildings	4 - 6
Structural steelwork in bridges	5 - 7

Source: EngineeringToolBox.com

Figure 6.2.10: Factor of Safety for parts

6.3 Overall Circuit & Electronic component

The inside circuit has the main function to interact with the outside signals and send feedback to control the motion of the device. The basic circuit structure is built up by Bluetooth signal sensor, ultrasonic sensor, speed-controlled motors, Microcontroller, and other required components(including power source and other physical ports).

<u>Design idea:</u>

The whole circuit is powered by a 36V DC Li-ion battery (capacity in 20AH). While in working (after the Microcontroller send out a start signal), the detected values of Bluetooth RSSI and Proximity sensors result will be the analog input signal that sent to microcontroller and analyzed by Motor drive program, the program will immediately give out a feedback signal to adjust the servo-motors & speed-motors with suitable direction and speed.

<u>Overall Circuit Structure:</u>

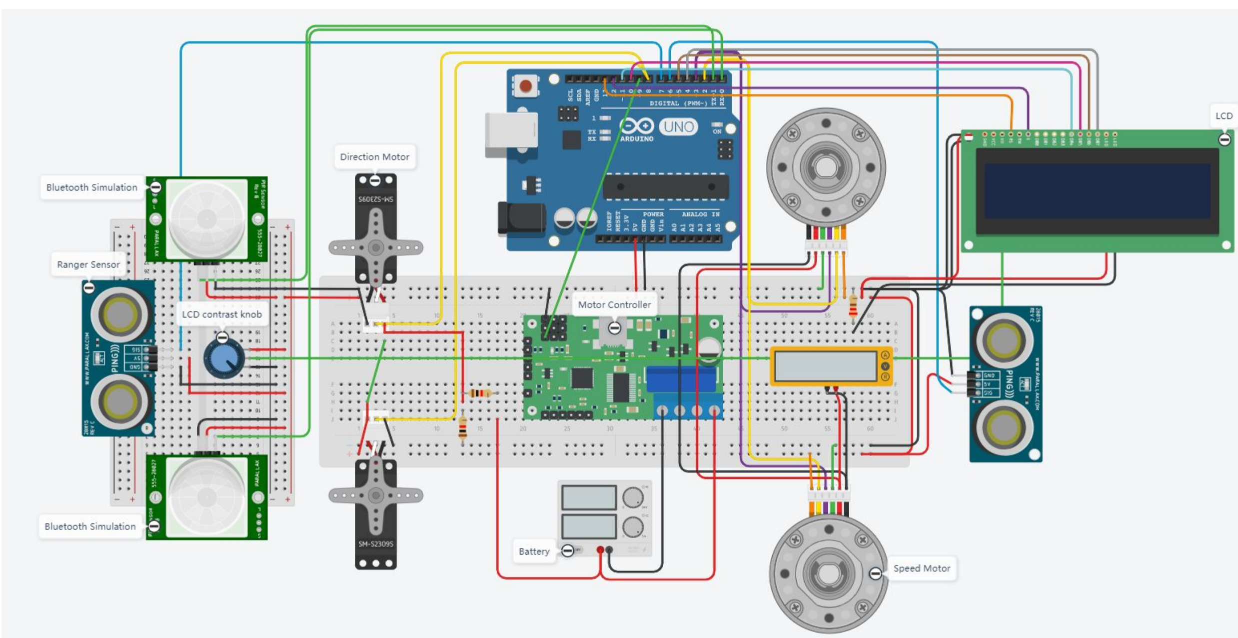


Figure 6.3.1 Overall circuit

The team decided to use four sensors as the signal input source; four motors and one LCD monitor as the output components.

Main tracking structure:

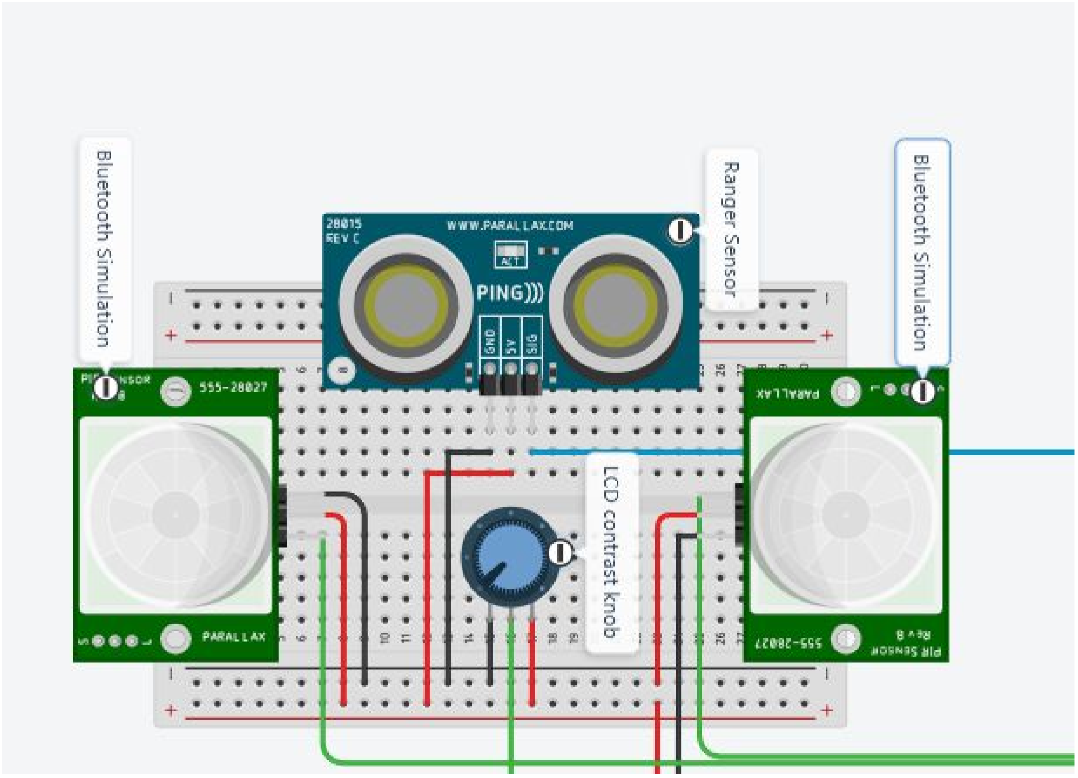
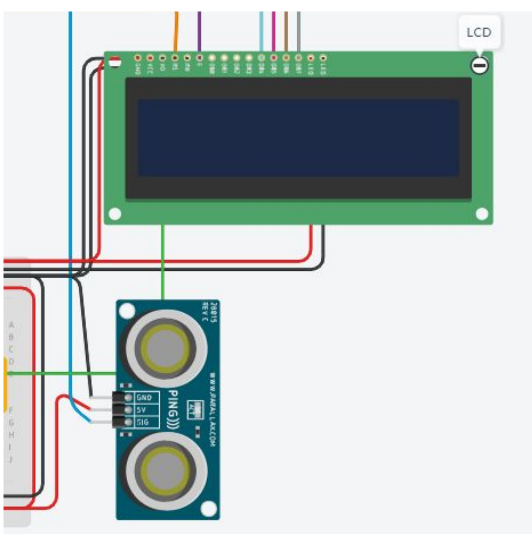


Figure 6.3.2 Position tracking structure

Two Bluetooth sensors and One Ultrasonic(Ranger) sensor compose the main customer tracking structure.

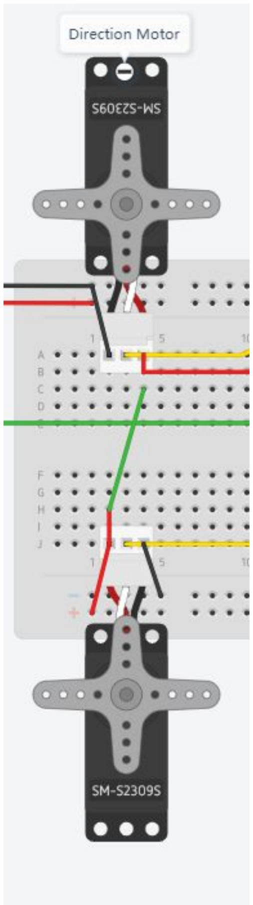
Safety structure:



One Ultrasonic sensor and one LCD monitor compose the caution warning system.

Figure 6.3.3 Warining structure

Power system structure:



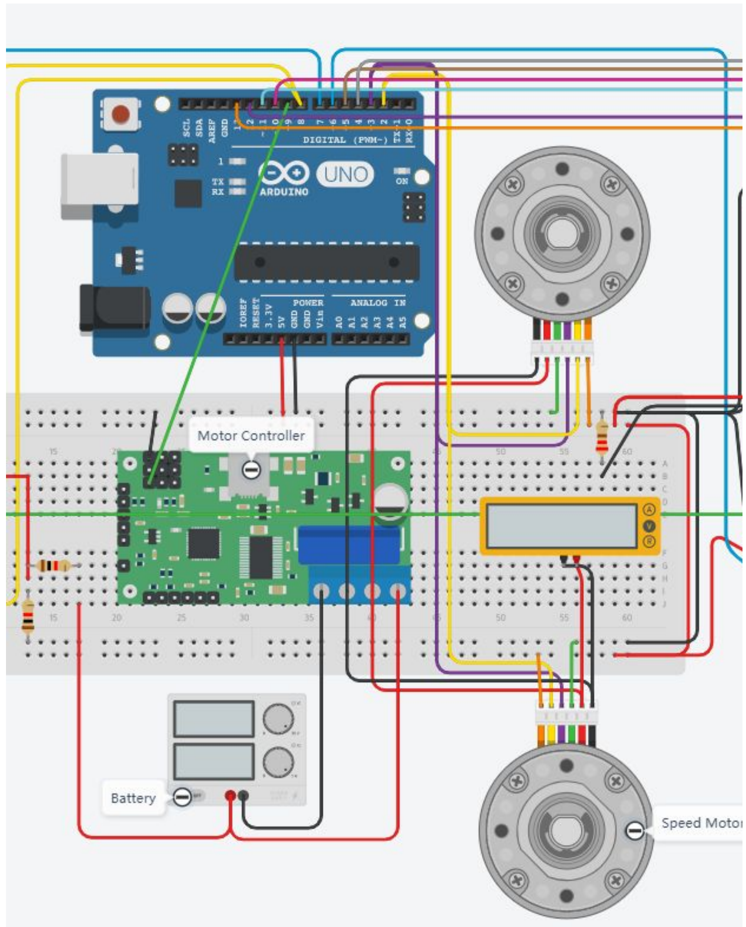


Figure 6.3.4 Servo motors **Figure 6.3.5 DC motors & motor controller**

Four motors compose the power system, two servo-motors at front on each side are responsible for the device heading direction adjustment(Figure 6.3.4); two DC-motors with the motor-controller at back on each side are responsible for the device speed control (Figure 6.3.5).

A 36V DC Battery is used to be the device power supply.

Component Selection:

The team chose the following existing electrical components for the device.

Table 6.3.1

	Type	Name	Data sheet
Powering System	DC motor	BEMONOC E. T. MOTOR	36 V, 350 W, 300 RPM
	Servo motor	SPT Digital Servo	7.4 V, 70 kg.cm, 0.16''/60°
Power Supply	Battery	Li-ion Battery	36 V, 20 Ah
	Microcontroller	Elegoo nano	72-Pin EDO SIMM Memory
Input Sensors	Ultrasonic Sensor	Smraza Ultrasonic Module	High precision for range below one meters.
	Bluetooth Sensor	Kuman wireless Module	High precision for range in one to three meters, 360° working area.

Pinout Form for Microcontroller:

The form shows the port connection between the electrical component and the microcontroller.

Table 6.3.2

Pin number	Component name
Digital pin 13	LCD RS
Digital pin 12	LCD Enable
Digital pin 11	LCD DB4
Digital pin 10	LCD DB5
Digital pin 9	Motor Controller
Digital pin 8	Servo Motors
Digital pin 7	Ultrasonic Sensor (Front)
Digital pin 6	Ultrasonic Sensor (Back)
Digital pin 5	LCD DB6
Digital pin 4	LCD DB7
Digital pin 3	DC motors Channel 1
Digital pin 2	DC motors Channel 2
Digital pin 1	Bluetooth Sensor (Right)
Digital pin 0	Bluetooth Sensor (Left)

Security:

Due to the relatively high operating voltage on the 36V DC motors, a motor controller is used for stabilizing the voltage into the motors and protecting against overloads and electrical faults so that will not make those errors directly hurt the motors or lead overheat of the device which is dangerous to the customer.

6.4 Sensors and Position tracking

The way in which the ALA device is able to determine its relative distance to the user is through two main methods of position and distance tracking. The first method of tracking that is utilized by the device is using the relative distance measurements between two Bluetooth modules and their respective RSSI values. The second method of position tracking is a very common and precise technique known as Ultrasonic sensing. Ultrasonic Sensing uses the speed of sound to calculate the distance between the sensor and the object immediately in front of the sensor.

Alternative Subsystem Designs:

Choosing the combination of Bluetooth RSSI sensing and Ultrasonic sensing did not come about automatically. In terms of concept selections and generation the team considered multiple options before landing on the combination of Bluetooth RSSI and Ultrasonic sensing. The team considered 2 other design approaches that are discussed below.

- **Ultrasonic Sensing Only**

  The first design approach utilized only the Ultrasonic sensors in order to determine distance from the user. The main benefit of such a position tracking system would be the ease of implementation and the precision offered by Ultrasonic sensing. However the main drawback of this design was the fact that it cannot be scaled and it is not resilient to noise in the environment. In the context of the use case of the ALA unit, the ultrasonic sensors do not have the capability to determine if the object immediately in front is a wall or the person it is meant to follow.

- **RF Distance Tracking**

  The next design approach considered was the utilization of RF or Radio Frequency communication to send distance data back to a receiver module. The largest benefit was the scalability and the range of radio transmitters and receivers. The expected maximum distance the ALA device would have to cover was roughly 3 meters which radio modules can easily communicate with an effective 0% error rate. There was a critical flaw with this design choice however. When communicating with radio frequency, the channel is only established with a given range of frequencies. This means there is no exclusivity between the user and the ALA unit that is supposed to follow, as all the ALA units will be communicating on the same frequency band. Furthermore we could only prove that the distance calculation would be accurate only within 1 meter of the user. For any distance shorter than this, we could not reliably determine if the user was directly in front of the ALA device leading to a safety concern.

The idea of combining Bluetooth RSSI with Ultrasonic sensing was then developed and after careful consideration, the decision was made to move forward with this design approach. With Bluetooth device pairing we are able to ensure a one to one connection between the user and the ALA unit following, and thus scale it up to an airport filled with ALA units. RSSI has the same huge range that RF connections have meaning we can reliably move to within 1 meter of the user. From that point the device can then incorporate Ultrasonic sensing to get accurate distance measurements and bring the device to within 0.3 meters of the user. How this is performed is described in the following sections.

Bluetooth RSSI Position Tracking:

RSSI stands for Radio Signal Strength Indicator. It is a number measured on a decibel by meter scale that represents the strength of the signal between two radio devices. The decibel by meter scale is mainly used for experimental and data analysis purposes and as a result most manufacturers report their own units called “chip units” when asked to report back RSSI values. These can be plotted in a similar way of “chip units” vs. distance. The trend of data between distance and RSSI values can be seen below.

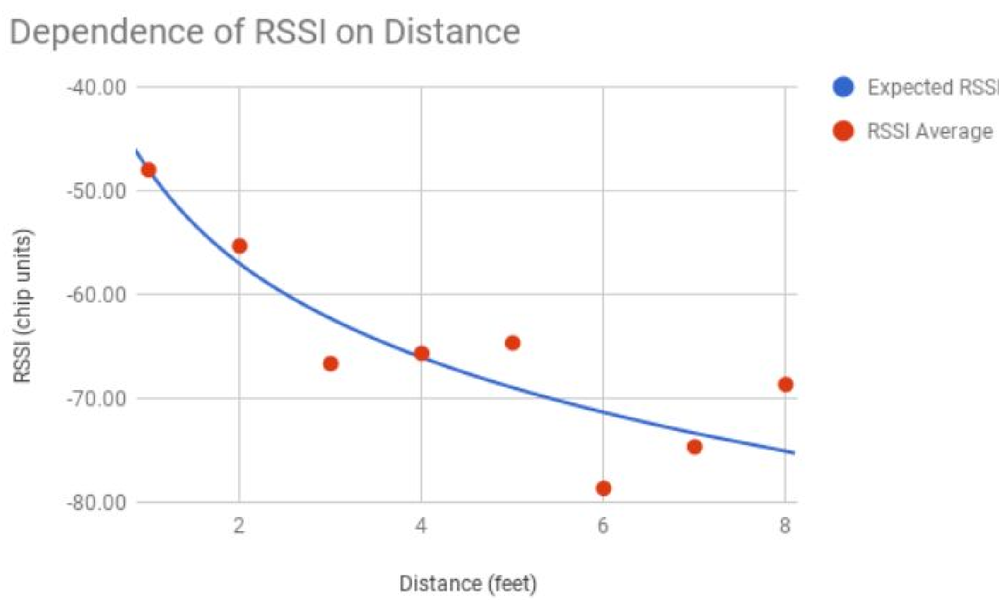


Figure 6.4.1: Relation of RSSI to Distance (Chip Units)

(Glueck et al., 2017)

The range of RSSI is directly related to the range of the Bluetooth device itself. The figure below shows RSSI (in dB) vs. Distance over a large range.

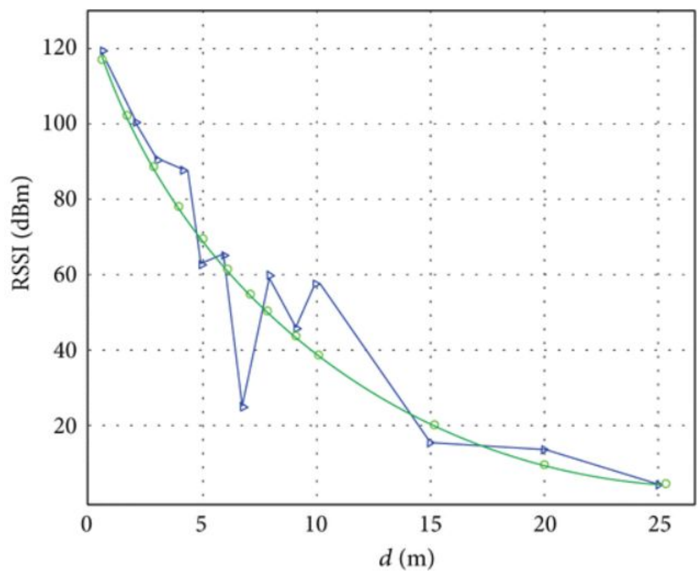


Figure 6.4.2: Relation of RSSI to Distance (dB)

(Shang et al., 2014)

From this is clear that the returned RSSI values can be used to trace the specific user it is paired to and follow them around.

Data Acquisition of RSSI and Distance Conversion

The Bluetooth Module used in our device is the HC-05 Bluetooth Module. Being a trans-receiver module it is able to both send and receive data. The HC-05 module communicates with the microcontroller and other Bluetooth devices via serial commands that can be found in the manufacturer’s data sheet.

Command	Respond	Parameter
AT+INQ	+INQ: <Param1>, <Param2>, <Param3> .... OK	Param1: Address Param2: Device Class Param3 : RSSI Signal strength

Example:
AT+INIT\r\n
OK
AT+IAC=9e8b33\r\n
OK
AT+CLASS=0\r\n
AT+INQM=1,9,48\r\n
At+INQ\r\n
+INQ:2:72:D2224,3E0104,FFBC
+INQ:1234:56:0,1F1F,FFC1
+INQ:1234:56:0,1F1F,FFC0

Figure 6.4.3: HC-05 RSSI Command

(HC-05 -Bluetooth to Serial Port Module, 2010)

Shown in the image above is an example of how the device communicates to the microcontroller and other Bluetooth devices in the area. The first important line is “AT+INQM=1,9,48\r\n” that sets the HC-05 module into “inquiry” mode and then begins searching for nearby Bluetooth devices and reports back what is found.

A response may look like “+INQ:1234:56:0,1F1F,FFC1” which means that device “1234:56:0” has been found with an RSSI value of “FFC1” which is hexadecimal for the chip units of RSSI. From that point it is easy to determine the distance from the user by converting the return value into an integer in base 10 and using the formula below.

$$Distance(m) = 10^{\frac{Measured\ Power - RSSI}{10*N}}$$

("How to Calculate Distance from the RSSI value of the BLE Beacon", 2016)

Measured Power is a constant also called the one meter RSSI threshold. This is determined on startup and remains constant until the user and ALA unit are disconnected. *N* is also a constant called the environmental factor. For the use case of the ALA unit *N* = 2.

By inputting the commands as shown from the HC-05 datasheet and using the distance formula as shown above we can use Bluetooth RSSI to reliably determine how far the user is from each sensor and the device itself.

Error Correction of Bluetooth RSSI

Bluetooth RSSI is a reliable way to calculate distance and the formula is well defined. The acquisition of the RSSI can be heavily affected by the noise and other environmental factors however. There is a way to combat this and receive reliable RSSI values. If the Bluetooth module is constantly polled and is receiving RSSI measurements, we can perform two techniques to remove the noise. The first step is creating a large enough data set where we can reliably find the correct RSSI value. This is easily accomplished by looping the RSSI request command and gathering values for the user’s Bluetooth signal. At that point the program can calculate the average of the data set returned and compare it to the mode of the data set returned. With both the average and the mode we are able to are to retrieve the correct RSSI values (Gao, 2015).

Data Acquisition of Ultrasonic Sensing and Distance Conversion

Working with the Ultrasonic sensors, as mentioned previously is a much more streamlined process. By sending out a pulse of sound, recording how long it took for the sound wave to return, and using the speed of sound the program is able to calculate how far an object is from the distance sensor. The specific equation used to calculate distance that the microcontroller uses is show below

$$Distance(cm) = PulseTime(\mu s) /29/2$$

(Morgan, 2014)

6.5 Determining specific speed and direction

Requirements and Specifications:

The device gets input from Ultrasonic sensors and Bluetooth. Generally, the device should always maintain a distance of 12 inches behind the user. If the device is more than 12 inches away from the user, the device should accelerate. If the device is less than 12 inches away from the user, the device should stop running. The servo motor should be also able to respond based on user position. More specifically, the front wheels should always point to the user and make sure the user is always in the center of the front of the device.

The maximum speed the device can reach is 5.346 mph and it is calculated by the number of rotations the wheels can make per time when the drive motors are outputting at maximum power times the diameter of the wheels. The turning angle ranges from 0 to 180 degrees and it is decided by the servo motors chosen. As a result, the speed should be between -5.346 mph to 5.346 mph and the turning angle should be between 0 to 180 degrees.

Initial design:

Initially, a pseudocode is designed to show the basic algorithm and functions the device should have. Simulated inputs are used for both Ultrasonic sensors and Bluetooth. Once the code is implemented, it should be able to interact with the drive motors and servo motors and output the exact speed and turning angle.

Drive motor and speed:

One of the Ultrasonic sensors is mounted on the front of the device. It is used to measure the distance between the device and the user or the distance between the device and other people. In order to let the drive motors output linearly based on user position. A pulse width is assigned to the drive motors and proportional control is used to determine the pulse width with the equation given as:

MOTOR_PW = MOTOR_NEUT + kdrive * (range_front - 12)

In the equation shown above, MOTOR_PW is the pulse width assigned to the drive motors; MOTOR_NEUT is the value of neutral pulse width; kdrive is a positive constant and is multiplied by the difference between the distance measured by front ultrasonic sensor and 12 inches.

Motor pulse width has a maximum value of 3502 and minimum value of 2027. When a maximum pulse width is assigned to the drive motors, the drive motors should be outputting at maximum power and the device should be moving forward at maximum speed. When a minimum pulse width is assigned to the drive motors, the drive motors should be outputting at maximum power in reverse direction and the device should be moving backward at maximum speed. When a neutral pulse width is assigned to the drive motors, the drive motors should output 0 power and the device remains stable (as shown in Figure 6.5.1). However, for safety concerns and convenience, when the distance measured is less than 12 inches, a neutral pulse width will be assigned to the drive motors and the device will remain stable instead of going backward.

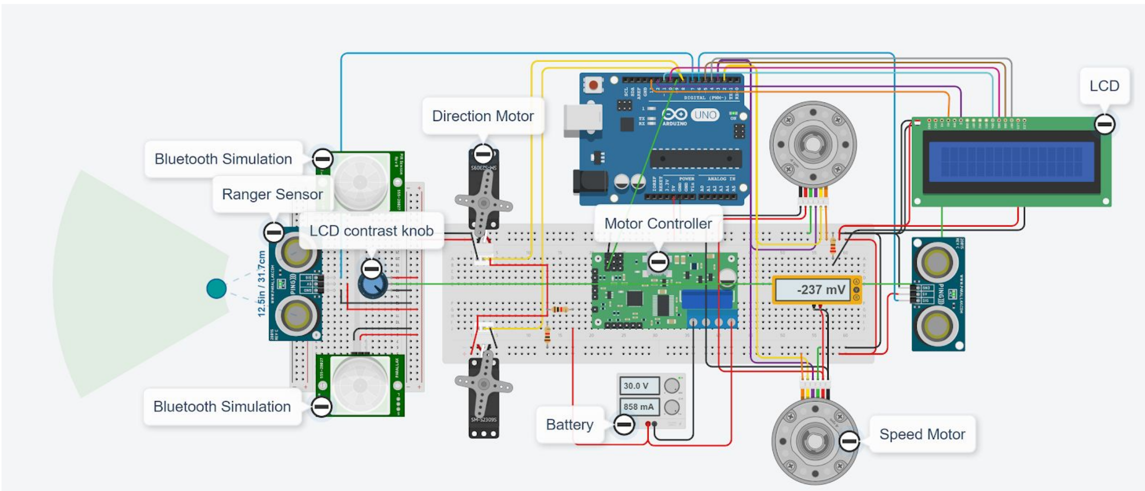


Figure 6.5.1 Drive Motor outputting 0 power when user is about 12 inches away

Speed is linearly related to the pulse width assigned to drive motors and the equation is given as:

speed = 0.00725373 * MOTOR_PW - 20.05657

Servo motor and turning angle:

Two Bluetooth sensors mounted on the left and right side of the device. They are mainly used to pair with the user and determine the direction of the user. The device reads RSSI values from two Bluetooth sensors. If the user is right in front of the device, two RSSI values should be the same. If the user is moving to the left, the RSSI value the device gets from the left Bluetooth sensor should be smaller than the RSSI value it gets from right Bluetooth. Similarly, if the user is moving to the right, the RSSI value it gets from the left Bluetooth sensor should be larger than the RSSI value it gets from the right Bluetooth. The pulse width assigned to the servo motors is given by:

SERVO_PW = SERVO_CENTER + ksteer * (RSSI_left - RSSI_right)

In the equation shown above, SERVO_PW is the pulse width assigned to the servo motors; SERVO_CENTER is the value of neutral pulse width; ksteer is a positive constant and is multiplied by the difference between the values measured by left Bluetooth and right Bluetooth.

Servo pulse width has a maximum value of 3871 and a minimum value of 1659. When a maximum pulse width is assigned to the servo motors, the front wheels should turn to the far right. When a minimum pulse width is assigned to the servo motors, the front wheels should turn to the far left. When a neutral pulse width is assigned to the servo motors, the front wheels should remain straight.

Turning angle is linearly related to the pulse width assigned to servo motors and the equation is given as:

turning_angle = 0.081374 * SERVO_PW - 135

When the turning angle is between 0 and 90 degrees, it means that the front wheels are turning to the left. When the turning angle is 90 degrees, it means that the front wheels remain straight. When the turning angle is between 90 and 180 degrees, it means that the front wheels are turning to the right.

Safety Features:

Since the device is used in airports, many factors need to be taken into consideration. After the basic functions of the device were implemented, several safety features were added to make sure the device can operate in complex situations as well as protect the safety of the user and surrounding people:

- The Ultrasonic sensor in the back is used to determine if there are any people in the back of the device. If the user is less than 30 inches away from the user, a warning message will be printed on the LCD keypad (as shown in Figure 6.5.2) in order to let other people be aware of the device.

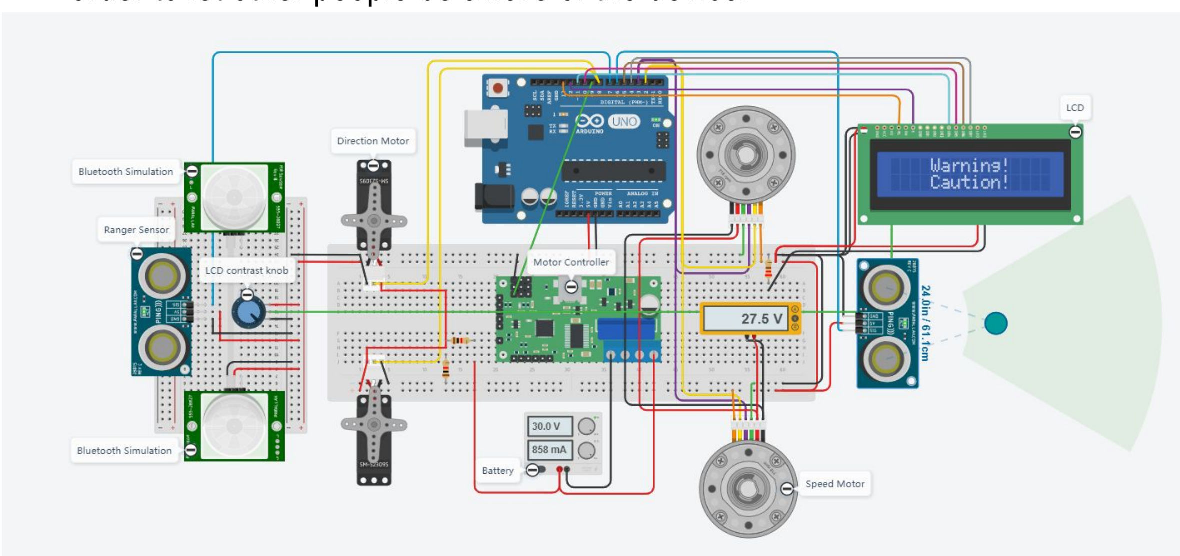


Figure 6.5.2 Warning message on LCD keypad

- When a person passes by the front of the device and is really close to the device, the device will immediately stop moving to avoid crashing into that person (as shown in Figure 6.5.3).

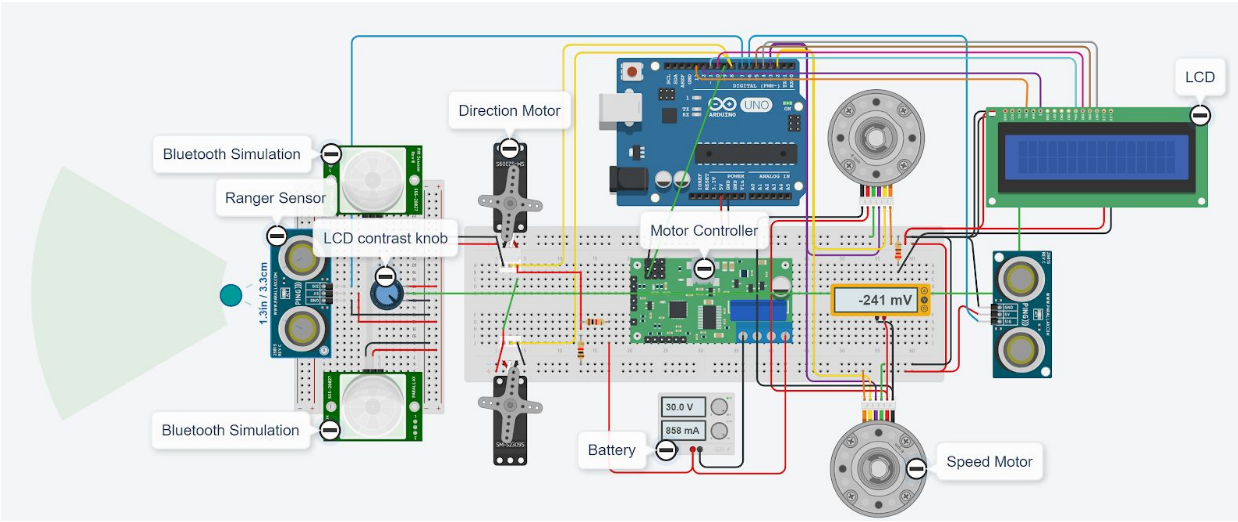


Figure 6.5.3 Drive Motor outputting 0 power when a person is really close

7 Results and Discussion

7.1 Model and Simulation Test and Results

<u>Deformation Analysis:</u>

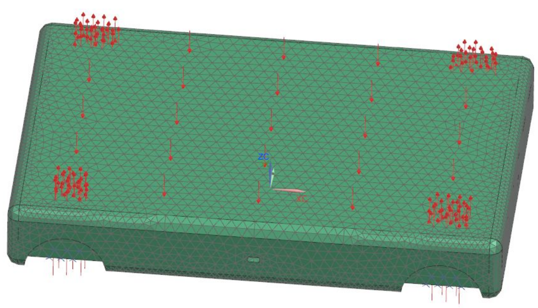


Figure 7.1.1: Model 1 for Simulation

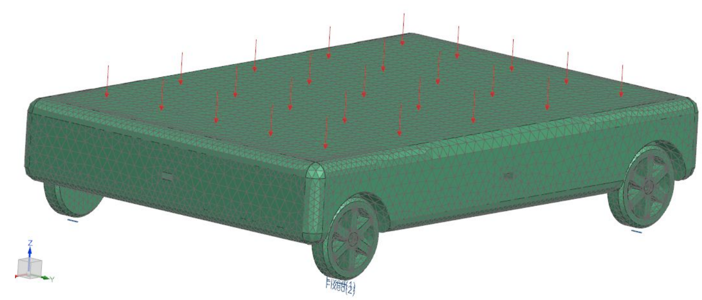


Figure 7.1.2: Model 2 for Simulation

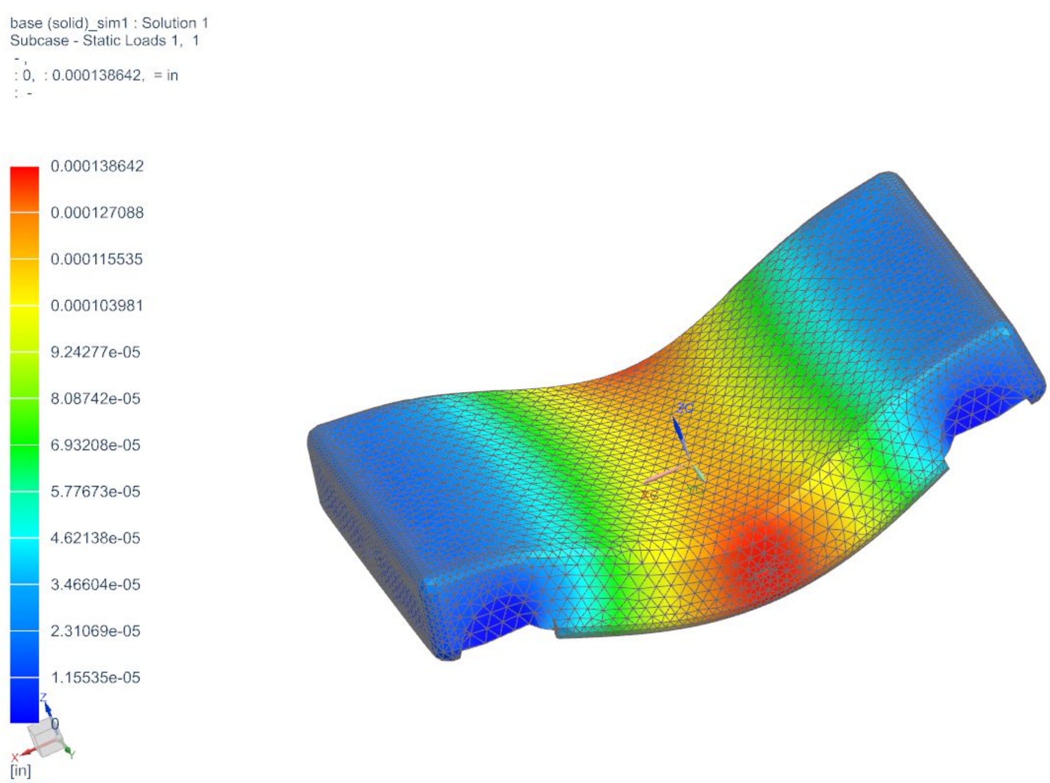


Figure 7.1.3: Deformation analysis

Figure 7.1.1 and figure 7.1.2 are the models for the finite element analysis. The simulation is for the base and wheels part. The finite element method is the most widely used method for solving problems of engineering. The largest deformation is shown in the left bar of the figure 7.1.3. Different colors present different degrees of deformation. The blue means the deformation is really small whereas the red means the most deformed. For figure 7.1.2, 220 lb load on the top surface because the capacity is 150 lb to 220 lb, and the 50 lb opposite reaction force from the wheel at each corner. Adding restraints at the bottom surface is very important. These restraints allow the model to be held in model space while still being able to deform due to applied loads. The restraints must be applied in each of the three primary directions to avoid rigid body motion. In addition, checking the model balance is an important step for verifying that all loads are acting upon restraints correctly. The software test for the maximum load here to make sure the deformation is less than the 0.0005 inch. The product meets the customer's requirement and it can bear 220 lb luggages.

7.2 Material, Assembly, and Stress Analysis Test and Results

Stainless Steel Ultimate Tensile Strength: 73,200 psi < 100,000 psi

$A_t = 0.7854(D - 0.9743/n)^2$

For our screw type and screw size

Basic Major Diameter (*D*)= 0.4375

Thread per Inch (*n*) = 5

$= 0.7854(0.4375 - 0.9743/5)^2 = \mathbf{0.0463\ in^2}$

Applying 8.5 factor of safety

Ultimate Force = (FS) * (Actual Force) = 8.5 * 250 lb

Tensile Stress = F/A

Tensile Stress= $2{,}125\ lb / 0.0465\ in^2 = \mathbf{45{,}698.92\ psi}$

45,698.92 psi < 73,200 psi

Meaning the screws are more than capable of withstanding the expected load of 250 lb with plenty of tolerance.

7.3 Powering System Components Test and Results

The force required to push wheeled equipment is always greatest at the start, just before movement begins. Ergonomists refer to this force as the initial or starting force. The initial forces typically last only a short time and drop to the sustained force levels once the acceleration begins and any mechanical interference at the start of movement is overcome. Once in motion at a relatively constant speed, the force requirement is generally lower. This force is called the sustained or rolling force.

According to the rolling friction theory, for an electrical powering car, the driving force created by the motors must be able to overcome the starting force then maintain to balance the rolling force for creating constant speed under maximum weight loaded.

The Formula: $F = f \times W/R$

F = the force required to overcome the rolling friction
f = the coefficient of rolling friction (units must match same units as R (radius))
W = Load on the Wheel
R = Radius of the Wheel

The device uses four 3 inches radius Polyurethane wheels which have the rolling friction coefficient for the wheel on a hard material floor(test using steel) for 0.057. Max overall weight is 574 lbs = 354 lbs (device) + 220 lbs (max cargo).

From the formula above, the force F required to overcome wheel rolling friction is 48.51 Newtons. The force to start (initiate) motion is in general 2 ~ 2.5 times the sustaining force. In this case the required starting force is approximately 105.6 Newtons. So, the two DC motors have to create at least 52.8 Newtons driving force for each to make the device move the maximum 574 lbs weight. For the 3 inch radius wheel connected to the DC motor, the required torque for motors should be 4.02 Nm.

The DC motor the team chose has the rated power as 350w with max speed at 300rpm.

According to the electrical motor torque equation:

Torque = 9550*Power(kW) / speed(RPM)

The max torque which the motor can reach is 11.14 Nm (11.14 Nm > 4.02 Nm). This rated motor torque(11.14 Nm) is relatively larger than the max torque the device needed. As under this condition, The DC motor will be working at a relatively low temperature that will make it more stable and safer. The two DC motors are able to do normally speed control under the maximum weight of 574 lbs.

The servo motor has the working angle for 320 degrees which reach the required

180 degrees working angle for the device and be able to change the angle at a speed of 60 degrees per 0.16 second.

The team chose a 36 V, 20 Ah, DC Li-ion battery to be the power supply for the device. In simulation, the rated currents for the components are set in the circuit to test the maximum battery current. For circuit arrangement, the two DC motors are in parallel connection for reaching the 36 V rated voltage and so that each motor's current is separately; The two servo motors are in series connection for reaching the 8.4 V rated voltage by dividing the 36 V battery input voltage through voltage divider.

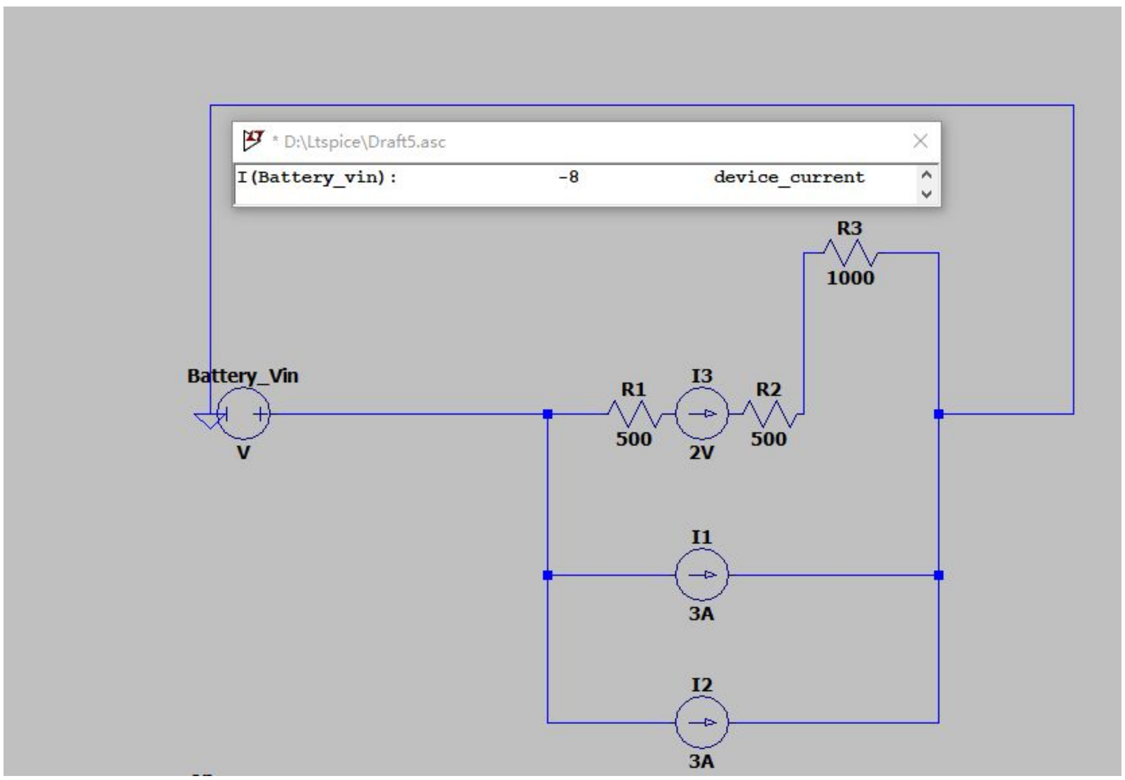


Figure 6.3.6 Circuit current simulation by Ltspice

*the current value in the simulation showed as -8 due to the negative direction of the current, the magnitude is still 8A

As the result shows, the maximum battery current is 8 A. Under the 20 Ah capacity, the device is able to work for 2.5hours when fully charged.

7.4 Position Tracking Test and Results

Due to the virtual environment we were not able to assess how the sensors would have reacted in real life. However we are able to simulate the usage of the sensors and determine an output from there. To simulate the Bluetooth sensors I sent in two commands that the device would normally see from a real HC-05 module. The results are shown in the figure below.

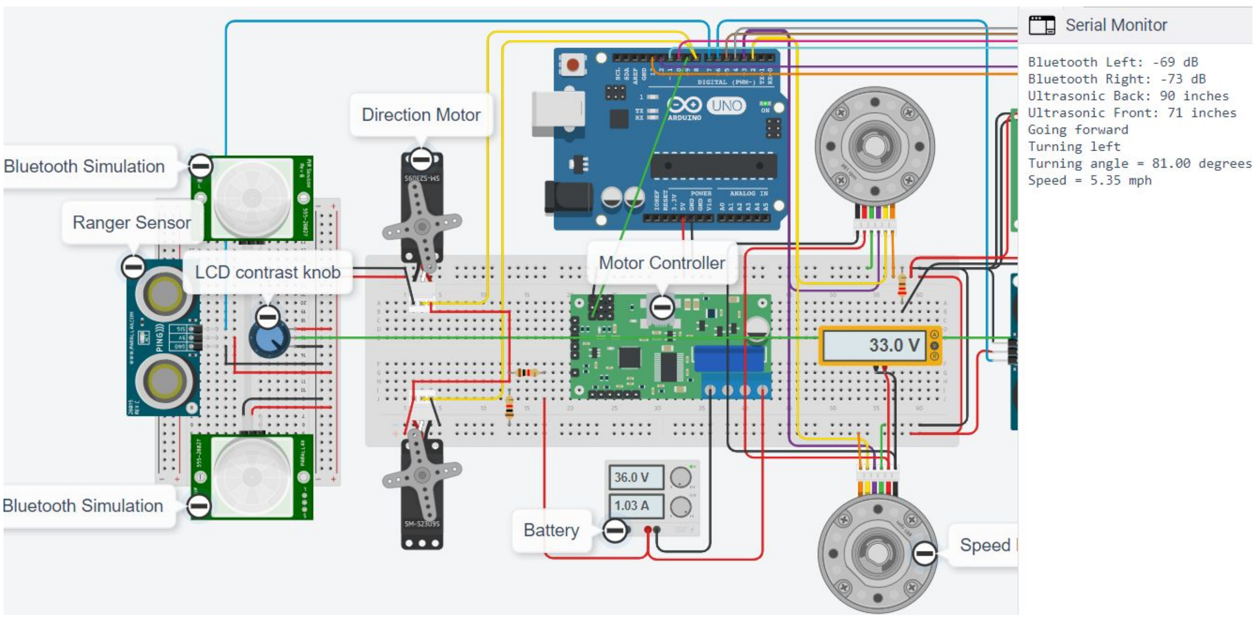


Figure 7.4.1: Bluetooth Simulation

The figure shows that the program was able to turn the commands into dB units for distance calculation. The distance we retrieved meant the device was further than 1 meter from the user so the motors turned on and began moving towards the user as shown by the motor voltage.

To simulate Ultrasonic sensing we run the same test but send in 2 different commands to show that the device is now close to the user and will utilize Ultrasonic sensing.

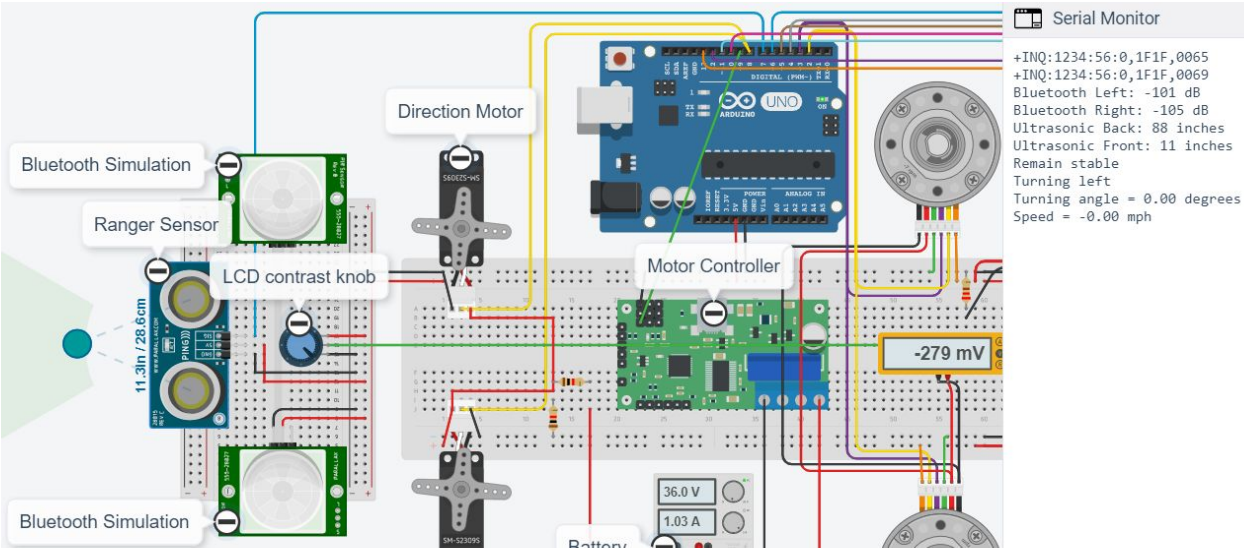


Figure 7.4.2: Ultrasonic Simulation

As shown above we placed an object roughly 11 inches from the sensor and the program was able to accurately determine the distance. Furthermore the simulated Bluetooth Commands changed as well since the device is now closer to the user. This is represented by the new dB calculated.

The results of both tests matched the expectations.

7.5 Speed / Turning angle Test and Results

The team managed to simulate the user's position in Tinkercad. Based on the user position, data received from Ultrasonic sensors is printed as well as simulated inputs received from Bluetooth. Specific speed and turning angle are also printed. By changing the position of the user, the team managed to see a change on the values of speed and turning angle. The team is also able to observe a change in the rotation speed of the drive motors and a continued change in the direction of the servo motors.

Following is the analysis the team did based on the position of the user as well as the specific speed and turning angle collected:

As shown in Figure 7.5.1, when the user is less than 12 inches to the device, speed is always 0 mph. As the distance between the user and the device increases, speed also increases linearly and when the distance is larger than about 65 inches, speed is at maximum value, which is about 5.35 mph.

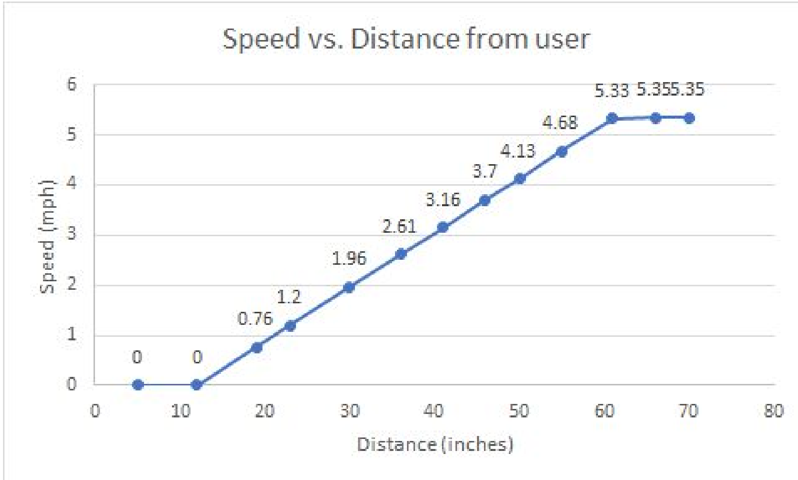
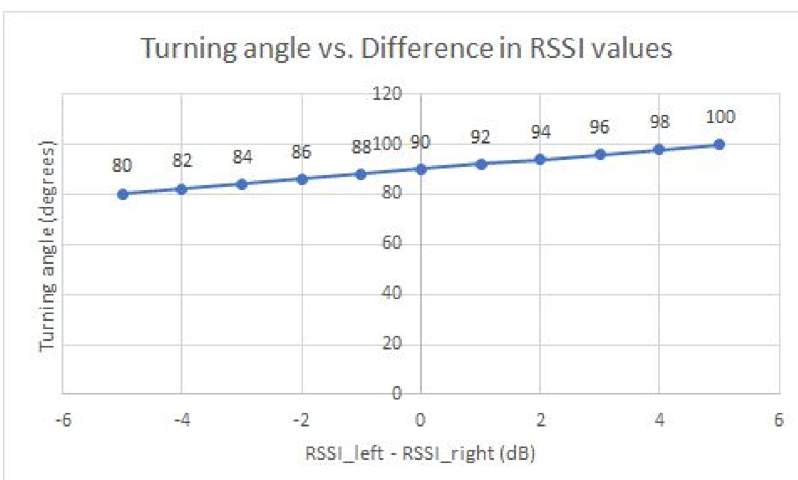


Figure 7.5.1: Speed vs. User Position

Simulated inputs of Bluetooth are collected. A difference between inputs get by left Bluetooth and right Bluetooth is calculated and is used to compare with the turning angle. As shown in Figure 7.5.2, when the inputs from left Bluetooth and right Bluetooth are the same, difference is equal to 0 and the turning angle is equal to 90 degrees, which means the front wheel is pointing straight forward. When the input from left Bluetooth is smaller than the input from right Bluetooth, the difference is a negative value and the turning angle is less than 90 degrees. In this case, the user is moving to the left and the front wheel is also turning to the left. When the input from left Bluetooth is larger than the input from right Bluetooth, the difference is a positive value and the turning angle is greater than 90 degrees. In this case, the user is moving to the right and the front wheel is also turning to right. The servo motors are also able to respond linearly based on user position.



7.5.2 turning angle vs. user position

Future Enhancements

Looking into the future, there are some adjustments and improvements the team can make in order to be safer and attract a larger number of customers.

- A theft prevention function can be added, if someone is trying to steal the luggage, an alert can be sent to the user to let the user be aware of the situation and stop this from happening immediately.
- More safety features can be added to the device to make sure the device can better operate in complex situations. For example, if people are approaching from the left or right of the device, the device should be able to respond to that situation as well.
- For now, the manufacturing price and rental price is still high, some people may think that it is too expensive and refuse to use the device. In the future, if cheaper components or a cheaper material could be found, a replacement will be made to make sure more travellers are able to afford that.
- The device may also be set to be lighter if a lighter material of the frame can be found. With lighter weight, it will be easier for airport staff to move and store the device. Furthermore, batteries can also support a longer use time.

7.6 Significant Technical Accomplishments

One of the largest technical accomplishments performed by the group was the ability to design and simulate the position tracking subsystem to that great of accuracy in terms of function. Developing this took a lot of time, and solving the first problem of determining distance took hours of research. The idea to combine two of the weaker design choices into one strong choice was the end to our research. Problems still arose as figuring out how the Bluetooth modulus worked and how they were supposed to be communicated took lots of testing and more research on a topic that is surprisingly light on documentation. With no access to the real modules themselves, performing this virtually is a great feat.

Another great accomplishment was performing the stress analysis on the whole model and the screws joining the parts of the model together. This seemed like an impossible task at the beginning due to the fact that we did not know how to use our software to perform such an analysis. After consulting with the professor and doing more research we were able to begin a proper stress and tolerance analysis for our design.

8 Conclusions

The objective of the Automatic Luggage Assistant (ALA) is to allow airport travelers the opportunity to retain some sense of comfort as they travel with many carry-ons and personal items in order to save money. To perform this task, the ALA device will be durable enough to carry any traveler's luggage while automatically following the traveler at a close distance.

As shown by the tests and results the simulated representation of the ALA device was able to meet the customer requirements. Targeted end users such as the elderly, those with physical challenges, and parents will be able to operate normally while using this device. Furthermore we address the needs of the secondary customer by offering a cheap way to achieve a higher level of comfort and ease while traveling.

The development of the ALA unit was accomplished through coordination and collaboration within the team. The team used techniques such as selection matrices, and brainstorming to develop the ideas and specifics of the device. The resulting ALA unit is a polypropylene base with aluminum side panels capable of withstanding over 200 pounds. The parts of the base are joined together by steel screws that will be able to hold the unit together under normal operating conditions with a large margin for error.

The drive for the ALA device is made of three main components, the main circuit, the sensors that provide input, and the driver code which controls the motors of the main circuit. The sensors consist of two Bluetooth modules that communicate distance values through RSSI and two Ultrasonic sensors that determine distance through sound. The driver code takes these inputs from the sensors and determines the resultant speed of the motors and what angle they should turn at. The main circuit interfaces the code in the microcontroller with the input sensors and powers the motors and other circuit components such as the LCD. The main circuit is able to provide power up to the set customer requirement.

There are improvements to be made to the design. The team would like to incorporate more safety features in the design, and potentially reduce the overall cost of the design. The team also aims to include stronger protection against theft and potential damage to the baggage under operations.

Group members followed guidelines set by each other and held each other accountable. All members were active communicators, collaborators, and engineers. By coming together under stress, working through problems and challenges together and organizing ourselves with resources such as a Gantt Chart, Webex Teams, and contracts the team was able to produce a successful product.

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10 Appendix A: Selection of Team Project

Our group brainstormed multiple project ideas as table () shown below. Meetings were held with professors to discuss the feasibility of each project regarding potential risks, estimated cost, subsystem distribution. We choose Automatic Luggage Assistant as our team project.

Table 7.1: Concept Selection Matrix

	Brainstormed Project		
Selection Criteria	**Solar Power Mobile Water Filter**	**Automatic Luggage Assistant(ALA)**	**VR Equipment for Online Course**
Description	The solar panel powers the filter and can be rolled around to and from the river to get clean water.	ALA will address the problem of users finding great struggle with carrying multiple backpacks and carry-ons with them in airports.	The students can be added to class like the group for now on Webex. They can feel in a real class room though the course is online.
Cost	-1	0	-1
Complexity	-1	1	-1
Time	0	1	-1
Durability	1	1	0
Market	1	0	1
Environmental Friendly	1	0	0
Portability	1	1	1
Net Score Rank	2	4	-1
Continue?	N	Y	N

Our product can deeply improve the travel experience for our customers, especially the aged, disabled, frequent travellers and families with young children. With our product, customers do not have to worry about carrying heavy luggage and focus more on the road, which decreases the possibility of getting hurt. The product can affect the customers' comfort during travel. Finally, traveling should be a time of relaxation,so the Automatic Luggage Assistant will solve their problems and concerns.

In the future, our auto-follow technology can be used in factories and industries to help workers carry heavy cargo. Compared to the traditional way of carrying cargo, using the auto-follow technology is a much safer and more efficient way.

11 Appendix B: Customer Requirements and Technical Specifications

Table 8.1: Complete Requirements

Customer Requirement	Importance (Out of 5)	Technical Requirement	Milestone 1 Targets	Revised Targets
Affordable	4	Rent Price	\$5-\$7	\$6.50
		Unit Sale Price	\$650-\$800	\$750.00
Safe	5	Speed	4-5 mph	5 mph
		Distance from Traveler	1-2 ft	1 ft
Efficiency	5	Capacity	150-250 lb	230 lb
Storable	3	Folded Dimensions	3.5 ft x 2.33 ft x 0.75 ft	3.5 ft x 2.33 ft x 0.75 ft

12 Appendix C: Gantt Chart

Project Name	Status	Owner	Start	End	Week 1: 6/12/20-6/18/20	Week 2: 6/19/20-6/25/20	Week 3: 6/26/20-7/02/20	Week 4: 7/03/20-7/09/20	Week 5: 7/10/20-7/16/20	Week 6: 7/17/20-7/23/20	Week 7: 7/24/20-7/30/20	Week 8: 7/31/20-8/06/20	Week 9: 8/08/20-8/14/20	Week 10: 8/15/20-8/21/20
Team Standards Agreement	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	6/12/2020	6/12/2020										
Brainstorming and choose the topic	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	6/12/2020	6/19/2020										
Research	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	6/19/2020	6/24/2020										
Define Subsystems	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	6/19/2020	6/20/2020										
Propose possible solutions	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	6/20/2020	7/8/2020										
Create M1 presentation slide	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	7/8/2020	7/10/2020										
Present M1 presentation	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	7/10/2020	7/10/2020										
Create M1 memo	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	7/10/2020	7/14/2020										
Adjust and make improvements to subsystems	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	7/10/2020	8/12/2020										

Project Name	Status	Owner	Start	End	Week 1: 6/12/20-6/18/20	Week 2: 6/19/20-6/25/20	Week 3: 6/26/20-7/02/20	Week 4: 7/03/20-7/09/20	Week 5: 7/10/20-7/16/20	Week 6: 7/17/20-7/23/20	Week 7: 7/24/20-7/30/20	Week 8: 7/31/20-8/06/20	Week 9: 8/08/20-8/14/20	Week 10: 8/15/20-8/21/20
Work through subsystem 1: strength, materials, calculations	100%	Jose	7/14/2020	8/12/2020										
Work through subsystem 1: sketches, CAD,analysis	100%	Hanyin	7/14/2020	8/12/2020										
Work through subsystem 1: Bluetooth	100%	Saaif	7/14/2020	8/12/2020										
Work through subsystem 1: sensor and motor circuit	100%	Ganqi	7/14/2020	8/12/2020										
Work through subsystem 1: Coding	100%	Zhan	7/14/2020	8/12/2020										
Combine Subsystems	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	7/24/2020	7/31/2020										
Test and Adjustments	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	7/31/2020	8/10/2020										
Come up with final solution	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	8/10/2020	8/14/2020										
M2 Demonstrate Product	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	8/14/2020	8/14/2020										
Create M3 presentation slide	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	8/14/2020	8/21/2020										
Present M3 presentation	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	8/21/2020	8/21/2020										

Project Name	Status	Owner	Start	End	Week 1: 6/12/20-6/18/20	Week 2: 6/19/20-6/25/20	Week 3: 6/26/20-7/02/20	Week 4: 7/03/20-7/09/20	Week 5: 7/10/20-7/16/20	Week 6: 7/17/20-7/23/20	Week 7: 7/24/20-7/30/20	Week 8: 7/31/20-8/06/20	Week 9: 8/08/20-8/14/20	Week 10: 8/15/20-8/21/20
Create M3 memo	100%	Saaif, Jose, Ganqi, Hanyin, Zhan	8/14/2020	8/21/2020										

Gantt Chart:

Gantt chart helps our group meet our requirements before the deadline. Each of us update the gantt chart when they finish their work. Gantt charts are useful for planning and scheduling projects. They help us assess how long a project should take, determine the resources needed, and plan the order in which we will complete tasks. The gantt chart also helps us work out practical aspects of a project, such as the minimum time it will take to deliver, and which tasks need to be completed before others can start.

13 Appendix D: Expense Report

Table 13.1: Expense Report

Cost of Plastic	$34.84
Cost of Aluminum	$15.18
Servo Motors (2)	$71.36
Speed Motors (2)	$181.76
Battery	$110.00
Bluetooth Sensors (2)	$10.00
Micro controller	$6.00
Ultrasonic sensors (2)	$14.00
PCB	$3.00
Wheels (4)	$72.00
Production and Assembly	$60.00
Total Cost Per Unit	**$578.14**

14 Appendix E: Team Members and Their Contributions

Hanyin Yuan

My contributions in terms of subsystems design is to design and analyze the overall model. I'm a mechanical engineering major, so I took the part which I'm good at, the CAD part. I talk with my team members about the overall design and get suggestions from them, especially Jose. In addition, I should consider the structure for our model. I did some research about frames and mechanics of structures. I need to draw each component for our device, and get dimensions from other people. The last step for the model part is assembling them. After talking with professors, I think I should do the simulation and analysis part for the model. While in the simulation, I was new to the finite element analysis in NX. I asked my friends for help and learned it from some Youtube videos.

I discussed the material of each part with Jose to make sure our model meets customer needs. We should find the proper material for the frame. I compared the deformation and load for different materials and analyzed them. Jose and I also discussed how to develop a comprehensive test so that the simulation will include as many real-life situations as possible. I also helped brainstorm subsystems and how they would work together. Outside of technical contributions, I gave lots of ideas about our project and helped them when they met troubles.

Saaif Ahmed

In terms of technical contributions to the group I designed the position tracking subsystem and served as a programmer for our simulation and demonstration. The ideas for the position tracking subsystem and the resultant research was primarily conducted by myself. I was responsible for finding different methods of how to find the distance between two devices and reporting back details on those methods. This includes, but is not limited to, each method's positive and negative characteristics, scalability, and difficulty of implementation. I then took this information and presented it to the group members, primarily Ganqi and Zhan, and as a collective we determined what method to move forward with. With that information I moved forward with designing the subsystem by choosing parts, and writing code and testing said code to determine the success of our design.

This task was incredibly daunting as my subsystem served as the main input to the ALA device and thus many subsystems relied on the information that I was to put forth. The specific sensors had to have their dimensions included in the model. Determining the specific output of the position tracking subsystem would later be used to determine the speed and turning angle of the motors. Finally, the current draw of each component would affect the battery life of the overall circuit. By working together with the team, setting deadlines and expectations, and iterating the design with tangible effects each step of the way led to great progress and the eventual completion of the subsystem and its demonstrated simulation.

Outside of technical contributions I served almost the role of team leader for the Zeta Group. I organized meetings and created agendas for those meetings. I took on the responsibility of dividing up tasks between members and determining how the group should move forward with upcoming milestone requirements. Furthermore I made sure to review each and every subsystem and the progress made on it in order to ensure we would meet the resultant deadlines and expectations. Without the team's help and cooperation for the duration of the project development time, I fear that our success would not be so noteworthy.

Zhan Shu

I proposed the idea of a device that can carry luggage and follow people around in the airport. After discussion and comparison of feasibility between other ideas, my idea was chosen to be the topic of our project. I also made the original version of Gantt Chart to give a brief overview of what each member should be doing in a certain amount of time.

In terms of technical contributions, I designed the main driver code for our device. I proposed a basic idea of how to track the position of the user, which is one of the major challenges in our design. In order to write the driver code, I am responsible for determining most of the functions the device should have, including safety features. My design process starts with a pseudocode showing basic algorithms and all the functions of the device. Then I write the code which should let the device actually move based on user position and output specific speed and direction. The code is able to interact with the circuit Ganqi built in Tinkercad as well as the Bluetooth code Saaif developed. My subsystem serves as the main output of the device and I continued to do add more features to the code to make sure the device operates correctly and safely under various situations.

Ganqi Xu

My subsystem has the goal to design the whole circuit which has the function to receive the outside signal then give the feedback to the device after computing through the microcontroller. My design process starts with building a basic structure on Tinkercad and making sure the whole circuit can work theoretically. Then I think about the real situation for the circuit: add the specific components in the circuit (like motor controller, voltage divider, etc) to make the circuit still be stable in reality. After setting the final circuit structure, I chose the suitable electrical components and proved that they can fulfill the goals under extreme situations by simulation and conclusion. I do basically the device's interaction structure for software to hardware. For Jose & Hanyin's subsystems, I can make sure that the circuit be able to work for suitable time under maximum weight; For Zhan & Saaif's subsystems, I can make sure the circuit can do correctly interaction between input and output when they adjust the driver code in microcontroller.

Jose Canales

My subsystem was material and assembly choice as well as stress analysis for the connections. In doing this I was in charge of deciding on the materials and relaying this information to Hanyin making sure the material choice results in an acceptable deformation and weight range. As well as choosing materials for the panels and connections. Based on our material choice I was tasked with choosing the best connection types as well as suitable fasteners to reduce cost, stress, and assembly time. I was also in charge of calculculating the stress of the connections and making sure they're acceptable for the applied load with enough factor of safety. This task took some accommodating as it was not my initial subsystem however with the help of my team I was able to fit into the role my team needed and contribute.

Apart from my subsystem I was influential in drawing up the concept designs and final designs for the device itself, I was also a vocal and outspoken member of the team during meetings, class, and presentations.

15 Appendix F: Statement of Work

Team: Zeta

Members: Saaif Ahmed, Hanyin Yuan, Ganqi Xu, Jose Canales, Zhan Shu

Semester Objectives:

1. Do research, make lists of customer requirements and question statements.
2. Decide a product with specific functions that the group plans to build.
3. Create subsystems for each single team member, the subsystems should be able to combine after all of them are finished to make the final product.
4. Do testing and simulations for all subsystems to make sure they can work normally and correctly.
5. Collect data from analysis, do revision and improvement for the product.
6. Gather information, demonstrate presentation, and create final technical report

Approach:

Be sure to create a Gantt Chart that shows the timeline of the whole design process, the Gantt Chart can be adjusted but basically the team should follow the setting time on it. In this way, the time for the design process would be highly efficient and have a plan beforehand. Also, be sure each subsystem the team creates is a "real subsystem" that a subsystem should have the whole engineering design process. In each meeting or discussion, the team members should always update their progress to the team. In the end make sure to finish a final technical product beyond the existing product.

Deliverables and Dates:

1. Choose the topic, do research about customer needs, and problem statements. (06/19)
2. Define Subsystems, state possible solutions. (06/22)
3. Milestone 1 presentation and Memo (07/14)
4. Begin on subsystems design (07/14)
5. Finish and test subsystems design (08/10)
6. Combine the subsystems to make the final product (08/12)
7. Milestone 2 Demonstration (08/14)
8. Milestone 3 Presentation (08/21)
9. Final technical report (08/22)

16 Appendix G: Professional Development - Lessons Learned

A lesson the team learned as a whole is the complexity and thought that goes into designing a product from scratch, as well as all the considerations that go into it. Our team also learned many value lenses on working as a team and how to communicate ideas efficiently within a team. Due to the unique circumstances we found ourselves in, our team gained very valuable experience on working efficiently within a virtual setting. This is important to consider as more and more jobs and tasks are done virtually.

This virtual form of working as a team definitely had an impact on how often our team could meet as well as how effective we could be at sharing our ideas and using our time within these meetings. However overall the whole team coped very well within a virtual setting and made the most out of all of our meetings. Our team set specified meeting times every single wednesday as well as being very active in the webex teams space over the weekends. This worked out very well as we were able to communicate our ideas as well as our progress efficiently. All group members were also very reliable to meet on time and willing to stay in meetings for long periods of time. A challenge our team did have was not meeting the subsystem requirements earlier in the semester. Next time our team could solve this problem by communicating more clearly what we know how to do and what we are willing or capable of learning, as well as having more communication with professors on our progress and team roles. As a team we could have also used more resources available to us in order to make sure we are meeting all expectations.

We would keep webex teams as our meeting space, webex teams were a very efficient tool in sharing information, data, and documents as well as quickly having team meetings and sharing screens. Our team also effectively used online resources such as Tinkercad and LTSpice to design components of our project virtually and also demonstrate them. Programs such as these were very helpful and something our team would use in the future and other teams should consider while working virtually. Overall reflecting on the project as a whole our team would make more use of tools to organize our time and delegating roles and tasks much more efficiently. Our team did not use tools such as Gantt charts as much as we should've which resulted in poor time management at times. Our project would’ve run smoother if we had maximized our use in resources for organization and management.

17 Appendix H: User Manual

Thank you for choosing to use the ALA unit!

The ALA device (Automatic Luggage Assistant) aims to relinquish you from the stress and hassle of carrying multiple bags around. Get started now by following the steps below.

<u>Connection:</u>

Please scan the QR Code above or head to https://ganqixu.wixsite.com/mysite to connect to the ALA device. Please stand about 3 feet away from the device before pairing your cellular device to the ALA unit.

<u>Usage</u>

If the connection was established successfully, congratulations! You are now able to begin loading your luggage and enjoying your time at the airport.

<u>**Safety**</u>

Please do not run more than 10 feet from the device. Please do not let small children ride on the device. If an obstacle is detected the device will stop to avoid a collision. Do not load the ALA unit with over 300 lbs of weight. Please continue to follow airport guidelines while using the ALA device.

Thank You for Choosing ALA!